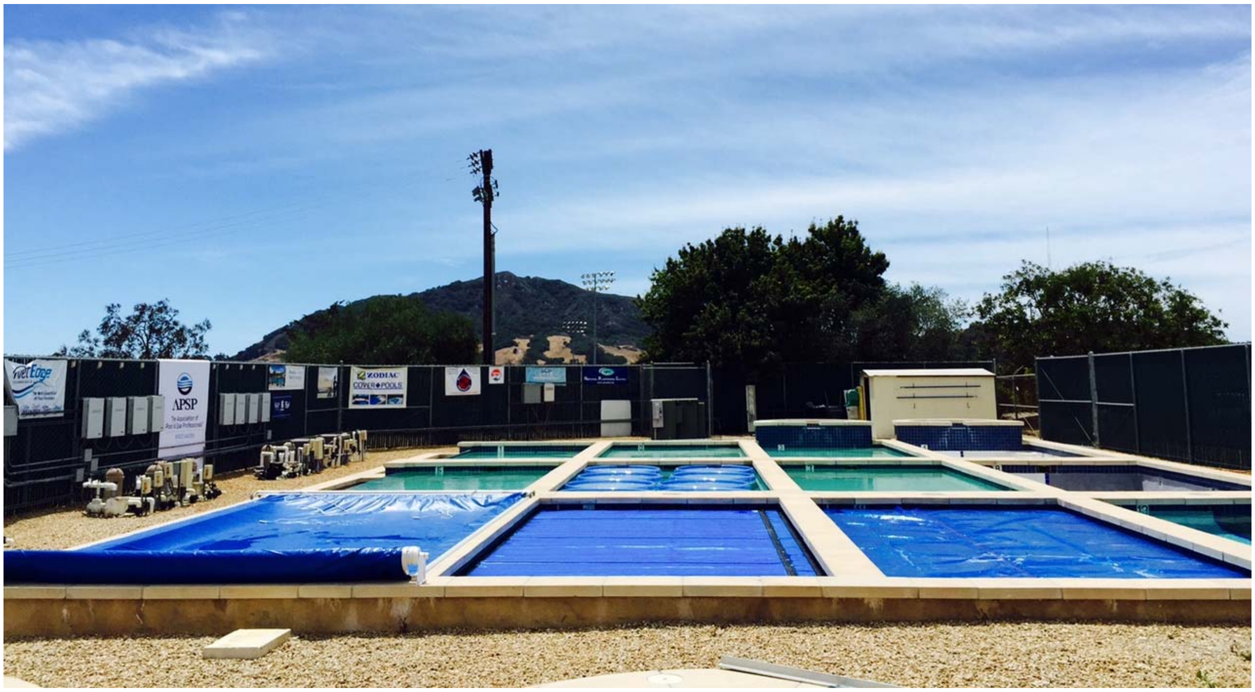
Effectiveness of Pool Covers to Reduce Evaporation from Swimming Pools



Prepared by

Misgana Muleta, Ph.D., P.E., D. WRE
Department of Civil and Environmental Engineering
California Polytechnic State University
San Luis Obispo, California 93407
Telephone: 805-756-1337
Email: mmuleta@calpoly.edu

Prepared for

National Plasterers Council
1000 N. Rand Road, Suite 214
Wauconda, IL 60084 USA
Telephone: 847-416-7272
Email: mail@npconline.org

Disclaimer

Reference to any specific product, process, or service, or the use of any trade, firm or manufacturer name does not constitute endorsement, recommendation, or favoring by the author, California Polytechnic State University, the National Plasterers Council, or any other party mentioned in this document. No party makes warranty of any kind, implied or expressed, and assumes no legal liability or responsibility for the accuracy or completeness of any data, process or product described in the document.

January, 2016

ACKNOWLEDGEMENTS

The project was sponsored by the National Plasterers Council (NPC). Besides providing financial support, several members of NPC Board of Directors including Mr. Alan Smith, Mr. Lee Valenzuela and Mr. Greg Garrett were instrumental throughout the study. Several organizations including California Pool and Spa Association (CPSA), The Association of Pool and Spa Professionals (APSP), and Independent Pool and Spa Service Association (IPSSA) also provided financial support. In addition, the following companies, listed in no particular order, donated money and/or product to the study: New Image Pool Interiors, Pool and Electrical Products, Alternative Pool Systems, California Pool Cover Services, Summers Pool Equipment Specialists, CoverPro, Zodiac Pool Systems, Aquamatic Cover Systems, Automatic Pool Covers, Coverstar, Gardner Pool Plastering, Universal White Cement, PoolCorp, HaloSource, NESPA Foundation, MasterTile, Pentair, Pebble Tec, Wet Edge, T-Star Enterprises, Natural Chemistry, SeaKlear, and Environmental Solutions.

Dr. Rakesh Goel, Associate Dean of Engineering at California Polytechnic State University, helped coordinate the project. The study would not have been possible without the outstanding help of Mr. Steven Riley, a retired professional pool operator who oversaw cleaning and operation of the pools, water quality monitoring, and balancing of water chemistry as a volunteer. Mr. Ernesto Jimenez and Mr. Evan Low, both students in the Department of Civil and Environmental Engineering at California Polytechnic State University, helped with data collection. The author is grateful to the organizations, companies, and individuals mentioned herein.

EXECUTIVE SUMMARY

In light of the severe drought that California has confronted over the last four years, water conservation is becoming a crucial component of water management solutions pursued by cities and water districts in the state. Proven urban water conservation methods include xeriscaping and replacing older toilets, showers, and appliances with new and water efficient counterparts. Likewise, owners of residential and public swimming pools could conserve water by reducing evaporation using pool covers. Ironically, water availability is often limited in regions where evaporation is high, making conservation via evaporation suppression crucial for water management. Driven by the pool industry's curiosity regarding the effectiveness of pool covers to reduce evaporation and save water, this study examined evaporation suppression efficiency of the pool cover types available on the market. Six different cover types, specifically four solid covers (i.e., solid track cover, foam cover, bubble cover, solar disks) and two liquid evaporation suppressants (liquid covers) were tested. Solid covers protect the entire or portion of the water surface from direct exposure to wind and sun. Liquid covers are chemical monolayers that produce ultra-thin film at the water surface that increases resistance to evaporation.

Rate of evaporation from water bodies such as swimming pools depends on local climate variables including wind velocity, solar radiation, differences in vapor pressure between a water surface and the overlying air, and temperature. A comparative evaporation study such as the one pursued here has to ensure that these factors are identical for the pools used to test the covers. The National Pool Industry Research Center (NPIRC) located at California Polytechnic State University, and used for this study consists of twelve pools of identical shape, size, and exposure to wind and sun making the facility suitable for the comparative study. The six covers were applied to one pool each. One additional pool was used as a control pool to evaluate evaporation reduction efficiency of the covered pools. No cover was applied to the control pool. Once placed on the water surface at the beginning of the protocol, the solid covers were not removed until the end of the study. The liquid evaporation suppressants were applied according to the instructions received from the manufacturers. One liquid cover was applied daily, and the second cover was applied weekly.

The water budget method was used to determine evaporation because of its ease, accuracy and suitability for the comparative study. As such, water levels in the test pools were monitored daily, typically between 7 and 9 am, when the wind is often calm and the water surface tranquil. Stainless steel rulers were mounted on the four walls of each test pool to measure the distance from the top of the pool to the water level. The pools were topped-off as needed to ensure that the filtration system runs properly. Water levels were recorded before and after the pools were topped-off to determine the quantity of water added to a pool. Water loss via leakage – via structural cracks or filtration system plumbing – was addressed by pre and

post relative water loss testing of all vessels used for this study. Rainfall and other climate data including wind speed, air temperature, humidity, and solar radiation data were obtained from a weather station located less than half-a-mile from NPIRC.

The pools were well maintained throughout the study so that the water remains clean and clear, and the water quality complies with the Association of Pool & Spa Professionals (APSP) standard. Water quality parameters including free available chlorine, pH, and total alkalinity were monitored weekly whereas calcium hardness and cyanuric acid were measured at the start, at half-way point, and at the end of the protocol. Water chemistry was balanced as needed. Shock-oxidation treatment was administered at half-way point.

The project involved two major data collection phases. The initial phase involved eleven days of relative water loss testing, sixty-five days of evaporation reduction testing, and then seven days of another relative water loss testing. About half-way through the 65-day testing, leakage was detected in the pool used to test one of the liquid covers. The crack was promptly sealed but the data collected from the leaking pool before the crack was sealed were deemed unreliable. Subsequently, the initial protocol was extended by four weeks to collect more data for the two liquid covers. A third relative water loss testing was carried out at the end of the extension study. The objective of the relative water loss tests was to compare water loss from each pool and to evaluate if the pools exhibit leakage via plumbing or structural cracks. No covers were applied to the pools during the relative water loss tests — evaporation should be identical for all pools. Therefore, any difference in water loss that the pools exhibit during the relative water loss test should be due to leakage. Assuming leakages in all pools were steady during the study, the water loss data gathered during the study was corrected for leakage based on the relative water loss test.

Table 1 shows the evaporation reduction efficiencies obtained for the pool covers tested.

TABLE 1: EVAPORATION REDUCTION EFFICIENCIES OF POOL COVERS

Cover Type	Average Efficiency (%)
Liquid Evaporation Suppressant A	14.4
Liquid Evaporation Suppressant B	15.8
Solid Track Cover	93.9
Foam Cover	95.9
Bubble Cover	94.9
Solar Disks	50.1

Performances of solid track cover, foam cover, and bubble cover were fairly identical — they reduced evaporation by about 95 percent. Solar disks reduced evaporation by 50 percent. However, it should be clarified that once installed, the covers were not removed from the pools throughout the study other than during cleaning and water level measurements of the pool covered with solid track cover. In reality, the covers will have to be removed, possibly for extended hours, when the pools are occupied. This suggests that the efficiencies reported here for the solid covers should be considered as maximum possible efficiencies. The two liquid evaporation suppressants tested in the study reduced evaporation by about 15 percent. Performances of the two liquid covers were somewhat similar. However, wind and storm were more frequent and stronger during the extension study (i.e., when the liquid covers were examined) compared to the initial protocol period, and might have negatively impacted efficiency of the liquid covers. At the same time, efficiency of the liquid covers was helped by the absence of swimmers who would temporarily disrupt performance. Water quality of the pools complied with APSP standard during the study except for few instances during the initial protocol when free chlorine and pH readings were outside the recommended ranges.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Water is one of the earth's most precious resources and is fundamental to quality of life, economic development, and the environment. However, drivers such as population growth, natural variability and change in climate, and urbanization are making water availability increasingly uncertain (Schnoor, 2008). In California, for example, the persistent and severe drought the state faced during the last four years has called for unprecedented measures including Executive Order from Governor Brown mandating 25 percent reduction in potable urban water use (http://ca.gov/drought/). In response, cities and water management agencies across the state have enforced water conservation measures to meet the mandate. Proven water conservation methods include xeriscaping and replacing older toilets, showers, and appliances with new and water efficient counterparts. Likewise, owners of residential and public swimming pools could conserve water by reducing evaporation using pool covers. Swimming pools lose water primarily through evaporation, leakage, and splash. Evaporation, the process by which water is transformed from liquid to vapor, is ironically higher in dry regions where water availability is often limited. Therefore, pool covers could be very beneficial in dry and water stressed regions such as the southwestern United States.

Substantial quantities of water could be saved by installing pool covers. As an example, mean annual evaporation from open waters such as lakes, reservoirs, and pools is estimated to vary from 50-inches to 80-inches in California (California DWR, 1979). According to metrostudy (http://www.metrostudy.com/), there are about 1.18 million residential swimming pools in California. Average surface area of the 43,000 swimming pools mapped in Los Angeles area (http://jk-lee.com/The-Big-Atlas-of-LA-Pools) was found to be 430 ft^2 (Gleick, 2013). Assuming mean annual evaporation of 60-inches and average pool surface area of 430 ft^2 for the state, a 50 percent reduction in evaporation from swimming pools by installing pool covers would save close to 9.5 billion gallons of water. Assuming average daily consumption rate of 100 gallons/person, the saved water would be sufficient to supply a city of over a quarter million people for an entire year. Given the severity of the drought California is confronted with, this potential saving is quite significant.

As such, the objective of this study was to examine the effectiveness of different types of market available swimming pool covers in reducing evaporation. Six different pool cover types were tested. Besides saving water, pool covers may offer additional benefits including reducing pool heating needs, reducing chemical consumption, and lessened cleaning time (US DOE, 2015). These additional benefits were not examined in this study. Furthermore, additional factors such as cost, ease of use, safety, maintenance needs, service life, and aesthetics may dictate pool owner's choice of a pool cover. These additional factors were also not considered in this study. The single objective of this project was to evaluate the benefit of pool covers from the perspective of reducing evaporation and saving water.

LITERATURE REVIEW

Water stored in lakes, reservoirs, and swimming pools is subject to loss by evaporation. The loss is typically higher in arid and semi-arid regions. According to the Arizona Department of Water Resources, for example, swimming pools in the state can lose up to 6-ft of water annually to evaporation (Arizona DWR, 2009). In Australia, up to half of the water stored in reservoirs could be lost to evaporation (Craig, 2005). Water availability is often limited in regions where evaporation is high, making conservation via evaporation suppression crucial for water management. A recent effort by the City of Los Angeles to reduce evaporation by releasing millions of "shade balls" in to their reservoirs illustrates measures that municipalities in water-stressed regions are pursuing to save water (LA Times, 2015).

Evaporation reduction techniques include design alteration (e.g., increasing depth of storage in order to minimize the surface area), windbreaks using trees, shrubs or a fence, shading structures, and covering the water surface partially or completely. Numerous laboratory and field studies have examined performance of various evaporation suppression methods over the years (Mansfield, 1953; USBR, 1961; USGS, 1963; Craig et al, 2006). The field tests were conducted, for the most part, on water reservoirs. Literature on the performance of evaporation suppressants for swimming pools is rather limited.

Shading Structures

Design modifications and windbreaks are valuable practices that ought to be considered all the time. Shading structures suspended above the water surface using cables or frames reduce evaporation by diminishing the impacts of solar radiation and wind speed (Cluff, 1975). A recent study tested seven different shading materials for the United States National Weather Service (NWS) Class-A pans and reported evaporation reductions ranging from 51% to 84% (Alvarez et al, 2006). The authors projected similar performances if the shading materials were to be used for water reservoirs. A study from the University of Southern Queensland in Australia also examined field performances of various types of covers on water storages (Craig, 2005). The study revealed evaporation reductions ranging from 60% to 80% for reservoirs covered by shading structures.

