Reduction of Evaporative Losses from Tropical Reservoirs using an Environmentally Safe Organic Monolayer

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Abstract

Singapore’s 3000 hectare reservoir system loses more than 45 million cubic meters of water annually through evaporation. This evaporation loss reduces supplies not only from rainwater, but also from all other sources stored in the reservoirs, including water brought in from neighbouring Malaysia. Additionally, this ‘leak’ will likely increase with predicted higher maximum temperatures associated with anticipated global warming. To maximize the available water resources, PUB (Singapore) is looking for cost effective methods to reduce evaporative losses for its 17 reservoirs.

WaterSavr, a commercially available product used successfully in the United States, Australia, and other countries to reduce surface water evaporation was trialled in a Singapore reservoir. *WaterSavr*, a patented blend of calcium hydroxide, food grade steryl and cetyl alcohols, effectively reduce surface water evaporation rates by 20-50% without adverse environmental effects or impacts on water treatment. It is an odourless white powder that automatically and rapidly spreads into an invisible, single molecule thin film over the surface of a body of water due to the natural “ionic repulsion” of the Ca^{+2} calcium ions that are disassociated on the calcium hydroxide’s contact with the water. This invisible film automatically reforms from wind, wave, or human activities, and fully biodegrades within approximately 48-72 hours.

To evaluate the efficiency and potential use of *WaterSavr* in reduction of evaporative losses under tropical conditions, a full-scale trial coupled with a mesocosm was carried out at Bedok Reservoir. This trial determined the quantitative and qualitative effects of daily application of *WaterSavr* to a reservoir’s surface and its concurrent correspondence to mesocosm trials, thus allowing extrapolation to other reservoirs. Three months of evaporation data were collected using four traditional Class A Evaporation Pans served as positive and negative controls, with *WaterSavr* applied to two pans while two pans served as experimental controls. A range of environmental parameters known to impact evaporation rates, including rainfall, temperature, solar radiation, relative and absolute humidity, wind speed and direction were monitored for their effect on the four evaporation pans to evaluate differences in evaporation losses with and without *WaterSavr*. Concurrently, *WaterSavr* was applied to the larger reservoir to monitor true environmental impacts to water quality. The data analysis from pan evaporation study shows more than 30% mean total reduction of evaporation by the use of *WaterSavr* product and subsequent cost-efficiency analysis indicates that it would be cost effective to implement at a larger, nation-wide scale.

Keywords
WaterSavr; evaporation; monolayer; Class-A pan; Environment; reduction

INTRODUCTION

Essential to life, a person's survival depends on drinking water and it is a key component in determining the quality of every life on earth. Although water covers more than 70% of the Earth, only 1% of the Earth's water is available as a source of drinking. Further, population growth, pollution and potential global warming are placing unprecedented stress on the Earth’s available water resources.

Out of many processes involved in the water cycle, condensation, infiltration, runoff, evaporation, precipitation and transpiration forms most important processes. Evaporation, the process whereby water changes from its liquid state to a gaseous state, is an essential part of the water cycle. Solar energy drives evaporation of water from oceans, lakes, reservoirs, moisture in the soil, and other open water sources. This evaporation ultimately reduces the available water sources to significant fractions and ultimately becomes key challenge in water supply and management for every nation in this world.

BACKGROUND

The quantity of water in a reservoir is dependant not only upon the quantity of water pumped into/out, but also the gain from incident rainfall falling into it, inflows and the losses from it by evaporation. Having a maritime equatorial climate, Singapore is blessed with substantial rainfall (2200-2400 mm avg. annual). Rain is a preferred source of Singapore's water as it is free of many of the costs, energy requirements, politics and environmental impacts. To help keep reservoirs full, Singapore has made substantial investments to develop an extensive catchment network that will soon cover 2/3rds of the country's land area (Public Utilities Board, 2010). Rainfall, however, is neither controllable, nor substantial enough to meet all of Singapore's current or future water demands. Although rainfall amounts have increased for periods in recent years, Singapore is still vulnerable to potential droughts and cyclical or long term decreases in rainfall which may be impacted further by global warming.

Being in the tropical / equatorial climate which brings rainfall to Singapore, it also creates an environment for potentially high evaporative losses. Singapore's year round high temperatures combined with approximately 5-6 hours per day of intense equatorial sunshine and frequent convectional upwelling, provides the fuel for potentially high evaporation.

Until now, PUB's has made substantial investments in the detection and reduction of leakage, but this has been limited to water transmission and distribution systems. Combined with consumer conservation programmes, the prevention of Unaccounted for Water (UAF) is a key part of Singapore's water program success. Evaporation, however, is the one leak in the water system that has yet to be tackled. PUB is now focusing on finding a safe and cost effective program for evaporation reduction to further protect and maximize its valuable water resources and stores.

EVAPORATION PROTECTION TECHNOLOGIES

There are few ways to control evaporation from the open water resources. However, the cost, application difficulties, and potential impacts on potable water and the environment have prevented the consideration of most evaporation control methods. In recent years the research and development for evaporation protection technologies has focused on two potential options: physical barriers and chemical mono-layers.