Solid Covers

Covers that float on the water surface or seal the water surface can be effective evaporation suppressants. Such cover types can be categorized as solid (plastic) covers and liquid covers. Evaporation suppression efficiency of 85% to 95% have been reported for solid covers that protect the entire water surface (Craig, 2005). Similarly, a fact sheet from the Arizona Department of Water Resources (2009) advocates that pool and spa owners can reduce evaporation up to 95% by installing covers. On the contrary, the U. S. Department of Energy estimates evaporation reductions of only 30% to 50% for solid pool covers (US DOE, 2015). Using a software developed by the US DOE, Maddaus and Mayer (2001) modeled performance of pool covers and reported efficiencies of 28% for a pool in Sacramento, California and 30% for a pool in Tampa, Florida. The discrepancy in the evaporation reduction efficiencies reported by these various studies for solid covers could be, among others, due to variations in the number of hours the water surface is covered on a typical day. If a pool is used for extended hours, which is the case with most commercial pools, then evaporation reduction efficiency of the solid cover would be low. Other factors could also affect the effectiveness.

Partial covers (i.e., solid covers that shield only a portion of the water surface area), are common evaporation suppressants. Effectiveness of partial covers depends on the fraction of the water surface area protected by the cover (Craig, 2005; Assouline et al, 2010; Assouline et al, 2011). Average evaporation reduction of 75% was reported for a partial cover that exposed only 16% of the water surface area (Burston, 2002). Assouline et al (2011) proposed the following equation to estimate evaporation suppression efficiency of partial covers:

$$\varepsilon = \frac{E - E_C}{E} = 1 - \left(1 - \frac{A_C}{A}\right)^{2/3} \qquad \text{Equation 1}$$

where ε is evaporation reduction efficiency

E is evaporation from uncovered reservoir

E_c is evaporation from a partially covered reservoir

A is total surface area of the reservoir

A_c is the surface area shielded by the cover

According to Equation 1, shielding 70% of the water surface area is expected to reduce evaporation by about 55%.

Liquid Evaporation Suppressants

Liquid evaporation suppressants, or liquid covers, have been widely studied for reservoirs. The work of Mansfield (1953) showed the capability of monolayers (i.e., films that are one molecule thick) to reduce the rate of evaporation in the field. Since then, numerous researchers have examined the performance of various monolayer compounds to reduce evaporation from reservoirs (La Mer, 1962; Barnes, 2008). In the United States, the U.S. Bureau of Reclamation (USBR) and the United States Geological Survey (USGS) have performed a number of studies especially in the 1950s and 1960s (USBR, 1961; USBR, 1962; USGS, 1960; USGS, 1963). Most of the latest research on liquid covers is from Australia (Craig, 2005; Barnes, 2008; McJannet, et al., 2008; Prime, et al., 2012; Fellows, et al, 2015).

Evaporation reduction efficiencies reported in the literature for liquid covers have been summarized by McJannet et al (2008). The reported efficiencies range from 0% to 43% depending on local climate (e.g., wind speed), type of the liquid cover, and characteristics of the reservoir (i.e., size, shape, and depth). Surface area of the reservoirs used for the studies summarized in McJannet et al. (2008) range from 840 ft^2 to 3.9 mi^2. Lake Cachuma which is located about 70 miles south of Cal Poly, was one of the reservoirs that the USBR used to test performance of liquid covers. Efficiency of 8% was reported for Lake Cachuma (USBR, 1962). Reductions of 5% to 30% were obtained by Craig (2005) for a commercial liquid cover. Likewise, Morrison et al. (2008) tested two commercial liquid covers and reported reductions ranging from 45% to 69% for one product and 11% to 16% for another. Morrison et al. (2008) used shallow tanks of 845 ft^2 surface area, a 31.54 ft^2 cattle troughs, and buckets of 0.689 ft^2 surface area for their study. As previously mentioned, the evaporation reduction efficiencies reported in the literature are mostly from water reservoirs. Not many studies have examined performance of swimming pool covers. Overall, performances of liquid covers seem highly variable depending on local climate, size of the water body, and type of the liquid cover.

COVER TYPES TESTED

This study tested one pool cover from each of the general categories of swimming pool cover types. The following six pool cover types were examined:

- Solid track cover
- Foam cover
- Bubble cover
- Solar disks
- Liquid Evaporation Suppressant A (LES A)
- Liquid Evaporation Suppressant B (LES B)

In order to remain impartial to all cover manufacturers, the specific products tested and name of the associated manufacturers will not be disclosed.

Solid Track Cover

A solid track cover typically consist of a cover, a reel mounted on one end of the pool, and tracks along two sides of the pool. The reel and tracks provide structural support for the cover and also help with retracting and rolling of the cover, a process that could be automatic, semi-automatic, or manual. The manual solid track cover used in this study (see Figure 1) has a hand-crank attached on one end of the reel to help with retracting the cover. The covers can be made from vinyl, polyethylene, or polypropylene, and have UV inhibitors (US DOE, 2015). The solid track cover used for this study has thickness of 28 mil and is made from a premium grade vinyl reinforced with a strong polyester mesh.

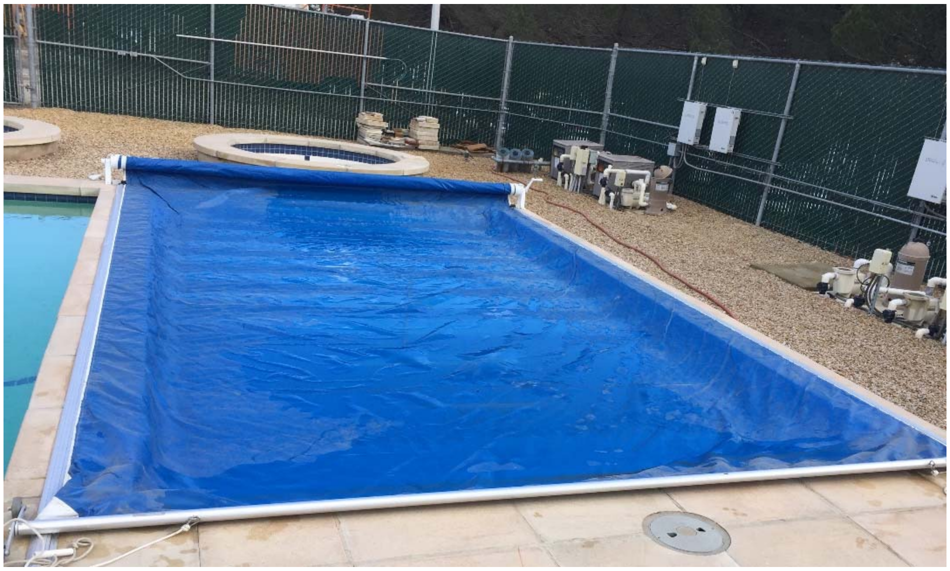


FIGURE 1. SOLID TRACK COVER MOUNTED TO A POOL AT THE NPIRC

Foam Cover

Foam covers float on the water surface and protect the water from direct exposure to wind and sun. Foam covers have multiple layers, each made from different materials designed to serve different purposes such as UV protection, chemical protection, provide structural strength, and provide heat insulation. Foam covers have light weight and are typically rolled and unrolled manually. The foam cover used for this study (Figure 2) is made from a 0.125-inch thick volara foam sandwiched between layers of UV-stabilized and heavy-duty material that are coated by 3.0 mil thick UV-protected, low-density polyethylene.

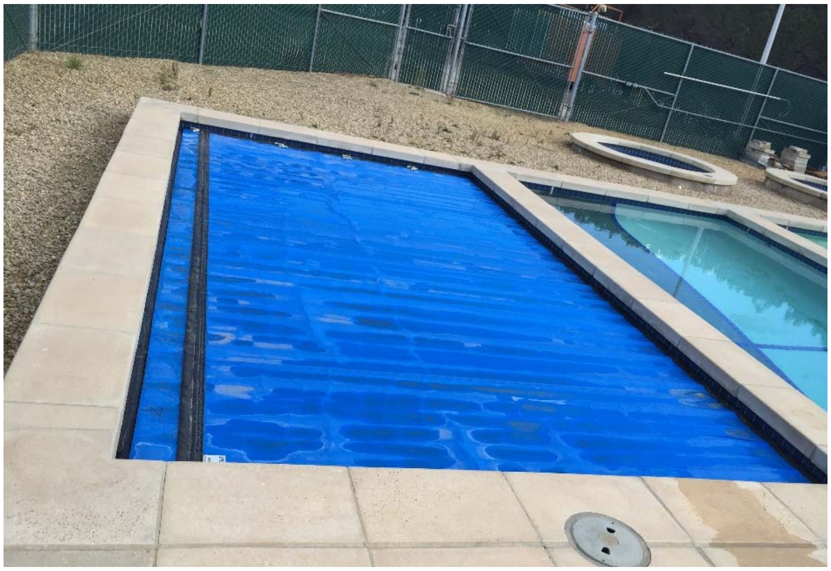


FIGURE 2. FOAM COVER INSTALLED ON A POOL AT THE NPIRC

Bubble Cover

Like foam covers, bubble covers float on the water surface and protect the water from direct exposure to wind and the sun. The covers resemble bubble packaging material but are made from a thicker grade plastic coated with ultraviolet inhibitors to extend service life of the cover (US DOE, 2015). The bubble cover used for the study (Figure 3) is made from polyethylene and is 11 mil thick.

FIGURE 3. BUBBLE COVER PLACED ON A POOL AT THE NPIRC

Solar Disks

Solar disks consist of multiple circular covers that provide partial cover of the water surface. The disks attach to one another via magnets installed on each unit but create small areas of uncovered spaces between the disks as shown in Figure 4. Eight solar disks of five feet diameter each were used for this study. The disks are made from two layers of UV resistant vinyl and are 2.5-inches thick as inflated. The eight disks protect close to 73% of the pool surface area. Evaporation reduction efficiency of solar disks is not expected to be as high as solid covers that provide complete coverage of the water surface area.

FIGURE 4. SOLAR DISKS INSTALLED ON A POOL AT THE NPIRC

Liquid Evaporation Suppressants

Liquid evaporation suppressants (liquid covers) are chemical monolayers typically made from compounds of long chain fatty alcohols such as cetyl and stearyl alcohol. Liquid covers spread spontaneously on contact with water and produce ultra-thin film (~2 millionths of a mm) at the water surface that acts as a diffusion barrier thus increasing resistance to evaporation (McJannet et al. 2008). Liquid covers are designed to be used while the pool is occupied which makes them suitable for public pools that are occupied for extended hours. Disturbances by pool users and wind could disperse the monolayers, thereby compromising efficiency of liquid covers. Molecules of the covers can, however, reorganize readily into a protective film as soon as the disturbance subsides (McJannet et al. 2008).

Two commercial liquid evaporation suppressants, referred to as LES A and LES B, were tested in this study. LES A and LES B are from two different manufacturers. Both liquid covers produce a film that is one molecule thick on the water surface. LESA contains isopropanol and ethanol whereas LES B contains propylene glycol. The dosage and frequency of application recommended by the respective manufactures were used for the study. Detailed chemical content and safety information of each liquid covers is declared by the respective manufacturers via Material Safety Data Sheet (MSDS) for the products**.** However, MSDS of the liquid covers used in this study are not included in this report to conceal the specific products tested.

RESEARCH METHODOLOGY

Evaporation Estimation Method

Rate of evaporation from water bodies such as swimming pools depends on local climate variables including wind velocity, solar radiation, differences in vapor pressure between a water surface and the overlying air, and temperature. A comparative evaporation study such as the one pursued here has to ensure that these factors are identical for the pools used to test the covers. The National Pool Industry Research Center (NPIRC) facility used for this study consists of twelve pools and four spas as shown in Figure 5. All twelve pools have identical shape, size, and exposure to wind and sun making the facility suitable for the comparative study. NPIRC is located on the campus of California Polytechnic State University (Cal Poly).

FIGURE 5. POOLS AND SPAS AT THE NATIONAL POOL INDUSTRY RESEARCH CENTER ON CAL POLY CAMPUS

Several methods are available to estimate evaporation from open water bodies. Evaporation pans, the water budget method, the energy budget approach, and the mass transfer technique are commonly used. Energy budget and mass transfer methods require costly instrumentation to collect the data needed to apply the equations. On the other hand, evaporation from a pan is typically higher than evaporation from larger water body requiring correction factor to translate the pan evaporation to evaporation from a pool. Value of the correction factor, referred to as pan coefficient, not only varies from region to region but also from season to season thus making it difficult to accurately estimate evaporation from pools. As such, the water budget method was used for this study because of its accuracy and suitability for the comparative study.

According to the water budget method, evaporation from a pool over a given period of time (e.g., one day), can be calculated as

$$Evaporation = Initial\ Water\ Level + Precipitation + Water\ Added\ to\ the\ Pool - Water\ Loss\ Via\ Leakage, Splash\ and\ Overflow - Final\ Water\ Level \qquad \textit{Equation 2}$$

For this study, precipitation data is obtained from Station 52 of the California Irrigation Management Information System (CIMIS) (http://www.cimis.water.ca.gov/). Station 52 is located on Cal Poly campus and is less than half-a-mile from the NPIRC facility. In addition to precipitation, other climate data including wind speed, air temperature, humidity, and solar radiation are obtained from the CIMIS station. Water loss via splash was negligible as the pools were not occupied during the study. One of the pools used for the study has spillway and trough system making it susceptible to water loss via overflow, particularly during high winds. As described later in the report, however, water level in the subject pool was carefully managed to avoid overflow. Water loss via leakage – via structural cracks or filtration system plumbing – was addressed by pre and post relative water loss testing of all vessels used for this study. Water levels were measured daily for the pools involved in the study. The pools were topped-off as needed to ensure that the filtration process runs properly. Water levels were recorded before and after the pools were topped-off to determine the quantity of water added to a pool.

Therefore, ignoring water losses via splash and overflow, Equation 2 can be rearranged as

$$Evaporation + Water\ Loss\ Via\ Leakage = Initial\ Water\ Level + Precipitation + Water\ Added\ to\ the\ Pool - Final\ Water\ Level \qquad \textit{Equation 3}$$

As previously described, the terms on the right side of Equation 3 have been monitored. The two terms on the left side of Equation 3 are combined in to one term and will be referred to as "water loss" for the remainder of this report. As such, water loss over a given period of time can be calculated as

$$Water\ Loss = Initial\ Water\ Level + Precipitation + Water\ Added\ to\ the\ Pool - Final\ Water\ Level \qquad \textit{Equation 4}$$

Water Level Measurement

Water levels in the test pools were monitored daily. Stainless steel rulers were mounted on the four walls of each test pool to measure the distance from the top of the pool to the water level. Figure 6 shows a ruler attached to the side of a pool. Accordingly, four daily water level readings were taken for each test pool to minimize measurement error. The readings were made in the mornings, typically between 7 and 9 am, when the wind is often calm and the water surface is tranquil. However, there were days when the wind was too strong in the mornings to take accurate water level readings. On those days, as many as three attempts to measure the water levels were made at different times of the day. If the wind was too strong during all attempts, then no water level measurements were taken on that day. The measurements taken the next day would represent cumulative water loss since the last reading.

FIGURE 6. A STAINLESS STEEL RULER FIXED TO A POOL AT THE NPIRC

Pool Operation and Maintenance

The pools were well maintained throughout the study so that the water remains clean and clear, and the water quality complies with the Association of Pool & Spa Professionals (APSP) standard given in Table 2. Mr. Steven Riley, a retired professional pool operator, helped with operation and maintenance of the pools as a volunteer. Mr. Riley oversaw pool cleaning, proper operation of the filtration process, water quality readings, and balancing of chemicals. Water quality parameters including free available chlorine, pH, and total alkalinity were monitored weekly whereas calcium hardness and cyanuric acid were measured at the start, at half-way point, and at the end of the protocol. Water chemistry was balanced as needed. Shock-oxidation treatment was administered at half-way point.

TABLE 2: AMERICAN NATIONAL STANDARD FOR WATER QUALITY IN PUBLIC POOLS

Water Quality Parameter	Acceptable Range	Ideal Range
Free Available Chlorine	1 to 4 ppm	2 to 4 ppm
pH	7.2 to 7.8	7.4 to 7.6
Total Alkalinity	60 to 180 ppm as $CaCO_3$	80 to 100 ppm as $CaCO_3$
Cyanuric Acid	25 to 100 ppm	30 to 50 ppm
Calcium Hardness	150 to 1,000 ppm as $CaCO_3$	200 to 400 ppm as $CaCO_3$

Source: APSP (2009).

Cover Application

As previously described, six different cover types were tested in this study. The covers were applied to one pool each. One additional pool was required as a control pool to evaluate evaporation efficiency of the covered pools. No cover was applied to the control pool. This means that at least seven pools are needed to conduct the study. NPIRC has twelve pools of identical shape and size. Figure 7 shows IDs and dimensions of the pools at NPIRC. With dimensions of 240 inches by 130 inches, each pool has surface area of 216.7 ft^2.

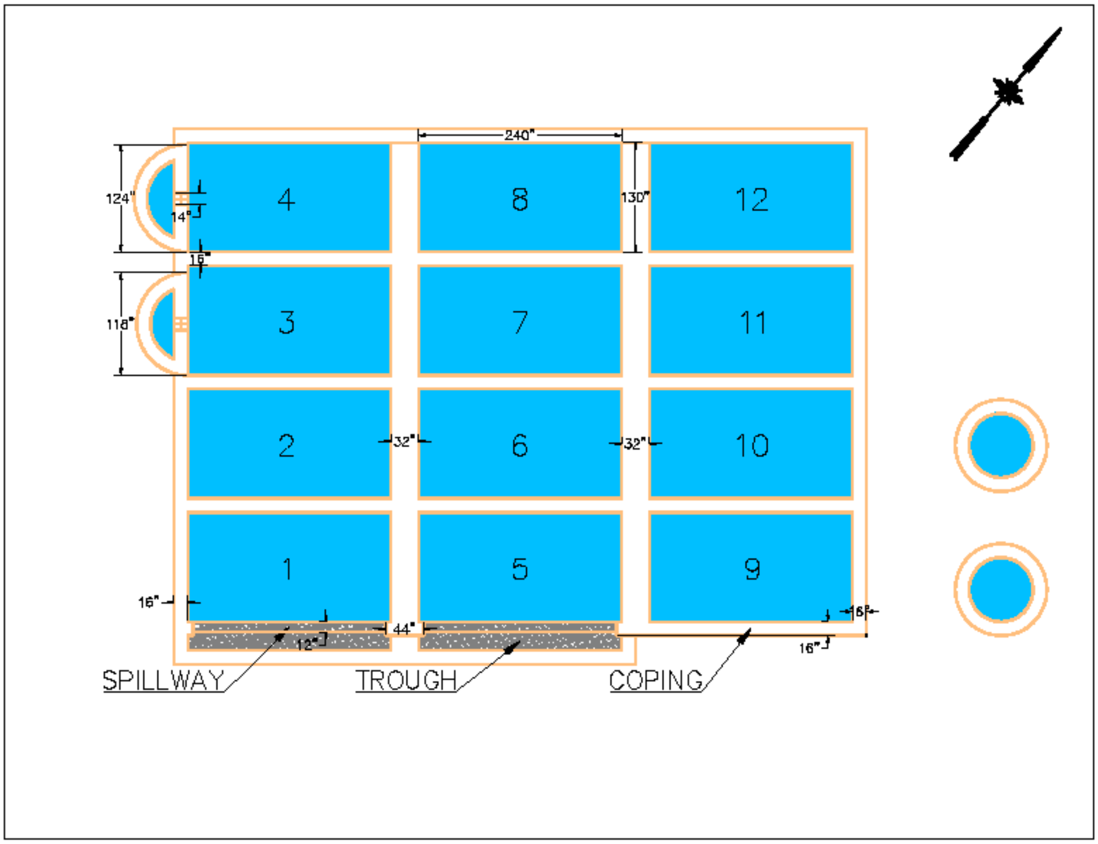


FIGURE 7: SCHEMATIC OF POOLS AND SPAS AT THE NPIRC

The covers were either donated by the manufacturers or purchased. Eight solar disks of 5-ft diameter each were used. Total surface area of eight solar disks is about 157.1 ft^2. Because each pool has surface area of 216.7 ft^2, eight disks cover 72.5 percent of the water surface area. All solid covers came in blue so that reflectivity (i.e., albedo) of the covers is not influenced by color. Albedo describes the fraction of incoming solar radiation that would be reflected back to the atmosphere, and it depends on surface characteristics including color.

Once placed on the water surface at the beginning of the protocol, foam cover, bubble cover, and solar disks were not removed until the end of the protocol. Water level readings were taken for the three cover types while the covers were on. However, the solid track cover was unrolled every morning to take water level readings and was rolled back after readings were complete. For a window of two weeks during the protocol, the solid track cover was not removed from the water surface to test if unrolling the cover every morning would cause extra water loss and reduce evaporation suppression efficiency of the cover.

The liquid evaporation suppressants were applied according to the instructions received from the manufacturers. LES A was applied daily while LES B was applied weekly. For the 216 ft^2 pools used for the study, 0.5 ounces of LES A was applied daily while 2.9 ounces of LES B was applied once a week. Both LES A and LES B were applied manually using a syringe. LES A was sprayed over the entire water surface while LES B was added to the water surface along the filtered water return line.

Data Collection Phases

The project involved two major data collection phases. The initial phase involved eleven days of relative water loss testing, sixty-five days of evaporation reduction testing, and then seven days of another relative water loss testing. About half-way through the 65-day testing, leakage was detected in the pool used to test one of the liquid covers. The crack was sealed using a two part, hand moldable epoxy product specifically formulated for underwater repair of concrete or gunite pools. An adjacent pool had been left empty during this period of testing. We speculated that this contributed to the crack and leaking. We filled this adjacent pool to minimize the stress at the point of the crack repair by equalizing the weight of water on both sides of the pool wall.

It was determined that the data collected from the leaking pool before the crack was sealed was impacted and not valid. Subsequently, the NPC decided to extend the initial protocol by four weeks to collect more data for the liquid covers (i.e., LES A and LES B). A third relative water loss testing was carried-out at the end of the extension study. The objective of the relative water loss tests was to compare water loss from each pool and to evaluate if the pools exhibit leakage via plumbing or structural cracks. No covers were applied to the pools during the relative water loss tests — evaporation should be identical for all pools. Therefore, any difference in water loss that the pools exhibit during the relative water loss test should be due to leakage. Assuming leakages in all pools are steady during the study, the water loss data gathered during the study could be corrected for leakage based on the relative water loss test. The leakage correction approach is described in more detail later in the report. However, if leakage rates for some or all pools change (i.e., increase or decrease) with time, then the relative water loss test might not characterize the leakage rates accurately. The data collection phases are illustrated in Figure 8, and are further described next.

Initial Relative Water Loss Test

The NPIRC facility was not used for several years— the pools were not filled with water during those years. Consequently, prior to beginning this study the pools were thoroughly cleaned, nine of the twelve pools were newly coated, and the plumbing was pressure tested. Then, relative water loss testing was conducted from June 19, 2015 to June 30, 2015 for the coated pools. The objective of the initial water loss test was to identify pools that may exhibit excessive leakage and to eliminate those pools from the protocol.

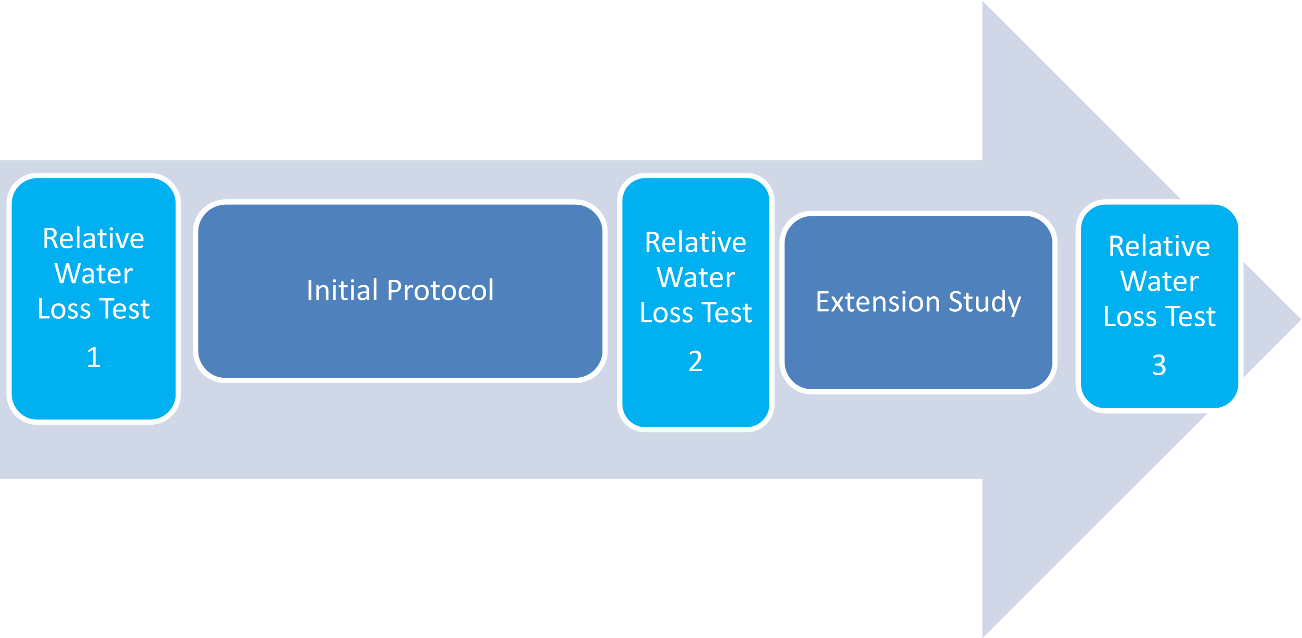


FIGURE 8. SEQUENCE OF THE DATA COLLECTION PHASES

Table 3 shows results of the initial water loss test. The results clearly show that pools 5 and 7 lost considerably more water than the other seven pools. As such, pools 5 and 7 were excluded from the initial protocol.

TABLE 3: INITIAL WATER LOSS TEST RESULT

Pool ID	Water Loss (cm)			
	6/19 - 6/23	6/23 - 6/25	6/25 - 6/30	Total
1	2.7	1.2	3.1	6.9
2	2.8	1.1	2.7	6.6
3	2.5	1.3	2.8	6.5
5	4.4	1.5	4.7	10.6
6	2.7	1.4	2.7	6.8
7	4.1	1.8	4.7	10.5
9	2.6	1.1	2.7	6.3
10	2.6	1.3	3.0	6.8
11	2.7	1.1	2.4	6.2

The Initial Protocol

The initial water loss test result helped with pool selection. Table 4 shows the pools used for the initial protocol and the cover types tested using each pools. Pool 1 (i.e., the primary control pool) has no coping — it is susceptible to overflow via its spillway, especially on windy days. Consequently, water level in Pool 1 had to be kept low to decrease the likelihood of overflow. A low water level, resulting in inadequate water flow to the pool skimmer, would result in heat damage to the filtration system, specifically the pool pump, as well as plumbing and valves in the vicinity of the pump. Therefore the water level in this pool had to be maintained within a narrow range. As a work around, a syphon was installed in the Pool (see Figure 9) to bypass the skimmer and ensure the filtration process remains active even when water level is lower than crest elevation of the skimmer. As extra precaution, Pool 12 was used as secondary control to back-up data from Pool 1 during a portion of the initial protocol.

TABLE 4: POOLS USED FOR THE INITIAL PROTOCOL

Pool ID	Cover Type Tested
1	Primary Control Pool
2	LES A
3	LES B
6	Solar Disks
9	Solid Track
10	Foam
11	Bubble
12	Secondary Control Pool

FIGURE 9. A SYPHON INSTALLED IN POOL 1

Leakage from Pool 3 to Pool 4 was detected midway through the initial protocol (see Figure 10). Pool 4 was not filled with water as it was not used for the protocol. As soon as the leak was detected, several corrective measures were taken. These include,

- The crack was sealed.
- Pool 4 was filled with water to reduce the difference in water levels of the two pools thereby restricting leakage between the two pools in case there were more cracks.
- In addition to Pool 3, we started to test LES B using Pool 12.

FIGURE 10: LEAKAGE FROM POOL 3 TO POOL 4

A seven day long relative water loss test was performed at the end of the initial protocol. The objectives of the second relative water loss test were

- Use the test data to correct for steady leakage the test pools might have had.
- Pool 12 was not tested in the initial relative water loss test but was used to back-up the control pool before the leak in Pool 3 was detected, and to back-up Pool 3 after the leak was detected.

The Extension Study

The extension study was proposed to address the leakage discovered in Pool 3. Data from the relative water loss study couldn't be used to correct water loss data for Pool 3 before the crack was sealed because the leakage increased over time. Pool 4, the pool that shared the cracked wall with Pool 3, was empty as it was not selected for the initial study. As a result, the weight of water exacerbated the crack and thus increased the leakage rate over time.

Both LES A and LES B were applied to two pools each to further scrutinize evaporation suppression efficiency of the two liquid covers. For the most part, the pools that were used to test the solid covers during the initial protocol were used to test the liquid covers during the extension. Bubble cover was also applied to the pool where LES A was tested during the initial protocol. Table 5 shows the pools used for the extension study.

TABLE 5: POOLS USED FOR THE EXTENSION STUDY

Pool ID	Cover Type Tested
2	Bubble Cover
6	Control Pool
8	LES B
9	LES A
10	LES A
11	LES B

Pool 2 was used to test LES A during the initial protocol. To limit potential residual effect of the liquid covers on the new test, Pool 2 was completely drained and refilled for the extension study. In addition, before the extension study was started leakage from a pool to the adjacent pools were observed by filling one pool and leaving the adjacent pools empty. No major leakage was observed except for the leakage from Pool 3 to Pool 4. Trickles were observed from Pool 2 to Pool 3. To further reduce leakage from one pool to the adjacent pools, all pools except for Pool 5, were filled with water to act as a hydraulic barrier and stop leakage via cracks that may exist between adjacent pools. Pool 5 was left empty as no leakage to the pool was observed from all adjacent pools (i.e., Pools 1, 6 and 9).