Physical barriers. Physical barriers include floating and shore attached material covers, and/or polymer /plastic objects laid on the surface of an open water resources such as reservoirs, and lakes (Figures 1). By physically blocking the escape path of water molecules and screening the reservoirs from solar gain with impermeable materials, these fabricated covers can be extremely effective at reducing evaporation as much as 90+% (Jennison, 2003). However, their high cost per square meter, physical limitations for covering larger or irregular shaped reservoirs, blocking natural aesthetic look, reduce/eliminate recreational usage, and possible harm to marine ecosystems/wildlife make this type of evaporation protection financially and practically unfeasible for reservoirs systems such as in Singapore.

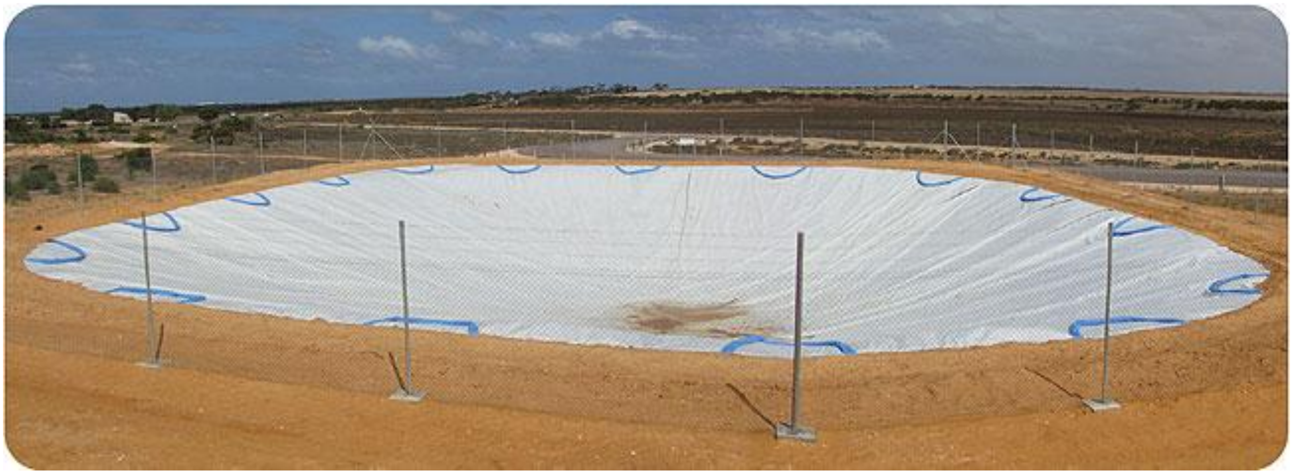


Figure 1. Example of a Physical Barriers (VapourGuard, 2010).

Chemical mono-layers. Chemical monolayers reduce evaporation by creating an insoluble film of a single layer of packed fatty alcohol molecules that acts as a physical barrier to water molecules escaping the surface (pores smaller than H_20) and a possible shield from air movements interacting with water surface molecules. In addition, the polar charged hydrophobic and hydrophyllic molecular ends reduce the surface tension of water thus lowering the surface area available for evaporation. Basically, chemical mono-layers are chemically engineered, single molecular layers (~2 millionths of a mm thick) of insoluble or sparingly soluble compounds. When applied to water these compounds form an invisible film that can be used to cover a reservoir and block evaporation. Chemical mono-layers for evaporation reduction have been in research and development since the 1920s (Langmuir, 1927). Of all the various compounds researched, the longer chain (carbon >C14), single-bonded, aliphatic (fatty) alcohols such as hexadecanol and octadecanol combinations were found to form the most effective barrier for preventing water molecules from evaporating (Figure 2) (Victor et al., 1963).

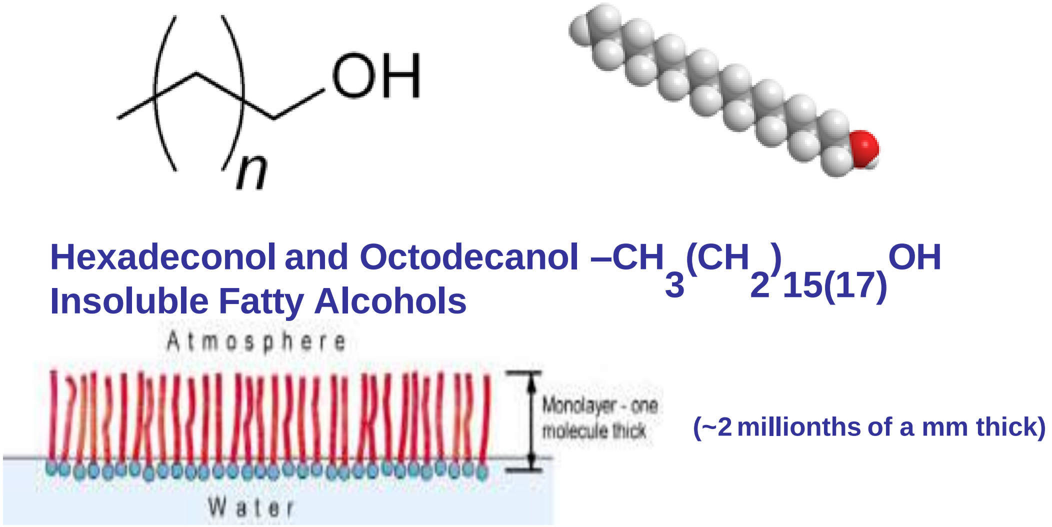


Figure 2. Chemical mono-layer (Source: Wikipedia)