A five-day long relative water loss test was carried-out at the end of the extension study. The objective of the third test was to quantify relative leakage among the pools and use the information to correct the water loss data gathered during the extension. The pools used to test LES A and LES B (i.e., Pools 8, 9, 10, and 11) were completely drained and refilled for the relative water loss test.

RESULTS AND DISCUSSION

The Initial Protocol Results

Remarks on the Data

The water level readings taken daily over a period of 65 days are given in Appendix A. The data represent distance to water level from tops of the stainless steel rulers attached to all four pool walls. As such, the values increase when water is lost to evaporation and leakage, and decrease when water is added to the pools. Comments such as days the pools were topped-off and windy days when readings were either skipped or delayed are given in the remark column. One can observe from Appendix A that Pools 9 and 10 have few data gaps.

Data was not collected for Pool 10 during the first 13 days of the study as foam cover was installed on August 3rd. For Pool 9, it was noticed during the first few weeks of the study that some water was removed from the pool while unrolling the cover every morning to take water level readings. For the other solid covers, readings were taken while the cover was on. We wanted to test if this discrepancy impacts performance of the solid track cover compared to the other solid covers. As such, water level readings were skipped for the solid track cover for a period of two weeks. Water levels were read on August 5th and then two weeks later on August 19. Those two readings helped calculate cumulative water loss over the period of two weeks. Daily readings were pursued for the pool after August 19. Finally, only seven solar disks were installed on Pool 6 during the first seven days of the study. One more disk was installed on July 28. Therefore, the first seven day readings were not used to analyze the effectiveness of solar disks.

As previously described, leakage was detected in Pool 3 during the last week of August. The crack was sealed on September 1st. The data collected from Pool 3 before September 1st was deemed unreliable and was not used to evaluate performance of LES B, the cover type tested using Pool 3. In addition, LES B was tested on Pool 12 starting August 27.

Relative Water Loss Test Results

As previously described, relative water loss tests were conducted before the initial protocol was started and also at the end of the protocol. Results of the test performed before the protocol began were given in Table 3, and were used to select the pools to be involved in the initial protocol. The second relative water loss test was performed from September 25 to October 2 (i.e., seven days), and the results are given in Table 6.

The results show that the pools lost water at different rates, some noticeably higher than the control pool. Because no covers were applied to the pools during the relative water loss tests and because environmental factors such as exposure to wind and sun are identical for all pools, water loss via evaporation is expected to be identical for the pools. The difference in water loss among the pools indicates that the pools are leaking. However, pool covers are designed to reduce the water lost to evaporation, but not the water lost via leakage. If leakage is not accounted for, evaporation reduction efficiency of the covers would be lower than what it would be if the pools were not leaking. Therefore, with the assumption that leakage rates are steady (i.e., do not change with time) for all pools during the study period, the water loss data shown in Appendix A will have to be corrected for relative leakage.

TABLE 6: RESULTS OF THE SECOND RELATIVE WATER LOSS TEST

Pool ID	Water Loss (cm)	Leakage Correction (cm/day)
1 (Control Pool)	3.4	0.000
2	3.8	-0.050
3	3.9	-0.061
6	4.2	-0.107
9	3.9	-0.068
10	4.0	-0.086
11	4.0	-0.082
12	4.5	-0.146

Table 6 shows that the control pool lost the least during the relative water loss test suggesting that leakage rate in the control pool is the lowest. Leakage for the other pools can be determined relative to water loss for the control pool. Consequently, the leakage correction rates given in Table 6 were calculated for each pool using Equation 5, and were used to correct the water loss data shown in Appendix A.

$$(Water\ Loss\ for\ the\ Control\ Pool - Water\ Loss\ for\ a\ Pool)/7 \qquad Equation\ 5$$

It should be noted that, the pools covered by LES A and LES B (i.e., Pools 2, 3 and 12) were not drained and refilled for the relative water loss test. As previously described, LES A was applied daily and LES B was applied weekly during the protocol. The leakage test began ten days after LES B was applied to Pool 3; seven days after LES B was applied to Pool 12; and a day after LES A was applied to Pool 2. However, the liquid covers could exhibit residual effect and reduce evaporation from the stated pools during the relative water loss test. This possibility was examined for LES B using data from Pool 12. Pool 12 was used as secondary control until August 27, and to test LES B after that. Total water loss from Pool 1 and Pool 12 between July 21 and August 27 (i.e., period of 38 days) was 21.23 cm and 26.78 cm, respectively. This suggests that Pool 12 lost, on average, 0.146 cm/day more water than Pool 1 during the stated period. As shown in Table 5, Pool 12 lost 0.146 cm/day more water than Pool 1 during the relative water loss test as well. This suggests that water loss rate for Pool 12 was not impacted by residual effect of LES B during the leakage test. Potential residual effect of LES A was not examined.

Daily Water Loss Calculation

Water loss from a pool between successive measurement days was calculated from the water level readings given in Appendix A as

$$Water\ Loss = \frac{1}{4}\left[\sum_{Side=1}^{4}(Water\ Level\ on\ Day\ 1 - Water\ Level\ on\ Day\ 2)_{Side}\right] + Rainfall + Leakage\ Correction \qquad \textit{Equation 6}$$

Leakage correction rates are from Table 6 and rainfall data was obtained from the CIMIS station located on Cal Poly campus. Because water level measurements were taken between 7 am and 9 am, total rainfall between successive days was calculated by adding hourly rainfall values from 8 am of day one to 8 am of day two. Similar analysis was performed for other weather data including solar radiation, relative humidity, air temperature and wind speed were also obtained from the CIMIS station. As shown in Appendix A, two sets of water level readings were taken on the days a pool was topped-off. One set of readings was taken before water was added to a pool and another set of readings after the pool was topped-off. The readings taken before water was added were used to calculate water loss from the previous reading day until the pool was topped-off whereas the readings taken after the pool was filled helped to quantify water loss from the moment the pool was topped-off until the next reading day. The water loss calculated for each pool using Equation 6 are given in Appendix B. In addition, daily total rainfall and daily average of the other weather variables, calculated from 8 am to 8 am of consecutive days, are given in Appendix C.

A closer look at the data given in Appendix B reveals that performances of both LES A and LES B are noticeably different before and after September 1st, the day the crack detected on Pool 3 was sealed. Figure 11 illustrates the discrepancy. Cumulative water loss from Pool 3 (i.e., the pool covered by LES B), is quite similar with cumulative water loss from the control pool until about August 20, and then it considerably increased until the crack was sealed on September 1st. This suggests that the leakage detected in Pool 3 was intensified around August 20. Performance of LES B has improved after the crack was sealed. Likewise, cumulative water loss for Pool 2 (i.e., the pool covered by LES A) was fairly identical to that of the control pool until September 1st, and the water loss began to decline after the crack in Pool 3 was sealed. This indicates that the leakage in Pool 3 might have impacted rate of water loss in Pool 2 as well. As such, the data collected for Pool 2 and Pool 3 before September 1st were not used to analyze the effectiveness of LES A and LES B, respectively.

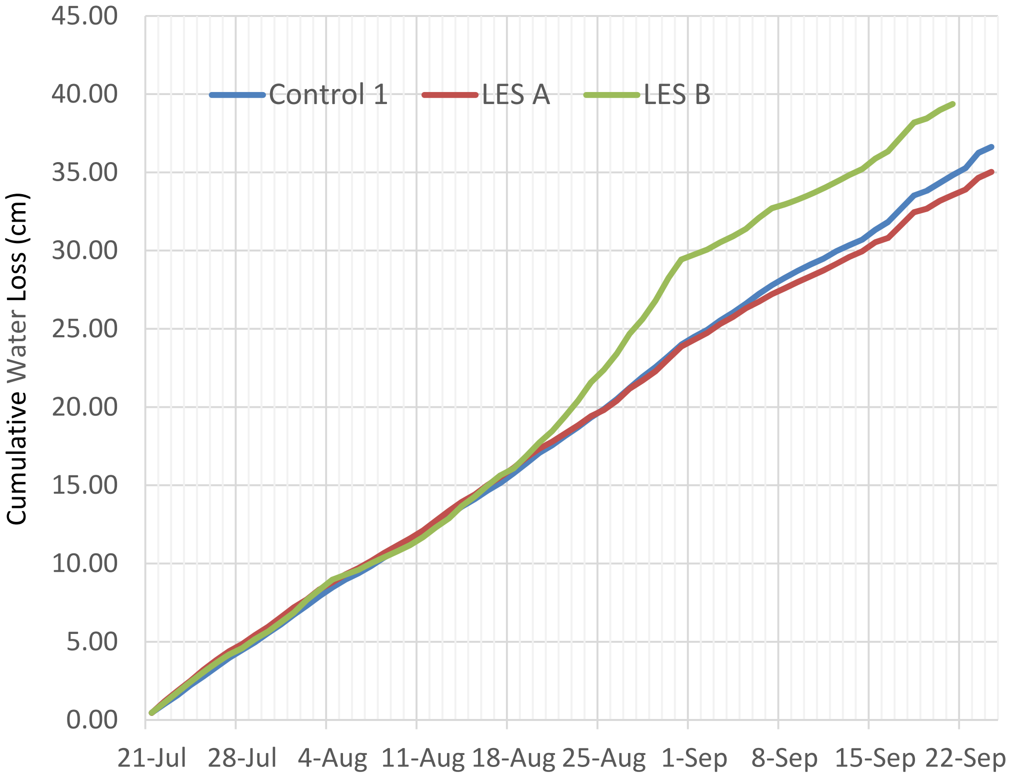


FIGURE 11. COMPARISON OF WATER LOSS FROM THE CONTROL POOL, AND POOLS 2 AND 3

Evaporation Reduction Efficiency of the Pool Covers

The water loss data given in Appendix B represent the quantity of water that a respective pool lost via evaporation in the subject pool and leakage in the control pool. The leakage correction methodology described in the previous section corrects for leakage in the test pools relative to water loss in the control pool which comprise evaporation as well as potential leakage in the control pool. Because quantifying leakage for the control pool is a daunting task, evaporation reduction efficiency of the covers was evaluated relative to water loss in the control pools as

$$Efficiency\ of\ a\ test\ pool = 100\left[\frac{Water\ Loss_{control\ pool} - Leakage\ Corrected\ Water\ Loss_{test\ pool}}{Water\ Loss_{control\ pool}}\right]$$

Equation 7

where *Water Loss* $_{control\ pool}$ represents water loss via evaporation and potential leakage for the control pool during the period of analysis; *Leakage Corrected Water Loss* $_{Test\ Pool}$ represents leakage corrected water loss from a test pool during the period of analysis. It should be noted that if the control pool has leakage, then Equation 7 underestimates efficiency of the cover.

Table 7 has results of the evaporation reduction efficiency calculated using Equation 7 for the cover types tested in the study. The results show that solid track cover, foam cover, and bubble cover produced fairly identical performance, and that they are all extremely effective in reducing evaporation from swimming pools. Solar disks reduced evaporation by half. As previously described, the eight solar disks installed on Pool 6 covered about 73% of the pool surface area. From Equation 1, covering 73% of the water surface is expected to reduce evaporation by about 58% which is slightly higher than the 50% efficiency obtained in this study. Figure 12 compares cumulative water loss for the control pool to the cumulative water loss obtained for the pools covered by bubble cover and solar disks. Figure 13 shows efficiency of the pool covers over the duration of the study. Bubble cover is used in both figures representing foam cover and solid track cover as well since performances of the three cover types are rather similar. Figures 12 and 13 illustrate that efficiencies of solar disks and bubble cover were fairly constant over the duration of the study. This suggests that any leakage that the respective pools (i.e., Pool 6, Pool 9, Pool 10, and Pool 11) might have had was steady throughout the duration of the project implying that the leakage correction methodology pursued in this study is reasonable at least for the listed pools.

TABLE 7: EVAPORATION REDUCTION EFFICIENCY OF POOL COVERS DURING THE INITIAL PROTOCOL

Cover Type	Pool ID	Data Period Used for the Analysis	Water Loss (cm)		Efficiency (%)
			Control Pool	Test Pool	
LES A	**2**	1-Sep to 24-Sep	12.6	11.2	11.7
LES B	**3**	1-Sep to 21-Sep	10.8	10.0	8.0
	12	27-Aug to 24-Sep	16.1	13.8	14.6
Solar Disks	**6**	28-July to 24-Sep	32.7	16.3	50.1
Solid Track	**9**	21-July to 24-Sep	36.6	2.2	93.9
Foam	**10**	1-Aug to 24-Sep	30.5	1.3	95.9
Bubble	**11**	21-July to 24-Sep	36.6	1.9	94.9

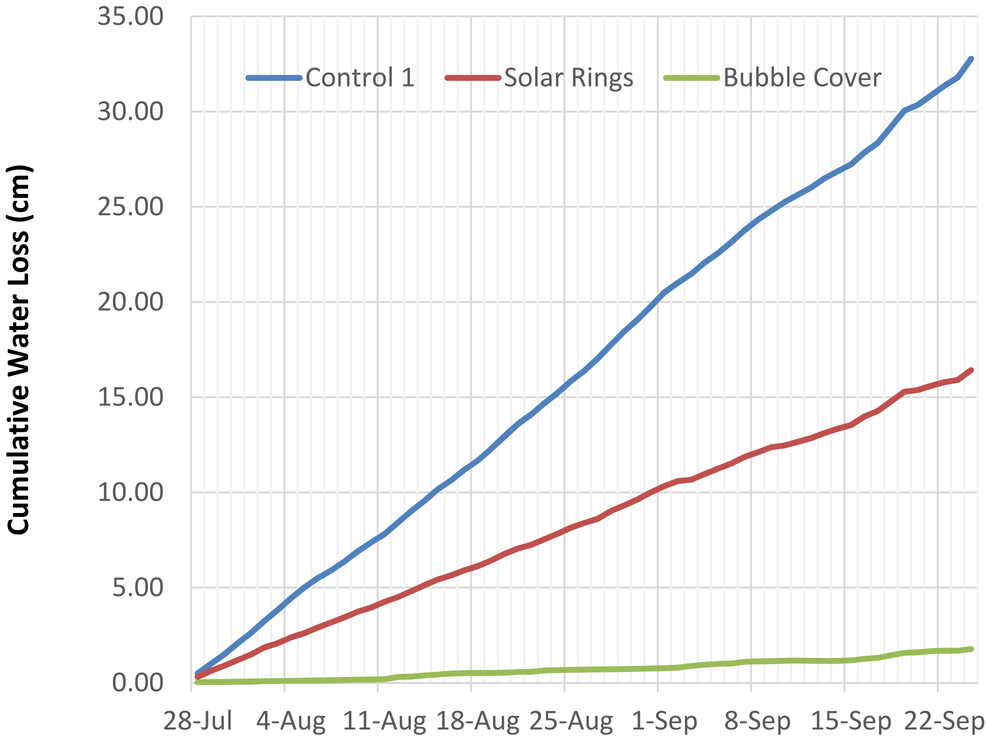


Figure 12. Cumulative Water Loss for the Pools Covered by Solar Disks and Bubble Cover