WATERSAVR

After over a decade of research and development, a Canadian chemist, Dr. Robert O'Brien (2001) engineered a breakthrough for protective mono-layers in 1985 by solving the problems of dilution and spreading. The newly engineered monolayer product was first commercialized by Flexible Solutions International (AMEX: FSI) of British Columbia in 1989 as HeatSavr™, a product for reducing energy costs in heated swimming pools. In 2002 the product became marketed as *WaterSavr* ™ for evaporation protection on larger bodies of water.

Since 2002, *WaterSavr* has become the only evaporation protection chemical to be proven safe in independent environmental testing, and receive the NSF-ANSI 60 (certified safe for potable water treatment by the US based Nation Sanitation Foundation and American National Standards Institute), the United Nations "Environmentally Sound Technologies", and US EPA (Environmental Protection Agency) Gold Seal designations. It also remains today the only economically viable, chemical monolayer that is commercially available and approved for reducing evaporation on potable water reservoirs.

WaterSavr is an internationally patented blend of calcium hydroxide (hydrated Lime), and food grade steryl and cetyl alcohols that can reduce surface water evaporation by 20-50% without negative environmental impacts. It is an odourless white powder that automatically and rapidly spreads into an invisible, molecule-thin film over the surface of a body of water. The self spreading mechanism (Figure 3) is a natural chemical reaction that results from the "ionic repulsion" of the positively charged Ca^{2+} calcium ions disassociated when calcium hydroxide is applied to the water. The ionic forces are strong enough to overcome waves and up to 16 km/hr winds helping push *WaterSavr* into all corners of a reservoir. It is fully biodegradable within approximately 48- 72 hours.

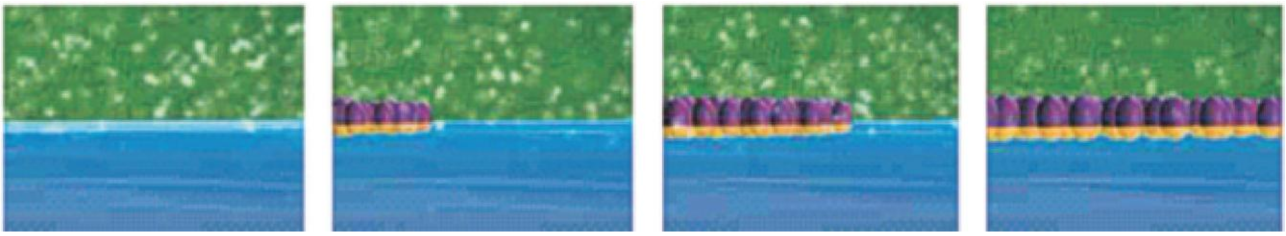


Figure 3. Self spreading mechanism of *WaterSavr*.

[As the hydrated lime (represented in yellow) starts to dissolve in the water, the resulting positively charged calcium ions repel each other and spread across the water's surface, carrying the hydroxy alkanes (represented in purple) along with the lime particle. (Source: FSI *WaterSavr* brochure)]

OBJECTIVES

Being a world leader in Water Industry, PUB (Singapore) is always leading in maximizing available water resources and utilizing cutting edge technologies for the conservation and creation of new sources of water. In this aspect, PUB (Singapore) aims to determine the real world viability of *WaterSavr* in the Singapore reservoir system. A three month trial at Bedok Reservoir was proposed and accepted by PUB (Singapore) in July 2009. The test bed trial was designed (i) to evaluate the extent of Singapore's evaporative losses; (ii) to determine the potential efficiency of *WaterSavr* for reducing evaporation in Singapore's specific microclimate including cost effectiveness; (iii) to determine the efficiency of *WaterSavr* application methods for the local climatic conditions and operational needs; (iv) to determine possible effects of the product on the environment and recreational activities, if any; and (v) to provide the potential costs, application procedures, and any operational or safety concerns that will need to be addressed in for a successful long term

WaterSavr programme on overall Singapore's reservoir system.

STUDY AREA

The Republic of Singapore situated at the southernmost tip of the Peninsular Malaysia lies to the north of the equator. The study area chosen for this trial is the Bedok Reservoir which is located in the eastern part (1°20′32″N 103°55′30″E) of Singapore, to the north of Bedok New Town. The reservoir has a surface area of 84 hectares, and a capacity of 12.8 million m³. The mean depth of the reservoir is about 9 m, with a maximum depth of 18.2 m. The shoreline length is about 4.3 km. Figure 4 shows the location of the study area and the position of *WaterSavr* auto-spreaders on the reservoir.