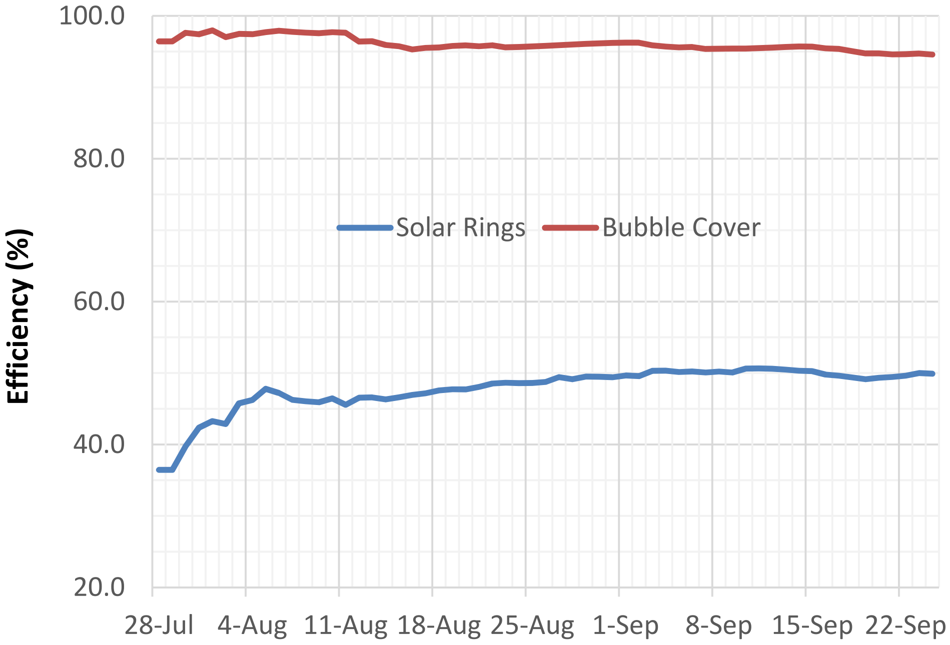


Figure 13. Performances of Solar Disks and Bubble Covers during the Initial Protocol

Water Quality Results

Free chlorine, pH, and total alkalinity were read weekly. Calcium hardness and cyanuric acid were monitored at the start, at the midway point, and at the end of the protocol. Table 8 shows the water quality data.

TABLE 8: WATER QUALITY DATA FOR THE INITIAL PROTOCOL

Pool ID		1	2	3	6	9	10	11	12
Cover Type		Control 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Control 2 (LES B)
Week	Parameter	Concentration (ppm)							
Week 1	Free Cl	2.0	1.0	3.0	1.0	2.0	1.0	2.0	2.0
	pH	7.4	7.5	7.4	7.4	7.4	7.4	7.4	7.6
	Alkalinity	110	110	110	100	120	110	120	120
	Calcium	220	220	240	200	210	210	200	200
	Cyanuric Acid	45	60	40	40	50	60	40	45
Week 2	Free Cl	4.0	2.0	1.0	4.0	5.0	1.0	5.0	1.0
	pH	7.4	7.5	7.5	7.4	7.4	7.4	7.4	7.5
	Alkalinity	120	120	120	100	120	120	120	100
Week 3	Free Cl	2.0	1.0	1.0	5.0	5.0	5.0	5.0	2.0
	pH	7.4	7.4	7.5	7.2	7.4	7.4	7.4	7.6
	Alkalinity	110	110	130	100	120	120	120	120
Week 4	Free Cl	5.0	1.0	10.0	1.0	3.0	3.0	5.0	2.0
	pH	7.6	7.4	7.4	7.2	7.4	7.2	7.2	7.8
	Alkalinity	110	100	120	110	120	110	100	110
Week 5	Free Cl	2.0	2.0	10.0	1.0	4.0	5.0	7.0	5.0
	pH	7.6	7.4	7.2	7.4	7.4	7.2	7.0	8.0
	Alkalinity	170	170	160	180	170	190	160	160
	Calcium	230	240	230	230	230	230	230	230
	Cyanuric Acid	70	65	75	80	80	70	65	75
Week 6 Pools shocked this week.	Free Cl	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	pH	7.4	7.2	7.0	7.2	7.4	7.2	7.0	7.4
	Alkalinity	110	100	80	110	110	120	110	100
Week 7	Free Cl	5.0	1.0	2.0	5.0	5.0	5.0	5.0	5.0
	pH	7.4	7.4	7.4	7.4	7.4	7.4	7.2	7.4
	Alkalinity	110	110	100	110	100	110	110	110
Week 8	Free Cl	10.0	2.0	2.0	2.0	2.0	2.0	3.0	3.0
	pH	7.6	7.4	7.4	7.6	7.4	7.4	7.2	7.5
	Alkalinity	110	100	90	120	100	120	140	110
Week 9	Free Cl	10.0	3.0	1.0	3.0	2.0	3.0	3.0	5.0
	pH	7.4	7.4	7.4	7.4	8.0	7.4	7.4	7.6
	Alkalinity	100	120	90	120	130	140	150	100
Week 10	Free Cl	2.0	2.0	1.0	2.0	2.0	1.0	2.0	1.0
	pH	7.5	7.4	7.5	7.4	8.0	7.4	7.4	8.0
	Alkalinity	64.8	89	72	109	88	105	105	72
	Calcium	240	250	250	230	210	220	210	240
	Cyanuric Acid	80	70	60	70	90	50	50	80

Note: Alkalinity and Calcium are in ppm as $CaCO_3$*.*

For the most part, the water quality parameter values shown in Table 8 are within the acceptable ranges recommended by APSP (see Table 2). There were few instances when free chlorine and pH readings did not comply with the APSP recommendation. Primarily, those instances were when the covered pools were shocked in Week 6, where the free chlorine readings remained high on those pools. Additionally, it can be seen that total alkalinity readings on the covered pools rose steadily over time due to the covers being left on throughout the protocol, eliminating the chance for the water to seek balance by gassing off part of that value at the water surface. The final total alkalinity readings provided in Table 8 were corrected for cyanuric acid's effect on total alkalinity readings.

The Extension Study Results

Performance of the liquid evaporation suppressants was appraised from October 19 to November 15 when half ounces of LES A was applied daily to both Pools 9 and 10, and 2.9 ounces of LES B was applied weekly (every Monday morning) to Pools 8 and 11. Pool 6 was used as a control. In addition, bubble cover was applied to Pool 2 about half-way through the extension study. It should be noted that during the initial protocol, Pools 6, 9, 10 and 11 were used to test solar disks, solid track cover, foam cover, and bubble cover, respectively. Because Pool 2 was used to test LES A during the initial protocol, the pool was fully drained and refilled for the extension study to ensure that performance of the bubble cover is not impacted by potential residual effect of LES A. Bubble cover was added to the study to test if the efficiency obtained for the cover during the initial protocol can be duplicated using the pool that was used to test one of the liquid covers during the initial protocol.

As done during the initial protocol, water level measurements were made every day, typically between 7 am and 9 am, except on windy days when readings were taken either later on that day or skipped. Water quality parameters were monitored weekly and water chemistry was balanced as needed. The pools were cleaned occasionally, as required. Relative water loss test was also performed at the end of the extension study, specifically from December 2 to December 7. The pools used to test LES A and LES B during the extension study (i.e., Pools 8, 9, 10 and 11) were fully drained and refilled for the relative water loss test. Water level data for the extension study are given in Appendix D. Comments such as days the pools were topped-off and windy days when readings may have been skipped are provided in Appendix D.

Results of the relative water loss test are given in Table 9. The results show that Pool 8 loses substantially more water than the other pools. The leakage correction rates provided in Table 9 were calculated using Equation 5 to correct for leakage in the test pools relative to water loss in the control pool. Equation 6 was then used to determine the water loss values given in Table 10.

Table 9: Relative Water Loss Test Results for the Extension Study

Pool ID	Water Loss (cm)	Correction (cm/day)
2	1.25	0.000
6 (Control Pool)	1.25	
8	2.58	-0.265
9	1.20	0.010
10	1.15	0.020
11	1.15	0.020
12	1.35	-0.020

Table 10: Water Loss Data for the Extension Study

Pool ID	2	6	8	9	10	11
Cover Type	**Bubble**	**Control**	**LES B**	**LES A**	**LES A**	**LES B**
Date	**Water Loss (cm)**					
19-Oct		0.73	0.54	0.61	0.52	0.65
20-Oct		0.53	0.34	0.54	0.40	0.47
21-Oct		0.43	0.29	0.59	0.37	0.42
22-Oct		0.43	0.26	0.51	0.40	0.45
23-Oct		0.48	0.29	0.49	0.40	0.42
24-Oct		0.35	0.14	0.44	0.37	0.42
25-Oct		0.45	0.31	0.46	0.37	0.47
26-Oct		0.38	0.36	0.44	0.42	0.42
27-Oct		0.40	0.39	0.26	0.40	0.27
28-Oct to 29-Oct		1.28	1.42	1.02	1.27	1.12
30-Oct		0.65	0.71	0.61	0.42	0.60
31-Oct		0.55	0.54	0.44	0.42	0.50
1-Nov	0.12	0.45	0.51	0.31	0.37	0.37
2-Nov	0.02	0.23	0.19	0.24	0.47	0.15
3-Nov	0.20	0.53	0.61	0.39	0.60	0.42
4-Nov	0.20	0.75	0.76	0.54	0.62	0.52
5-Nov	0.20	0.70	0.66	0.49	0.42	0.55
6-Nov	0.20	0.90	0.84	0.81	0.82	0.72
7-Nov	0.30	0.58	0.44	0.39	0.37	0.37
8-Nov	0.23	0.33	0.19	0.32	0.33	0.18
9-Nov	0.33	0.35	0.29	0.21	0.17	0.32
10-Nov	0.26	0.54	0.45	0.42	0.43	0.46
11-Nov to 12-Nov	0.85	2.00	2.07	1.65	1.44	1.34
13-Nov	0.13	0.43	-0.14	0.26	0.25	0.27
14-Nov to 15-Nov	1.01	1.03	0.73	1.00	1.02	1.02

The evaporation reduction efficiencies obtained during the extension study are given in Table 11. The results show that performances of the two liquid evaporation suppressants is quite similar, and are consistent among the pools they were tested in. Compared to the efficiencies obtained during the initial protocol and shown in Table 7, the leakage detected in Pool 3 seems to have compromised performances of both LES A (i.e., 11.7 %) and LES B (i.e., 8 % for Pool 3). However, the efficiency obtained for LES B using Pool 12 during the initial protocol (i.e., 14.7%) is consistent with the efficiencies reported in Table 11.

Previous studies have suggested that performance of liquid evaporation suppressants can be sensitive to wind speed and storm events (McJannet et al. 2008). Winds higher than 5 miles/hr are believed to reduce efficiency of the liquid covers (Vines, 1962). As shown in Figure 14, both wind speed and rainfall were stronger and more frequent during the extension study (i.e., October 19 to November 15) than during the initial protocol (i.e., July 21 to September 24). The number of days with average daily wind speed higher than 5 miles/hr is, however, comparable for the initial protocol (i.e., 2 days) and the extension study (i.e., 3 days). Regardless, the stronger winds and more frequent rain events experienced during the extension study might have negatively impacted evaporation reduction efficiency of the liquid covers. Appendix E has daily total rainfall and daily average of the other climate variables for the extension study.

TABLE 11: EVAPORATION REDUCTION EFFICIENCIES OBTAINED FOR THE EXTENSION STUDY

Cover Type	Pool ID	Data Period Used for Analysis	Water Loss (cm)		Efficiency (%)
			Control Pool	Subject Pool	
LES A	**9**	19-Oct to 15-Nov	15.42	13.37	13.3
	10	19-Oct to 15-Nov	15.42	13.03	15.5
LES B	**11**	19-Oct to 15-Nov	15.42	12.85	16.7
	8	19-Oct to 15-Nov	15.42	13.12	14.9
Bubble Cover	**2**	1-Nov to 15-Nov	8.79	1.20	86.3

Evaluating efficiency of the bubble cover was tricky for the extension study. The region received 3.79 cm of rainfall during the extension study compared to only 0.05 cm during the initial protocol period. All of the rain occurred between November 1 and November 15, the period the bubble cover was tested. We noticed that after a rain event, the rainwater sits on the bubble cover and raises water level in the pool by buoyancy effect. The water sitting on the cover evaporates at the rate dictated by environmental factors thus dropping water level in Pool 2 faster than it would had there been no rain. In addition, it is not clear what fraction of the rain is captured by the cover, what fraction flows over the cover and enter the pool, or what fraction may splash off the cover to another pool or ground. This issue has caused doubt on how to calculate efficiency of the bubble cover for the extension. The efficiency given in Table 11 for bubble cover (i.e., 86.3%) was calculated with the arbitrary assumption that only twenty five percent of the rainfall would enter the pool while the remaining 75% would be captured by the cover and evaporate at a rate identical to uncovered pools. For the sake of comparison, if none of the rainwater is assumed to enter the pool, then efficiency of the bubble cover would be 97.2% which is more consistent with the efficiency obtained for the cover during the initial protocol.