Figure 4. Bedok reservoir and *WaterSavr* auto-spreaders location map.

METHODOLOGY

Class-A Evaporation Pan method

There are many instruments are in use for evaporation measurements from free water surfaces. The standard Class-A Evaporation Pan method forms the basis for several techniques for evaporation estimation (Gangopadhyaya, 1966). Four Class-A evaporation pans (2 pans as a control and 2 as an experiment) have been used for this trial to estimate the evaporation rate over the reservoir. Evaporation rate can be estimated by manually measuring the changes in pan water levels 1-2 times per day throughout the trial through the use of hook gauge and also considering the rainfall events.

The Experiment pans received a measured dosage of 150 mg to 400 mg of *WaterSavr* at the end of each reading (1-2 times per day). The pan dosage levels needed to be substantially higher per area than reservoir proportions to account for a higher percentage of powder clumping per dosage level. Calculating the savings % for *WaterSavr* usage was simply comparing the differences in evaporation between Control and Experiment pan sets once evaporation amounts for all 4 pans were measured for any period. Pan effect was considered and typically a correlation factor between actual evaporation on the reservoir and the Class A pan is 0.70 to 0.80 for temperate climates. This adjustment factor is necessary to account for the heat gains that the steel evaporation pans receive through their sides during day time hours and the lower emissivity to direct sunlight (infra red heat reflection) of the metal construction as compared to actual natural reservoir conditions.

WaterSavr Spreaders on Reservoir

To test the real life impacts of *WaterSavr* on Bedok Reservoir, including manpower and operational requirements, product spreading efficiency, water quality affects, environmental and human impacts, a trial protocol for applying *WaterSavr* to the reservoir was implemented. Four M60R automated *WaterSavr* applicators produced by Global Equipment Services of Australia were anchored on the reservoir. Each spreader has a capacity of 50-60 kg and was deployed to cover approx 20 hectares. Using a solar panel, battery and timer the units can be set to dose the reservoir with *WaterSavr* automatically at anytime as shown in Figure 5. The manufacturer of *WaterSavr*, Flexible Solutions International (and previous *WaterSavr* studies) recommended a daily dosage of 350 grams per hectare per day or 1kg every 3 days. As *WaterSavr* biodegrades in 48-72 hours, a daily dosage was considered for the trial to maintain more consistent coverage. The 4 spreaders were running daily during the trial period with bi-weekly refills and observations. However the units were removed for regular maintenance services and repair services whenever necessary during the trial.


(a) (b) (c)

Figure 5. (a) Anchored Spreaders; (b) Automatic dosing of *WaterSavr* on the Reservoir; (c) *WaterSavr* (mono-layer) spreading

Data collection

Daily weather data such as rainfall data, wind speed and direction, solar Radiation (Pyranometer and Pyrradiometer), air temperature, water temperature (at surface and depth), and relative humidity and water quality data such as total dissolved solids, turbidity, pH, chlorophyll-*a*, DO, NH_4 were collected from a Lake Diagnostic System installed at the Bedok Reservoir for the trial period (from Aug 2009 to Nov 2009). Daily (and Bi-daily) observations on weather conditions including cloud cover, intensity and timing of rain and wind periods were also collected.

Daily (and Bi-daily) observations on evaporation rate in all 4 pans were collected as per the methodology for the trial period. Each pan included a thermometer for water temperature readings. In all, a total of 100 data collection periods on the evaporation pan sets were recorded between August 18th and November 2nd, 2009. The shortest period of length for accumulated data was 7 hours 40 minutes, and the longest was 48 hours and 20 minutes. Combining pan sets A & B (each one consist of a control and an experiment pan), 193 evaporation rate and 181 savings rate calculations were made. Data readings for both evaporation and savings rates were categorized into night time, daytime and 24 hour periods to account for differences in evaporation rates and comparison purpose. 62 data calculations were then screened out due to significant rainfall or rainfall caused errors, 31 savings calculations were eliminated due to the unnatural destruction of the monolayer from overheating of the pans, and 8 readings were removed from final numbers due to known human or equipment error.

ANALYSIS AND RESULTS

For the trial it was unavoidable for the pans to be located adjacent to some vegetation, trees and near the Bedok Pumping Station buildings. These shelters would have been likely to reduce evaporation influences such as wind and solar gain by a noticeable but acceptable percentage. However, the reductions in evaporation also would be offset by higher daytime heating of the pans in what is known as the pan effect. It must be noted that while trying to provide an accurate representation of the adjacent reservoir conditions, evaporation pans can show varying degrees of direct correlation to the reservoir. This was apparent in the trial pans' water temperature on hot sunny days when it reached as high as 34-36°C, while air temperatures reached only 32 °C and the reservoir temperature remained at 30-31°C.

However, unlike in non-tropical climates were reservoir water temperatures are typically cooler than air temperatures, the water at Bedok reservoir remained as high as 31°C even when night time or rain induced drops in air temperature hit 23-25°C. As the pans' temperature also dropped quickly to levels matching the air, more evaporation is expected to occur on the reservoir during cooler periods than in the pans. Also taken into consideration were the regular cloudy periods which occurred during the second half of the trial (mid September to early November), necessitating a higher coefficient / smaller adjustment for the pan effect on evaporation rates. Accounting for these factors as well as observations and temperature data collected during this trial, a conservative pan correlation factor of 0.85-0.95 to 1 is most realistic (dependent on weather conditions).

Singapore's Unique Evaporation Factors

The following observations were resulted from both trial period observations and historical data analysis:

1. High and Constant Water Temperatures in the Reservoir (30-32 ^{0}C)
2. High Constant Air Temperatures (23-33 ^{0}C)
3. Peak Solar Radiation betweem10AM and 3PM and up to 1200+ w per meter sq.
4. Wind increases primarily during daylight hours and also just prior to rainfall (thermal upwelling)
5. Peak Winds observed between December and March
6. Humidity increases and temperature decreases during rain & early morning
7. Rainfall periods usually short duration (minutes to few hours)
8. More rainfall events during Nov-Jan, Apr-May and less during Feb-Mar, Jun-Sep
9. Very Consistent Barometric Pressure

It is noticed that evaporation during the rainy periods of Nov-Jan remains of concern as higher wind speeds and sunny dry periods between rain showers keep daily rates of evaporation at significant levels. From late January to early March, the weather conditions (less cloud cover, high wind speeds and high temperatures) lead to the highest levels of evaporation during the year. The Southwest monsoon in June-September brings moderate winds as well as lower rainfall amounts, so moderate to higher evaporation rates are expected. This was reflected in the data from the initial 30 days of the trial study. Similarly during the inter-monsoonal periods of April-May and October increased cloud cover, combined with low winds, moderate rainfall and high humidity potentially represents the lowest evaporation rates.

At the end of the trial study, evaporation data from Control pans was screened for errors and segregated into night (7PM-7AM) and day (7AM-7PM) 12 hour periods plus observed 24 hour periods. The average and median for these categories was then calculated to arrive at an order of magnitude for each period that could be used to extrapolate monthly and annual evaporation rates for Singapore's reservoirs. In addition to the 24 hour observed data totals, a "night plus day" (24 hr) combined calculation was assembled from the high, low, average and median figures to represent the best approximation of daily average and median evaporation rates during the trial (Figure 6).

Using a pan adjustment factor of 0.90 based on trial weather conditions, an estimated reservoir evaporation rate of 5.2-5.5 mm per day would be a reasonable assumption for period of the year (mid August- mid November). Evaporation throughout the year would depend on seasonal weather conditions as discussed in earlier paragraph, but the rough range of 3mm to 8mm per day would be a reasonable order of magnitude for high to low daily rates. The midpoint of the rounded high and low daily range is again 5.5mm.

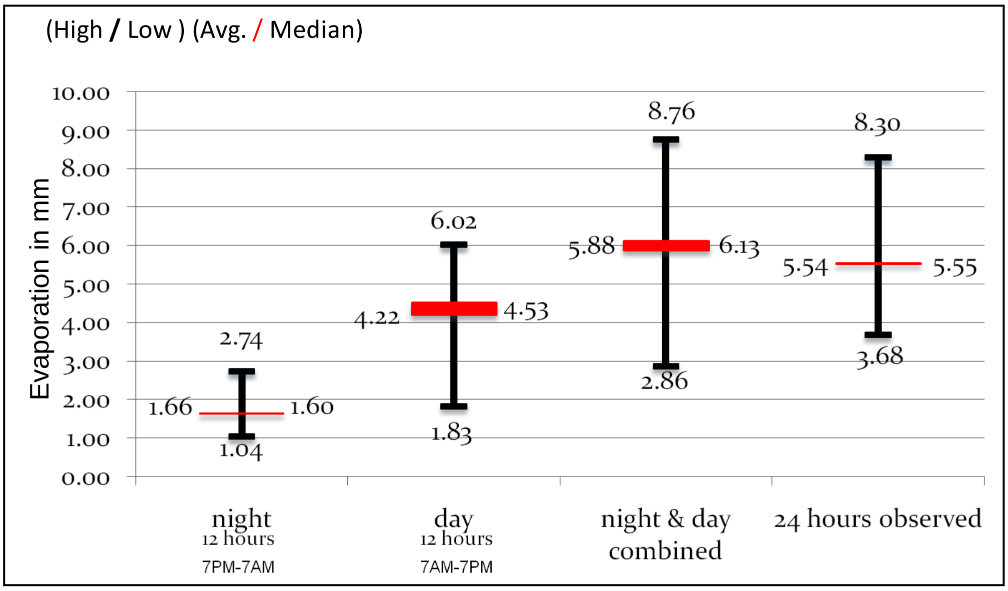


Figure 6. Daily pan evaporation rates during the trial period.