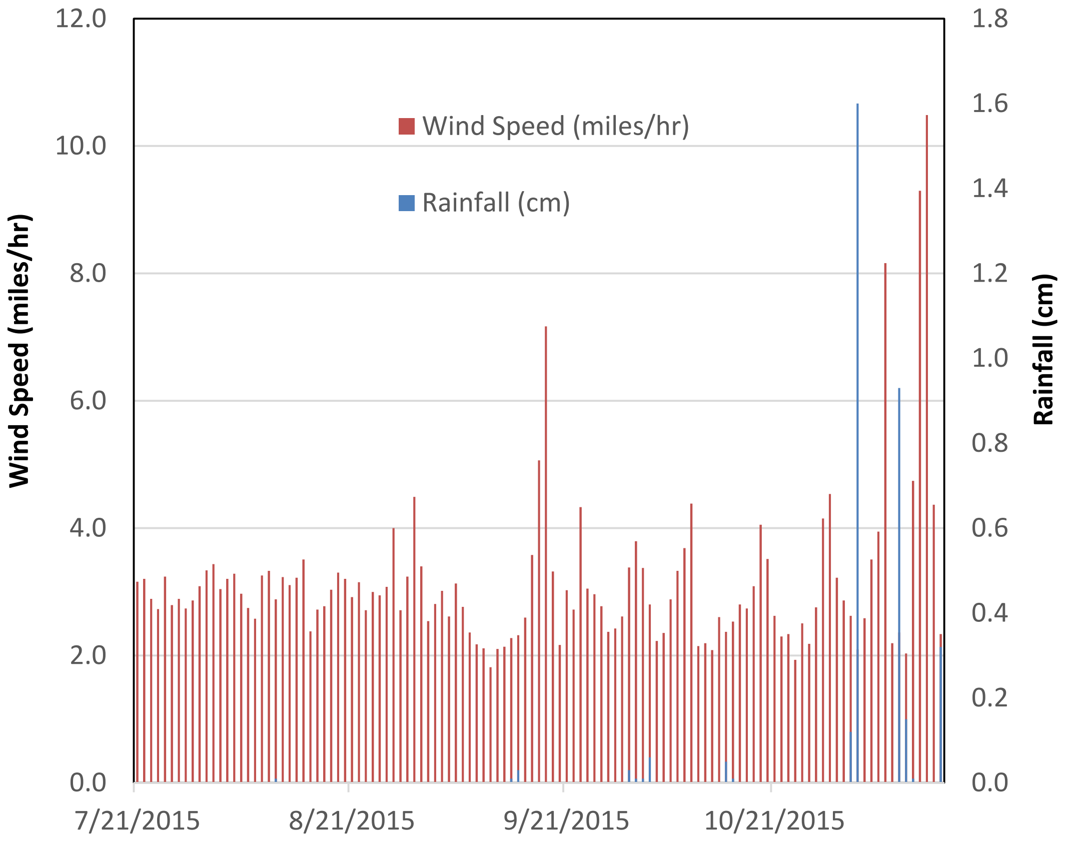


FIGURE 14. AVERAGE DAILY WIND SPEED AND TOTAL DAILY RAINFALL DURING THE INITIAL PROTOCOL AND THE EXTENSION STUDY

Finally, water quality data for the extension study are given in Table 12. Values of all the monitored water chemistry parameters are within the range recommended by APSP.

Table 12: Water Quality Data for the Extension Study

Pool ID		2	6	8	9	10	11
Cover Type		Bubble	Control	LES B	LES A	LES A	LES B
Week	Parameter	Concentration (ppm)					
Week 1	Free Cl		3.0	3.0	3.0	3.0	3.0
	pH		7.6	7.6	7.6	7.4	7.5
	Alkalinity		140	120	120	110	120
	Calcium ls		230	200	250	220	230
	Cyanuric Acid		80	60	70	50	40
Week 2	Free Cl		3.0	2.0	2.0	2.0	1.5
	pH		7.0	7.6	7.4	7.4	7.8
	Alkalinity		140	110	110	130	140
Week 3	Free Cl	3.0	1.0	1.0	1.0	1.0	2.0
	pH	7.4	7.4	7.6	7.4	7.4	7.5
	Alkalinity	120	90	120	120	120	110
	Calcium	250					
	Cyanuric Acid	90					
Week 4	Free Cl	2.0	1.5	1.5	2.0	2.0	2.0
	pH	7.4	7.5	7.6	7.4	7.4	7.4
	Alkalinity	120	90	120	120	120	120

CONCLUSIONS

In light of the severe drought that California has confronted over the last four years, water conservation is becoming a crucial component of water management solutions pursued by municipalities and water districts in the state. Driven by the pool industry's curiosity regarding the effectiveness of pool covers to reduce evaporation from swimming pools and save water, this study examined evaporation suppression efficiency of the pool cover types available on the market. Six different cover types, specifically, solid track cover, foam cover, bubble cover, solar disks, and two liquid covers were tested. The National Pool Industry Research Center (NPIRC) facility located at Cal Poly was used for the study.

For the initial protocol, the six cover types were applied to at least one pool each and one more pool was used as a control. Water levels were monitored daily, typically between 7 am and 9 am when wind is often calm and the water surface is tranquil. The pools were professionally maintained throughout the study so that water quality parameters including free available chlorine, pH, total alkalinity, calcium hardness, and cyanuric acid comply with the standard recommended by the Association of Pool & Spa Professionals (APSP). Free available chlorine, pH, and total alkalinity were monitored weekly, whereas calcium hardness, and cyanuric acid were tested occasionally. To examine leakage, relative water loss tests were performed before the initial protocol began as well as at the end of the protocol. About midway through the initial protocol, major leakage was detected in the pool used to test one of the liquid covers. Subsequently, the protocol was extended by four weeks to collect additional data for the liquid covers. Relative water loss test was performed at the end of the extension study as well.

Major findings of the study are as follows.

- Solid track cover, foam cover, and bubble cover reduced evaporation by about 95 percent. Performance of the three cover types was identical. Solar disks reduced evaporation by 50 percent. However, it should be clarified that once installed, the covers were not removed from the pools throughout the study other than during cleaning and water level measurements of the pool covered with solid track cover. In reality, the covers will have to be removed, possibly for extended hours, when the pools are occupied. This suggests that the efficiencies reported here for the solid covers should be considered as maximum possible efficiencies.

- The two liquid evaporation suppressants tested in the study reduced evaporation by about 15 percent. Performances of the two covers were fairly similar, and were consistent among the pools used to test the liquid covers. However, wind and storm were more frequent and stronger during the extension study (i.e., when the liquid covers were examined) compared to the initial protocol period, and might have negatively impacted efficiency of the liquid covers. At the same time, efficiency of the liquid covers was helped by the absence of swimmers who would temporarily disrupt performance.

- Water quality of the pools complied with APSP standard during the study except for few instances during the initial protocol when free chlorine and pH readings were outside the recommended ranges.

- The relative water loss tests revealed that the pools lose water at different rates indicating that the pools have leakage. The test results were used to correct for the leaks with the assumption that the leakage rates were steady during the study.

REFERENCES

APSP, 2009. American National Standard for Water Quality in Public Pools and Spas. (http://standards.nsf.org/apps/group_public/download.php/17496/ANSI-APSP-11%202009-for-apsp-store.pdf), Accessed December, 2015.

Arizona Department of Water Resources, 2009. "Pools and Spas Water Saving Tips and Technologies."http://www.azwater.gov/azdwr/StatewidePlanning/Conservation2/Technologies/documents/pool_spas.pdf. Accessed in October, 2015.

Assouline, S., K. Narkis, and D. Or (2011), Evaporation suppression from water reservoirs: Efficiency considerations of partial covers, Water Resour. Res., 47, W07506, doi:10.1029/2010WR009889.

Assouline, S., K. Narkis, and D. Or (2010), Evaporation from partially covered water surfaces, Water Resour. Res., 46, W10539, doi:10.1029/2010WR009121.

Barnes, G.T. (2008). The potential for monolayers to reduce the evaporation of water from large water storages. Agricultural Water Management, 95, pp 339-353.

Burston, I. (2002). Conservation of water from open storages by minimising evaporation, Doctor of Philosophy (PhD), Department of Mechanical and Manufacturing Engineering, RMIT University.

Cluff, C.B. (1975). Engineering aspects of water harvesting research at the University of Arizona. Proc. Water Harvesting Symp., Phoenix, AZ, ARS W-22. USDA, pp. 27-39.

Craig, I. P. (2005), Loss of storage water due to evaporation—A literature review, Univ. of South. Queensland, Toowoomba, Australia.

Craig, Ian and Schmidt, Erik and Scobie, Michael (2006) Evaporation control using covers - some realistic solutions for the irrigation industry. In: Irrigation Australia 2006: Irrigation Association of Australia National Conference and Exhibition, 9-11 May 2006, Brisbane, Australia.

California Department of Water Resources, 1979. "Evaporation from Water Surfaces in California". Bulletin 73-79.

Fellows, C. M. , Coop, P. A., Lamb, D. W., Bradbury, R. C., Schiretz, H. F., Woolley, A. J., 2015. Understanding the role of monolayers in retarding evaporation from water storage bodies. Chemical Physics Letters 623:37–41.

Gleick, P (2013). Water Policy: What about All Those Swimming Pools in Los Angeles? http://pacinst.org/water-policy-what-about-all-those-swimming-pools-in-los-angeles/ (Accessed October, 2015).

La Mer, V. K. (1962). Retardation of Evaporation by Monolayers: Transport Processes. Academic Press, New York.

LA Times, 2015. “Millions of shade balls helping protect California's precious water” Available at http://www.latimes.com/local/lanow/la-me-ln-shade-ball-water-20150812-htmlstory.html. Accessed October 2015.

MANSFIELD, W. W. 1953. The effect of surface films on the evaporation of water. Nature, Volume 172, No. 4389, page 1101

McJannet, D., Cook, F., Knight, J., and Burn, S. (2008). Evaporation Reduction by Monolayers: Overview, Modelling and Effectiveness. Urban Water Security Research Alliance Technical Report No. 6.

Morrison P, Gill R, Symes T, Misra R, Craig I, Schmidt E & Hancock N (2008). Small scale evaporation mitigation trials, 2007–08, Field tests on the performance of commercially available chemical evaporation-retarding products. National Centre for Engineering in Agriculture, Publication 1002040/1, Toowoomba, Queensland, Australia.

Prime, E., Leung, A., Tran, D., Gill, H., Solomon, D., Qiao, G., Dagley, I. (2012). New technology to reduce evaporation from large water storages. Waterlines Report Series No 80.

Schnoor, J. L. (2008). “Living with a Changing Water Environment”. The Bridge: Linking Engineering and Society, National Academy of Engineering, Volume 38(3).

U.S. Department of Energy, 2015 “Swimming Pool Covers” http://energy.gov/energysaver/swimming-pool-covers. (Accessed in October 2015)

USBR, 1961. 1960 evaporation reduction studies at Sahuaro Lake, Arizona, and 1959 monolayer behavior studies at Lake Mead, Arizona-Nevada and Sahuaro Lake Arizona. Denver, Col., U.S. Bureau of Reclamation. (Chem. Eng. Lab. rept. no. SI-32.)

USBR, 1962. Water-loss investigations: Lake Cachuma - 1961 evaporation reduction investigations. Chemical Engineering Laboratory report no, SI-33, US Bureau of Reclamation, Denver.

USGS, 1960. Review of Literature on Evaporation Suppression. Geological Survey Professional Paper 272-C, WASHINGTON, D.C.

USGS, 1963. Evaporation Control Research, 1959-1960. Geological Survey Water-Supply Paper 1692, WASHINGTON, D.C.

Vines, R.G., 1962. Evaporation control: A method of treating large water storages. In: V.K. La Mer (Editor), Retardation of evaporation by monolayers: Transport processes. Academic Press, New York, pp. 193-202

APPENDIX A-1. WATER LEVEL DATA FOR THE INITIAL PROTOCOL

Pool ID			1		2	3	6	9	10	11	12
Cover Type			Ctrl 1		LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side		Distance to Water Level (cm)							
21-Jul		S	12.9		5.8	6.5	5.5	4.2		4.7	5.7
		W	13.6		5.5	5.7	5.4	4.6		5.2	5.6
		N	13.6		6.0	6.7	5.9	4.9		4.9	6.4
		E	13.4		6.1	6.8	5.8	4.9		5.5	6.3
22-Jul		S	13.4		6.3	7.1	5.7	4.2		4.7	6.3
		W	14.0		6.1	6.2	5.4	4.6		5.2	6.2
		N	14.1		6.5	7.3	6.1	4.9		5.0	6.9
		E	13.8		6.5	7.2	5.9	4.9		5.5	7.0
23-Jul		S	14.0		7.1	7.9	6.2	4.2		4.8	7.0
		W	14.5		6.8	6.9	5.9	4.6		5.2	6.9
		N	14.7		7.3	8.0	6.5	4.9		5.0	7.7
		E	14.4		7.4	7.9	6.3	5.0		5.5	7.7
24-Jul		S	14.6		7.8	8.6	6.5	4.3		4.8	7.8
		W	14.9		7.5	7.7	6.2	4.6		5.2	7.8
		N	15.3		8.0	8.8	6.8	4.9		5.0	8.5
		E	15.0		8.1	8.6	6.7	5.0		5.6	8.5
25-Jul		S	15.2		8.5	9.3	7.0	4.4		4.9	8.6
		W	15.7		8.2	8.4	6.7	4.7		5.3	8.6
		N	15.9		8.7	9.5	7.4	4.9		5.0	9.4
		E	15.6		8.8	9.3	7.1	5.1		5.6	9.4
26-Jul		S	15.8		9.3	10.0	7.5	4.5		4.9	9.5
		W	16.2		9.0	9.1	7.2	4.8		5.3	9.4
		N	16.4		9.4	10.2	7.8	5.0		5.0	10.3
		E	16.2		9.5	10.0	7.6	5.1		5.7	10.2
27-Jul		S	16.4		10.0	10.7	8.0	4.5		5.0	10.3
		W	16.9		9.6	9.7	7.6	4.9		5.3	10.2
		N	17.0		10.1	10.9	8.3	5.1		5.1	11.0
		E	16.7		10.2	10.7	8.1	5.2		5.7	11.0

APPENDIX A-2

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
28-Jul	Before Adding Water	S	17.0	10.6	11.3	8.5	4.6		5.1	11.1
		W	17.5	10.2	10.3	8.1	5.0		5.4	11.0
		N	17.6	10.8	11.5	8.8	5.2		5.2	11.7
		E	17.3	10.8	11.3	8.6	5.3		5.8	11.7
	After adding water to Pools 1, 2, 3, and 12. One More Solar disk was Placed in Pool 6	S	16.0	6.9	7.0	8.5	4.6		5.1	4.8
		W	16.4	6.6	6.0	8.1	5.0		5.4	4.7
		N	16.6	7.1	7.2	8.8	5.2		5.2	5.6
		E	16.3	7.1	7.1	8.6	5.3		5.8	5.5
29-Jul		S	16.5	7.4	7.5	8.9	4.7		5.1	5.4
		W	16.9	7.1	6.5	8.5	5.0		5.5	5.3
		N	17.1	7.6	7.7	9.3	5.2		5.4	6.2
		E	16.8	7.6	7.5	9.0	5.4		5.9	6.1
30-Jul		S	17.0	8.0	8.1	9.3	4.8		5.2	6.2
		W	17.4	7.7	7.2	8.9	5.0		5.6	6.0
		N	17.6	8.2	8.3	9.7	5.3		5.4	6.9
		E	17.3	8.3	8.2	9.3	5.5		6.0	6.9
31-Jul		S	17.5	8.6	8.7	9.7	4.8		5.3	6.8
		W	18.0	8.3	7.7	9.3	5.0		5.7	6.8
		N	18.2	8.8	8.9	10.1	5.3		5.5	7.5
		E	17.9	8.8	8.7	9.7	5.6		6.1	7.5
1-Aug		S	18.1	9.3	9.4	10.1	4.9		5.4	7.6
		W	18.6	9.0	8.3	9.7	5.2		5.8	7.5
		N	18.7	9.4	9.6	10.5	5.5		5.5	8.3
		E	18.4	9.5	9.4	10.1	5.7		6.2	8.3
2-Aug		S	18.7	9.9	10.1	10.5	4.9		5.5	8.4
		W	19.3	9.7	9.0	10.2	5.2		6.0	8.3
		N	19.3	10.1	10.2	10.9	5.6		5.6	9.1
		E	19.0	10.2	10.1	10.7	5.8		6.3	9.1
3-Aug		S	19.2	10.5	10.9	10.9	5.0	7.0	5.6	9.2
		W	19.8	10.2	9.9	10.5	5.3	7.3	6.0	9.1
		N	19.9	10.7	11.1	11.2	5.6	7.4	5.7	9.9
		E	19.7	10.7	11.0	11.0	5.9	7.3	6.3	9.9