The following insights were observed from the trial: (1) As expected, night time evaporation rates were significantly lower than in the daytime due to the combination of solar gain and higher diurnal wind speeds during sunlight hours and increased relative humidity at night; (2) Night time evaporation is still a significant 25-30% of total evaporation with 12 hour rates observed as high as 2.74 mm; (3) An annual averaged daily evaporation rate of between 5 and 6 mm is a reasonable estimate for Bedok Reservoir and the other reservoirs in Singapore. The extrapolated estimate of annual evaporation is 1825-2190mm or approx 2000mm per year. These results match data from other equatorial/tropical locations; (4) 75-100+% of annual rainfall on the reservoirs is returned to the atmosphere; (5) Bedok Reservoir at 84 ha loses an estimated 4.2 million+ litres per day or 1.5 billion litres per year (based on 5mm evaporation per day); (6) Singapore's 3000 hectare reservoir system loses an estimated 60 Million+ m^3 of water per year based on annual evaporation of 2000mm; and (7) 60 million m^3 lost to evaporations is a UAF leak of 20-22% of the potable water supply equal to the consumption of 230,000 households (based on consumption estimate of 155 litres per day per capita from PUB Singapore).

***WaterSavr* Savings**

It is found that the *WaterSavr* showed a significant impact on reducing evaporation in the trial study with the average and median savings from screened data exceeding 30% and shown as in Figure 7. During the trial it is observed that the *WaterSavr* product was able to quickly spread and maintain an insoluble film of the active fatty alcohols on the evaporation pans (and reservoir). Regardless of the physical ability of alkane mono-layers to reduce evaporation, savings rates both in the pans and on the reservoir are predominantly functions of coverage ratio. At 80-100% initial coverage of the water surface area, which was easily achievable in the evaporation pans, the saving rates were as high as 50- 65% over a 12 hour period. Savings rates then declined over time if additional dosing was not added due to the monolayer's natural degradation and the cumulative effects of wind or rain disrupting the coverage. By applying a twice a day dosage of *WaterSavr* during portions of the pilot trial, consistent evaporation 24 hr rates of 30-60% were achieved in the pans. When a dosage was missed, rates dropped significantly.

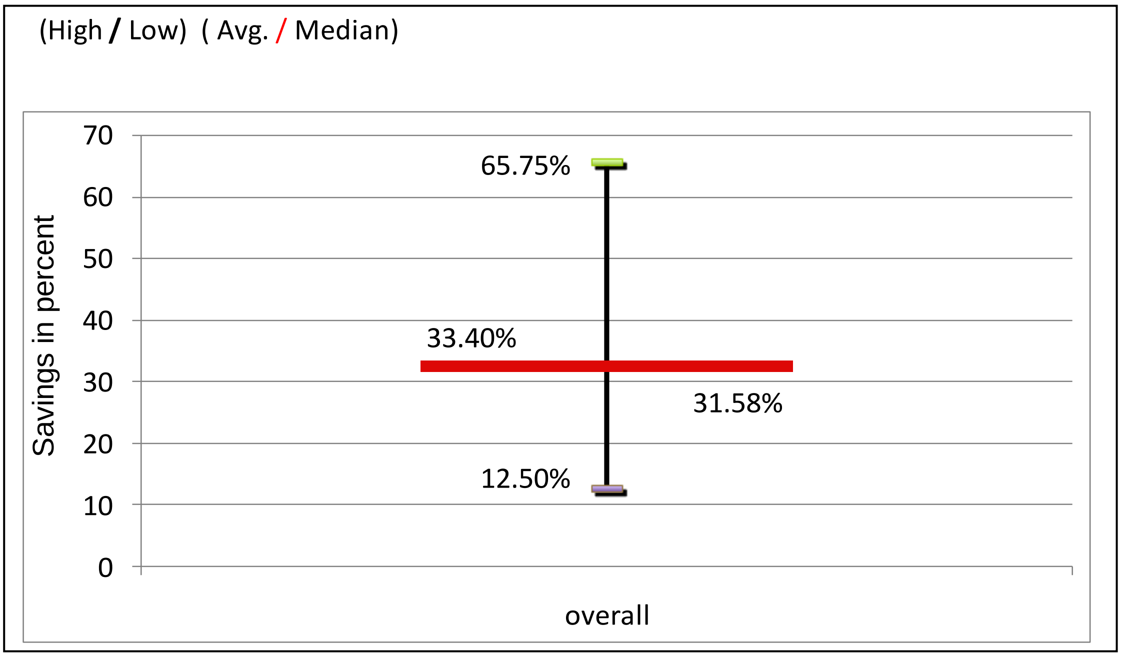
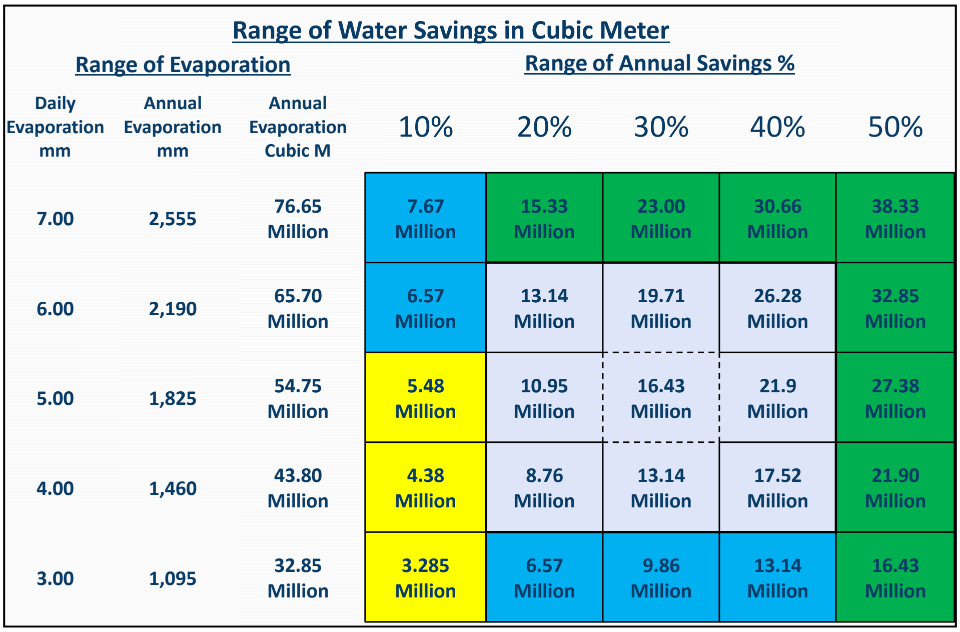


Figure 7. *WaterSavr* savings.

On an actual reservoir, 80+% coverage ratio averages are technically possible, but would be difficult to maintain without substantial *WaterSavr* product consumption. Based on previous research applying the same fatty alcohols to actual reservoirs as large as 400 hectares, coverage of 60-80% of the reservoir could be achieved. This target level of coverage resulted in evaporation savings of 25-40% similar to what is projected for Singapore. Evaporation rates were never constant for more than a couple hours to couple days due to the dynamic/unstable nature of weather variables in Singapore. Savings rates were equally dynamic. At night time for example when evaporation rates slowed due to the lack of solar radiation and lower wind speeds, the ability to maintain maximum *WaterSavr* coverage was also increased along with the percentage of evaporation that was saved. During the trial the evaporation pans were exposed to a significant variety of weather conditions that as a whole provided a good reference for projecting both seasonal and day / night variances. The importance of this data is to reveal the likely ranges of both evaporation and savings potential that will average out over longer periods of time.

Cost-efficient analysis

Figure 8 below represents the likely combinations and permutations of potential evaporation rates vs. savings rates with *WaterSavr*. The results are possible range of water volume saved in cubic meters annually using *WaterSavr* on PUB's 3,000 hectare reservoir system 90% of the year. The central 9 cells represent the most likely average / median conditions. At 5mm of daily evaporation and 30% savings using *WaterSavr*, an estimated 16.43 million $m^3$of water could be saved. At 5.5mm evaporation and 33% savings (trial average results) the number of cubic meters that *WaterSavr* could add to the potable supply increases to approximately 20 million annually.