APPENDIX A-3

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
4-Aug	Before Adding Water	S	19.9	11.2	11.6	11.3	5.2	7.1	5.7	10.0
		W	20.5	10.9	10.7	10.9	5.5	7.4	6.1	9.9
		N	20.5	11.4	11.8	11.7	5.7	7.5	5.8	10.7
		E	20.2	11.4	11.7	11.4	6.0	7.4	6.4	10.7
	After Adding Water to Pools 1,2,3,6 and 12	S	15.7	6.9	7.5	5.8	5.2	7.1	5.7	7.0
		W	16.0	6.6	6.6	5.4	5.5	7.4	6.1	7.0
		N	16.3	7.2	7.5	6.0	5.7	7.5	5.8	7.6
		E	16.0	7.2	7.5	5.8	6.0	7.4	6.4	7.5
5-Aug		S	16.2	7.4	8.2	6.0	5.3	7.2	5.8	7.6
		W	16.6	7.1	7.1	5.7	5.6	7.5	6.1	7.5
		N	16.8	7.6	8.3	6.4	5.8	7.6	5.9	8.3
		E	16.5	7.6	8.2	6.1	6.1	7.4	6.5	8.2
6-Aug		S	16.7	8.0	8.5	6.4		7.3	5.8	8.2
		W	17.1	7.6	7.5	6.1		7.5	6.2	8.1
		N	17.3	8.2	8.7	6.8		7.6	6.0	8.9
		E	17.0	8.1	8.6	6.5		7.5	6.6	8.9
7-Aug		S	17.1	8.4	8.9	6.8		7.4	5.9	8.8
		W	17.5	8.1	7.9	6.4		7.6	6.3	8.7
		N	17.7	8.6	9.1	7.2		7.7	6.1	9.5
		E	17.4	8.6	8.9	6.9		7.6	6.7	9.5
8-Aug		S	17.5	8.9	9.4	7.2		7.5	6.0	9.4
		W	18.0	8.6	8.4	6.8		7.7	6.4	9.3
		N	18.2	9.1	9.6	7.5		7.8	6.2	10.1
		E	17.9	9.2	9.4	7.3		7.7	6.8	10.1
9-Aug		S	18.1	9.5	9.9	7.6		7.6	6.1	10.0
		W	18.5	9.2	8.9	7.2		7.8	6.5	10.0
		N	18.7	9.6	10.0	7.9		7.9	6.3	10.8
		E	18.4	9.7	9.8	7.7		7.8	6.9	10.8
10-Aug		S	18.5	10.0	10.3	7.9		7.6	6.2	10.7
		W	19.0	9.7	9.3	7.5		7.9	6.5	10.6
		N	19.2	10.2	10.5	8.3		7.9	6.3	11.4
		E	18.9	10.2	10.3	8.0		7.9	6.9	11.4

APPENDIX A-4

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
11-Aug	Before Adding Water	S	19.0	10.5	10.8	8.3		7.7	6.3	11.3
		W	19.4	10.2	9.7	7.9		7.9	6.6	11.2
		N	19.6	10.7	11.0	8.7		8.0	6.4	12.0
		E	19.3	10.7	10.8	8.4		7.9	7.0	12.0
	After Adding Water to Pools 1,2,3 and 12	S	13.2	5.8	7.2	8.3		7.7	6.3	6.2
		W	13.7	5.6	6.3	7.9		7.9	6.6	6.1
		N	13.9	6.1	7.4	8.7		8.0	6.4	6.9
		E	13.5	6.1	7.4	8.4		7.9	7.0	6.8
12-Aug		S	13.8	6.4	7.8	8.7		7.9	6.5	6.6
		W	14.2	6.1	6.8	8.3		8.1	6.8	6.5
		N	14.4	6.6	8.0	9.0		8.2	6.6	7.3
		E	14.1	6.6	7.8	8.7		8.1	7.2	7.3
13-Aug		S	14.4	7.1	8.5	9.1		8.0	6.6	7.3
		W	14.8	6.7	7.5	8.8		8.2	6.9	7.2
		N	15.0	7.3	8.7	9.4		8.3	6.7	8.0
		E	14.7	7.3	8.5	9.1		8.2	7.3	8.0
14-Aug	Windy Day	S	15.0	7.8	9.1	9.5		8.1	6.8	7.9
		W	15.3	7.4	8.1	9.3		8.3	7.1	7.9
		N	15.5	7.9	9.4	9.8		8.4	6.8	8.6
		E	15.3	8.0	9.1	9.5		8.3	7.4	8.7
15-Aug		S	15.5	8.4	10.0	9.9		8.1	6.8	8.8
		W	16.0	8.0	9.0	9.5		8.4	7.2	8.7
		N	16.2	8.6	10.2	10.3		8.4	7.0	9.5
		E	15.8	8.6	10.0	10.0		8.4	7.6	9.5
16-Aug		S	16.0	8.9	10.7	10.2		8.2	7.0	9.4
		W	16.5	8.6	9.6	9.9		8.4	7.4	9.3
		N	16.6	9.1	10.9	10.6		8.5	7.1	10.1
		E	16.3	9.1	10.7	10.3		8.4	7.7	10.1
17-Aug		S	16.5	9.5	11.5	10.6		8.3	7.1	10.1
		W	17.0	9.2	10.4	10.2		8.5	7.4	10.0
		N	17.2	9.8	11.6	11.0		8.6	7.2	10.8
		E	16.9	9.8	11.5	10.7		8.5	7.8	10.8

APPENDIX A-5

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
18-Aug	Before Adding Water	S	17.0	10.1	12.2	10.9		8.3	7.2	10.8
		W	17.5	9.8	11.1	10.6		8.6	7.5	10.7
		N	17.7	10.3	12.4	11.3		8.6	7.3	11.5
		E	17.4	10.4	12.2	11.0		8.6	7.9	11.5
	After Adding Water to Pools 1,2,3,6,10 and 12	S	13.3	7.5	7.2	8.0		6.2	7.2	7.6
		W	13.8	7.2	6.4	7.7		6.6	7.5	7.6
		N	14.0	7.7	7.5	8.5		6.6	7.3	8.4
		E	13.7	7.7	7.4	8.1		6.5	7.9	8.4
19-Aug		S	13.9	8.0	7.8	8.4	7.0	6.3	7.3	8.2
		W	14.3	7.7	6.7	8.0	7.5	6.6	7.5	8.1
		N	14.5	8.3	8.0	8.8	7.6	6.7	7.4	8.9
		E	14.2	8.3	7.8	8.4	7.9	6.6	8.0	8.9
20-Aug		S	14.5	8.7	8.7	8.8	7.1	6.4	7.4	9.0
		W	14.9	8.4	7.6	8.5	7.6	6.7	7.6	8.9
		N	15.2	9.0	8.8	9.2	7.7	6.8	7.5	9.7
		E	14.9	9.0	8.7	8.9	8.0	6.7	8.1	9.7
21-Aug	Before Adding Water	S	15.2	9.4	9.6	9.2	7.2	6.5	7.5	9.7
		W	15.6	9.0	8.5	8.9	7.7	6.8	7.8	9.6
		N	15.8	9.6	9.8	9.6	7.8	6.8	7.6	10.4
		E	15.5	9.6	9.6	9.3	8.1	6.8	8.2	10.4
	After Adding Water to Pools 1,2,3, and 12	S	12.0	5.6	5.0	9.2	7.2	6.5	7.5	5.4
		W	12.6	5.3	4.2	8.9	7.7	6.8	7.8	5.4
		N	12.7	5.8	5.4	9.6	7.8	6.8	7.6	6.3
		E	12.5	5.8	5.4	9.3	8.1	6.8	8.2	6.1
22-Aug		S	12.6	6.1	6.0	9.5	7.3	6.5	7.5	6.0
		W	13.0	5.8	5.0	9.2	7.8	6.8	7.8	5.9
		N	13.3	6.3	6.2	9.9	7.9	7.0	7.7	6.7
		E	12.9	6.3	6.0	9.6	8.2	6.8	8.3	6.7
23-Aug		S	13.2	6.7	7.0	9.9	7.4	6.7	7.7	6.6
		W	13.6	6.3	6.1	9.6	7.9	6.9	8.0	6.5
		N	13.9	6.9	7.2	10.3	8.0	7.1	7.8	7.3
		E	13.5	6.9	7.0	10.0	8.3	6.9	8.4	7.3
24-Aug		S	13.7	7.2	8.1	10.3	7.5	6.8	7.8	7.3
		W	14.2	6.9	7.1	10.0	8.0	7.0	8.1	7.2
		N	14.4	7.5	8.3	10.7	8.1	7.1	7.9	8.0
		E	14.1	7.5	8.1	10.4	8.4	7.0	8.5	8.0

APPENDIX A-6

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	**Remark**	**Side**	**Distance to Water Level (cm)**							
25-Aug	Before Adding Water	S	14.4	7.9	9.3	10.7	7.6	6.9	7.9	8.1
		W	14.8	7.5	8.3	10.4	8.1	7.1	8.2	8.0
		N	15.0	8.1	9.5	11.2	8.2	7.2	8.0	8.8
		E	14.7	8.1	9.4	10.8	8.5	7.1	8.6	8.8
	After Adding Water to Pools 1,2,3,6,9,10, 11 and 12	S	11.8	5.9	7.1	7.2	8.3	7.5	7.4	6.2
		W	12.3	5.5	6.2	6.9	8.8	7.7	7.8	6.1
		N	12.5	6.2	7.3	7.6	9.0	7.9	7.5	7.0
		E	12.2	6.2	7.2	7.3	9.1	7.9	8.1	7.0
26-Aug		S	12.3	6.4	8.0	7.5	8.4	7.6	7.5	6.9
		W	12.9	6.0	7.0	7.2	8.8	7.8	7.8	6.8
		N	13.0	6.6	8.2	8.0	9.0	8.0	7.6	7.6
		E	12.7	6.6	8.1	7.7	9.2	7.9	8.2	7.6
27-Aug	Windy Day	S	13.0	7.0	9.2	7.8	8.5	7.7	7.6	7.5
		W	13.5	6.6	8.0	7.6	9.0	7.9	7.9	7.5
		N	13.6	7.3	9.3	8.3	9.1	8.1	7.7	8.3
		E	13.4	7.3	9.2	8.0	9.4	8.0	8.3	8.3
28-Aug	Before Adding Water. Stated to Test LES B in Pool 12.	S	13.7	7.8	10.5	8.4	8.6	7.9	7.7	8.5
		W	14.2	7.5	9.4	8.1	9.0	8.1	8.0	8.4
		N	14.4	8.1	10.7	8.8	9.1	8.2	7.8	9.2
		E	14.1	8.1	10.5	8.5	9.4	8.1	8.4	9.2
	After Adding Water to Pools 1, 2, 3 and 12.	S	10.4	5.3	7.5	8.4	8.6	7.9	7.7	5.6
		W	10.9	5.1	6.6	8.1	9.0	8.1	8.0	5.5
		N	11.1	5.7	7.8	8.8	9.1	8.2	7.8	6.3
		E	10.8	5.6	7.6	8.5	9.4	8.1	8.4	6.3
29-Aug		S	11.1	6.0	8.6	8.8	8.7	8.0	7.8	6.1
		W	11.6	5.6	7.5	8.5	9.1	8.2	8.0	6.0
		N	11.8	6.2	8.8	9.2	9.2	8.3	7.9	6.8
		E	11.5	6.2	8.6	8.9	9.5	8.2	8.5	6.8
30-Aug		S	11.8	6.6	9.8	9.2	8.8	8.1	7.9	6.6
		W	12.2	6.3	8.8	8.9	9.2	8.3	8.1	6.5
		N	12.4	6.8	10.0	9.6	9.3	8.4	8.0	7.4
		E	12.1	6.8	9.9	9.4	9.6	8.3	8.6	7.4
31-Aug		S	12.5	7.5	11.3	9.7	8.9	8.2	8.0	7.4
		W	12.9	7.1	10.3	9.4	9.3	8.4	8.2	7.4
		N	13.1	7.6	11.5	10.1	9.4	8.5	8.1	8.2
		E	12.8	7.7	11.5	9.8	9.7	8.4	8.7	8.2

APPENDIX A-7

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
1-Sep	Before Adding Water	S	13.2	8.3	12.5	10.2	9.0	8.3	8.1	8.3
		W	13.6	7.9	11.5	9.8	9.4	8.5	8.3	8.2
		N	13.9	8.5	12.8	10.5	9.5	8.6	8.2	9.0
		E	13.5	8.5	12.8	10.2	9.8	8.5	8.8	9.0
	After Adding Water to Pool 3.The crack detected on Pool 3 was sealed	S	13.2	8.3	8.5	10.2	9.0	8.3	8.1	8.3
		W	13.6	7.9	7.6	9.8	9.4	8.5	8.3	8.2
		N	13.9	8.5	8.7	10.5	9.5	8.6	8.2	9.0
		E	13.5	8.5	8.7	10.2	9.8	8.5	8.8	9.0
2-Sep	Before Adding Water	S	13.7	8.8	8.9	10.5	9.1	8.4	8.2	9.0
		W	14.1	8.4	7.9	10.2	9.4	8.6	8.4	8.8
		N	14.4	9.0	9.2	10.9	9.7	8.7	8.3	9.7
		E	14.0	9.0	9.0	10.6	9.9	8.6	8.9	9.7
	After Adding Water to Pools 1,2,6, and 12	S	11.5	6.6	8.9	8.3	9.1	8.4	8.2	5.7
		W	11.9	6.2	7.9	8.0	9.4	8.6	8.4	5.7
		N	12.2	6.8	9.2	8.7	9.7	8.7	8.3	6.4
		E	11.8	6.8	9.0	8.3	9.9	8.6	8.9	6.5
3-Sep		S	11.9	7.0	9.3	8.5	9.2	8.5	8.3	6.2
		W	12.4	6.7	8.3	8.1	9.5	8.8	8.6	6.0
		N	12.6	7.3	9.5	8.9	9.8	8.9	8.5	6.9
		E	12.3	7.3	9.4	8.5	10.0	8.8	9.1	6.9
4-Sep	Before Adding Water	S	12.5	7.7	9.8	8.9	9.3	8.6	8.5	6.9
		W	13.0	7.3	8.8	8.5	9.6	8.9	8.8	6.8
		N	13.2	7.9	10.1	9.3	9.9	9.0	8.6	7.7
		E	12.9	7.9	9.9	8.9	10.1	8.9	9.2	7.6
	After Adding Water to Pools 1,3 and 12	S	10.9	7.7	4.9	8.9	9.3	8.6	8.5	4.1
		W	11.3	7.3	3.9	8.5	9.6	8.9	8.8	4.1
		N	11.5	7.9	5.2	9.3	9.9	9.0	8.6	4.9
		E	11.1	7.9	5.1	8.9	10.1	8.9	9.2	4.8
5-Sep		S	11.3	8.2	5.4	9.3	9.4	8.7	8.6	4.5
		W	11.8	7.8	4.4	8.9	9.7	8.9	8.9	4.5
		N	12.0	8.4	5.6	9.7	10.0	9.1	8.7	5.3
		E	11.7	8.4	5.5	9.3	10.2	9.0	9.4	5.3
6-Sep		S	11.9	8.8	5.9	9.7	9.5	8.8	8.7	5.2
		W	12.4	8.4	5.0	9.3	9.8	9.0	9.0	5.2
		N	12.5	9.0	6.1	10.0	10.1	9.2	8.8	5.9
		E	12.3	9.0	6.0	9.7	10.4	9.1	9.5	5.9
7-Sep		S	12.5	9.3	6.7	10.1	9.6	8.9	8.9	5.6
		W	13.0	8.8	5.6	9.7	9.9	9.2	9.2	5.6
		N	13.2	9.5	7.0	10.5	10.2	9.3	9.0	6.4
		E	12.9	9.5	6.8	10.2	10.4	9.2	9.6	6.4