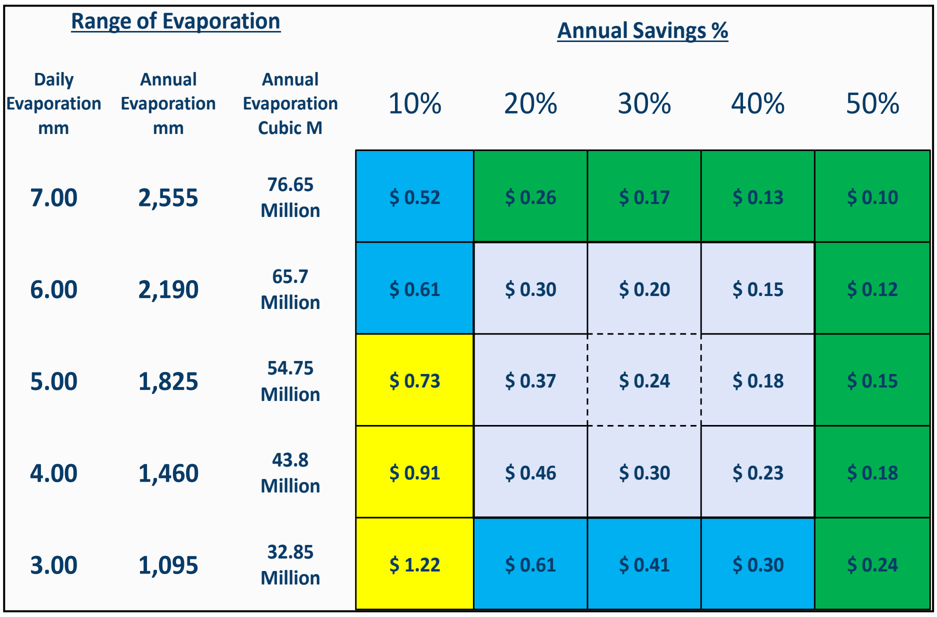
Range of Water Savings in Cubic Meter

Range of Evaporation			Range of Annual Savings %				
Daily Evaporation mm	Annual Evaporation mm	Annual Evaporation Cubic M	10%	20%	30%	40%	50%
7.00	2,555	76.65 Million	7.67 Million	15.33 Million	23.00 Million	30.66 Million	38.33 Million
6.00	2,190	65.70 Million	6.57 Million	13.14 Million	19.71 Million	26.28 Million	32.85 Million
5.00	1,825	54.75 Million	5.48 Million	10.95 Million	16.43 Million	21.9 Million	27.38 Million
4.00	1,460	43.80 Million	4.38 Million	8.76 Million	13.14 Million	17.52 Million	21.90 Million
3.00	1,095	32.85 Million	3.285 Million	6.57 Million	9.86 Million	13.14 Million	16.43 Million

Figure 8. Potential evaporation rates vs. savings rates with *WaterSavr*.

Based on the operational experiences and observations from the pilot trial, annual cost estimates were projected for a *WaterSavr* program. With a daily dosage of 350 g/Ha over 90% in a year estimated to cost S$ 113,525 for Bedok Reservoir. Similarly the projected cost for the entire Singapore reservoir system (3000 Ha of reservoir area) is about S$ 4 million annually. This cost estimates includes cost of *WaterSavr* powder, annual labour cost, spreaders maintenance and services, fuel, storage, parts cost, and spreader capital recovery cost, etc.

From the above, the potential cost of the saved water can be found by dividing the projected annual potential water saved by *WaterSavr* application by the annual cost of *WaterSavr* operations and depicted as in Figure 9. Assuming the reasonably expected 5-6 mm of daily evaporation and 30%+ evaporation savings, *WaterSavr* would result in a maximum total cost per cubic of water saved of $0.20-0.24.



Range of Evaporation			Annual Savings %				
Daily Evaporation mm	Annual Evaporation mm	Annual Evaporation Cubic M	10%	20%	30%	40%	50%
7.00	2,555	76.65 Million	$ 0.52	$ 0.26	$ 0.17	$ 0.13	$ 0.10
6.00	2,190	65.7 Million	$ 0.61	$ 0.30	$ 0.20	$ 0.15	$ 0.12
5.00	1,825	54.75 Million	$ 0.73	$ 0.37	$ 0.24	$ 0.18	$ 0.15
4.00	1,460	43.8 Million	$ 0.91	$ 0.46	$ 0.30	$ 0.23	$ 0.18
3.00	1,095	32.85 Million	$ 1.22	$ 0.61	$ 0.41	$ 0.30	$ 0.24

Figure 9. Potential cost per cubic metre of saved water by *WaterSavr*.

The projected \$0.20-0.24 SGD cost of water saved with *WaterSavr* is not only very inexpensive compared to other new sources of water, but also reflects a true all inclusive cost of water with capital recovery. There is no large capital outlays needed for plant construction, real estate, distribution lines, etc for the implementation of *WaterSavr*. In reality, *WaterSavr* would reduce the costs of other sources of water by preventing wastage more that it would compete against them. Compared to the annual costs of other UAF programmes *WaterSavr* is also very efficient. An equivalent annual expenditure of only \$4 million to potentially eliminate a leak of 5-8% of the annual potable supply would be impossible to replicate in the distribution and supply network. In addition, with a short implementation time frame and a minuscule need for energy, (less than 1% of total costs), a *WaterSavr* programme's costs can be predicted more accurately and be secured for longer period.

Safety and Environmental Impact

During the three month pilot trial on Bedok Reservoir no harmful effects from *WaterSavr* on water quality parameters such as Total Dissolved Solids (TDS), Turbidity, pH, DO, Chlorophyll-*a*, etc., aesthetics of water, treatment equipment, PUB staff / *WaterSavr* project team, public health, fish and other wild life were either recorded or observed even a dosages as high as 3kg per hectare (5-10times standard dose). The dilution level of *WaterSavr* is only about 0.04 mg per litre for surface layer of water. There were no effects on shoreline vegetation, and recreational activity during this trial period. The *WaterSavr* powder handling will only cause minor temporary irritation when inhaled or in contact with eyes and can be mitigated easily by using mask and goggle while handling.

CONCLUSIONS

The following conclusions were made from this study:

1. Evaporation Losses in Singapore are a substantial UAF leak in the water supply that must be addressed.
2. An estimated 60 million + m^3or 20-22% of annual potable needs is lost to evaporation each year.
3. *WaterSavr* trial resulted in potential savings of 30%+ of water lost due to evaporation.
4. *WaterSavr* can become an extremely cost effective tool in maximizing Singapore's water supply.
5. Savings of 16-20 million m^3 per year with *WaterSavr* @ only \$ 0.20- \$ 0.24 SGD per m^3 can be reasonably expected.
6. *WaterSavr* does not show any negative impacts to PUB personnel, public health, the ecosystem, water quality or recreational activities.
7. A *WaterSavr* program can be implicated quickly at low capital cost using Singapore built automated spreading units and existing PUB manpower and resources.

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