APPENDIX A-8

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
8-Sep	Before Adding Water	S	13.1	9.8	7.4	10.5	9.7	9.0	9.0	6.1
		W	13.5	9.4	6.3	10.1	10.1	9.3	9.3	6.0
		N	13.8	10.0	7.6	10.8	10.3	9.4	9.1	6.8
		E	13.4	10.0	7.5	10.5	10.5	9.3	9.7	6.8
	After Adding Water to Pools 1, 2, 3 and 7. Started Using Pool 7 to test LES A	S	11.0	3.5	2.7	10.5	9.7	9.0	9.0	6.1
		W	11.5	3.3	1.8	10.1	10.1	9.3	9.3	6.0
		N	11.7	3.6	3.0	10.8	10.3	9.4	9.1	6.8
		E	11.3	3.9	2.9	10.5	10.5	9.3	9.7	6.8
9-Sep		S	11.5	3.9	3.0	10.8	9.8	9.1	9.1	6.7
		W	11.9	3.7	2.1	10.5	10.2	9.4	9.4	6.6
		N	12.2	4.2	3.3	11.2	10.4	9.5	9.2	7.4
		E	11.8	4.2	3.2	10.9	10.6	9.4	9.8	7.4
10-Sep		S	11.9	4.4	3.4	11.0	9.9	9.2	9.2	7.3
		W	12.4	4.1	2.4	10.7	10.3	9.5	9.5	7.2
		N	12.6	4.6	3.7	11.4	10.5	9.6	9.3	7.9
		E	12.3	4.7	3.6	11.1	10.7	9.5	9.9	7.9
11-Sep	Before Adding Water	S	12.3	4.8	3.8	11.3	10.0	9.3	9.3	7.7
		W	12.8	4.5	2.8	11.0	10.4	9.6	9.6	7.6
		N	13.0	5.1	4.1	11.7	10.6	9.7	9.3	8.4
		E	12.7	5.1	4.0	11.4	10.8	9.6	10.0	8.4
	After Adding Water to Pools 1,6 and 12	S	10.9	4.8	3.8	3.6	10.0	9.3	9.3	3.0
		W	11.4	4.5	2.8	3.3	10.4	9.6	9.6	2.9
		N	11.6	5.1	4.1	4.1	10.6	9.7	9.3	3.7
		E	11.3	5.1	4.0	3.9	10.8	9.6	10.0	3.7
12-Sep		S	11.3	5.3	4.3	4.0	10.0	9.4	9.4	3.3
		W	11.7	4.9	3.2	3.7	10.4	9.7	9.6	3.3
		N	12.0	5.5	4.5	4.3	10.6	9.8	9.3	4.0
		E	11.7	5.5	4.4	4.1	10.9	9.7	10.1	4.0
13-Sep		S	11.8	5.7	4.8	4.4	10.1	9.5	9.4	3.8
		W	12.2	5.4	3.7	4.0	10.5	9.8	9.7	3.7
		N	12.5	6.0	5.0	4.7	10.7	9.8	9.4	4.5
		E	12.1	6.0	4.9	4.5	11.0	9.8	10.2	4.5
14-Sep		S	12.1	6.2	5.3	4.7	10.1	9.6	9.5	4.2
		W	12.6	5.8	4.2	4.4	10.6	9.8	9.8	4.1
		N	12.9	6.5	5.5	5.0	10.8	9.9	9.5	4.9
		E	12.5	6.5	5.3	4.8	11.0	9.8	10.2	4.9

APPENDIX A-9

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
15-Sep	Last Day to Apply LES B to Pool 3	S	12.5	6.6	5.7	5.0	10.2	9.7	9.6	4.6
		W	12.9	6.2	4.6	4.7	10.8	9.9	9.9	4.5
		N	13.2	6.8	6.0	5.2	10.9	10.0	9.6	5.4
		E	12.8	6.9	5.8	5.1	11.1	9.9	10.3	5.4
16-Sep	Windy Day	S	13.1	7.2	6.4	5.5	10.4	9.8	9.8	5.5
		W	13.5	6.8	5.4	5.2	10.8	10.1	10.0	5.4
		N	13.8	7.5	6.7	5.9	11.0	10.1	9.8	6.2
		E	13.5	7.5	6.5	5.6	11.3	10.1	10.5	6.2
17-Sep	Windy day	S	13.6	7.6	7.0	5.9	10.5	9.9	9.9	6.1
		W	14.0	7.1	5.8	5.6	10.9	10.3	10.2	6.0
		N	14.3	7.8	7.2	6.3	11.1	10.3	9.9	6.8
		E	14.0	7.8	7.1	6.0	11.3	10.2	10.6	6.8
18-Sep	Windy Day - Data not taken. Last Day to Apply LES B to Pool 12	S								
		W								
		N								
		E								
19-Sep	Before Adding Water. Data was taken between 3:30 pm and 4:30 pm because of Wind	S	15.3	9.2	8.8	7.1	10.7	10.2	10.2	8.1
		W	15.7	8.9	7.8	6.8	11.1	10.5	10.6	8.0
		N	16.0	9.5	9.1	7.5	11.3	10.6	10.3	8.7
		E	15.7	9.5	9.0	7.1	11.4	10.5	10.9	8.7
	After filling Pools 1 and 2	S	11.1	8.0	8.8	7.1	10.7	10.2	10.2	8.1
		W	11.6	7.6	7.8	6.8	11.1	10.5	10.6	8.0
		N	11.9	8.3	9.1	7.5	11.3	10.6	10.3	8.7
		E	11.4	8.3	9.0	7.1	11.4	10.5	10.9	8.7
20-Sep		S	11.4	8.3	9.2	7.3	10.8	10.4	10.3	8.5
		W	11.9	8.0	8.1	6.9	11.2	10.6	10.6	8.4
		N	12.1	8.5	9.4	7.7	11.4	10.7	10.4	9.2
		E	11.8	8.5	9.3	7.4	11.5	10.6	11.1	9.2
21-Sep		S	11.9	8.8	9.8	7.6	10.8	10.5	10.5	9.1
		W	12.4	8.5	8.7	7.3	11.2	10.7	10.7	9.0
		N	12.6	9.1	10.0	8.0	11.5	10.8	10.6	9.8
		E	12.3	9.1	9.9	7.7	11.6	10.7	11.2	9.8

APPENDIX A-10

Pool ID			1	2	3	6	9	10	11	12
Cover Type			Ctrl 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Ctrl 2 (LES B)
Date	Remark	Side	Distance to Water Level (cm)							
22-Jan	Before Adding Water	S	12.4	9.3	10.2	7.9	10.9	10.5	10.6	9.7
		W	12.9	8.9	9.2	7.6	11.3	10.8	10.8	9.6
		N	13.1	9.5	10.5	8.3	11.5	10.9	10.7	10.4
		E	12.8	9.5	10.3	8.0	11.6	10.8	11.3	10.4
	After Adding Water to Pool 3	S	10.4	4.2	4.4	4.5	7.0	7.9	7.5	5.4
		W	10.8	3.8	3.4	4.3	7.4	8.2	7.9	5.5
		N	11.0	4.4	4.7	4.9	7.6	8.3	7.6	6.2
		E	10.7	4.4	4.5	4.7	7.8	8.2	8.3	6.2
23-Sep		S	10.8	4.6	4.9	4.8	7.0	8.0	7.6	6.0
		W	11.2	4.2	3.9	4.4	7.4	8.3	7.9	5.9
		N	11.5	4.8	5.2	5.2	7.6	8.4	7.7	6.7
		E	11.2	4.8	5.0	4.9	7.8	8.4	8.3	6.7
24-Sep	Windy Day	S	11.7	5.4	6.0	5.4	7.1	8.2	7.8	7.1
		W	12.2	5.0	5.0	5.1	7.5	8.5	8.0	7.0
		N	12.5	5.6	6.3	5.8	7.7	8.6	7.9	7.8
		E	12.2	5.6	6.1	5.5	7.9	8.6	8.5	7.8
25-Sep		S	12.1	5.8	6.4	5.7	7.2	8.3	7.9	7.6
		W	12.6	5.4	5.3	5.3	7.5	8.5	8.2	7.5
		N	12.9	6.1	6.6	6.0	7.8	8.7	8.0	8.3
		E	12.5	6.0	6.5	5.7	8.0	8.6	8.6	8.3

APPENDIX B-1. WATER LOSS RESULTS FOR THE INITIAL PROTOCOL

Pool ID	1	2	3	6	9	10	11	12
Cover Type	Control 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Control 2
Date	Water Loss Corrected for Rainfall and Relative Leakage (cm)							
21-Jul	0.45	0.45		0.02	0.00		0.00	0.45
22-Jul	0.58	0.75		0.34	0.00		0.00	0.58
23-Jul	0.55	0.65		0.22	0.00		0.00	0.68
24-Jul	0.65	0.65		0.39	0.01		0.00	0.70
25-Jul	0.55	0.70		0.37	0.01		0.00	0.70
26-Jul	0.60	0.62		0.37	0.01		0.00	0.63
27-Jul	0.60	0.58		0.39	0.03		0.02	0.60
28-Jul	0.50	0.45		0.32	0.00		0.02	0.45
29-Jul	0.50	0.58		0.27	0.01		0.00	0.60
30-Jul	0.57	0.53		0.29	0.00		0.02	0.50
31-Jul	0.55	0.63		0.29	0.08		0.00	0.63
1-Aug	0.63	0.62		0.37	0.00		0.04	0.65
2-Aug	0.57	0.50		0.22	0.01	0.01	0.00	0.65
3-Aug	0.63	0.65		0.32	0.08	0.01	0.02	0.65
4-Aug	0.55	0.45		0.22	0.03	0.00	0.00	0.55
5-Aug	0.50	0.50		0.29		0.00	0.00	0.48
6-Aug	0.40	0.40		0.27		0.01	0.02	0.45
7-Aug	0.48	0.48		0.27		0.01	0.02	0.45
8-Aug	0.53	0.50		0.29		0.01	0.02	0.53
9-Aug	0.48	0.48		0.22		0.00	0.00	0.48
10-Aug	0.44	0.46		0.30		0.00	0.03	0.46
11-Aug	0.60	0.50		0.24		0.11	0.12	0.43
12-Aug	0.60	0.63		0.32		0.01	0.02	0.55
13-Aug	0.55	0.63		0.32		0.01	0.07	0.50
14-Aug	0.60	0.58		0.29		0.00	0.04	0.70
15-Aug	0.48	0.48		0.22		0.00	0.07	0.45
16-Aug	0.55	0.60		0.27		0.01	0.00	0.55
17-Aug	0.50	0.53		0.22		0.00	0.02	0.55
18-Aug	0.60	0.58		0.29	0.86	0.00	0.00	0.50
19-Aug	0.65	0.65		0.34	0.03	0.01	0.02	0.65
20-Aug	0.65	0.58		0.29	0.03	0.00	0.04	0.55
21-Aug	0.50	0.45		0.19	0.03	0.00	0.00	0.38

APPENDIX B-2

Pool ID	1	2	3	6	9	10	11	12
Cover Type	Control 1	LES A	LES B	Disks	Solid Track	Foam	Bubble	Control 2
Date	Water Loss Corrected for Rainfall and Relative Leakage (cm)							
22-Aug	0.60	0.53		0.29	0.03	0.04	0.07	0.45
23-Aug	0.55	0.53		0.29	0.03	0.00	0.02	0.55
24-Aug	0.63	0.58		0.32	0.03	0.01	0.02	0.65
25-Aug	0.53	0.40		0.24	0.00	0.00	0.00	0.50
26-Aug	0.65	0.60		0.22	0.08	0.01	0.02	0.53
27-Aug	0.73	0.78		0.42	0.00	0.06	0.02	0.78
28-Aug	0.70	0.53		0.29	0.03	0.01	0.00	0.35
29-Aug	0.63	0.58		0.32	0.03	0.01	0.02	0.40
30-Aug	0.70	0.80		0.37	0.03	0.01	0.02	0.68
31-Aug	0.73	0.78		0.32	0.03	0.01	0.02	0.68
1-Sep	0.50	0.45	0.31	0.27	0.03	0.01	0.02	0.53
2-Sep	0.45	0.43	0.31	0.07	0.03	0.09	0.09	0.28
3-Sep	0.60	0.58	0.46	0.29	0.03	0.01	0.07	0.60
4-Sep	0.50	0.45	0.39	0.29	0.03	0.00	0.04	0.28
5-Sep	0.58	0.55	0.46	0.27	0.06	0.01	0.02	0.50
6-Sep	0.63	0.43	0.71	0.34	0.01	0.04	0.09	0.30
7-Sep	0.55	0.48	0.61	0.24	0.06	0.01	0.02	0.28
8-Sep	0.48	0.38	0.24	0.27	0.03	0.01	0.02	0.45
9-Sep	0.45	0.40	0.31	0.09	0.03	0.01	0.02	0.40
10-Sep	0.40	0.38	0.34	0.19	0.03	0.01	0.00	0.30
11-Sep	0.38	0.38	0.36	0.19	0.00	0.01	0.00	0.18
12-Sep	0.48	0.43	0.44	0.27	0.03	0.00	0.00	0.33
13-Sep	0.39	0.44	0.42	0.23	0.00	0.00	0.00	0.26
14-Sep	0.36	0.36	0.42	0.20	0.09	0.04	0.05	0.33
15-Sep	0.63	0.58	0.66	0.44	0.06	0.06	0.09	0.70
16-Sep	0.50	0.28	0.46	0.29	0.01	0.06	0.04	0.45
17-Sep to 18-Sep	1.70	1.65	1.84	1.07	0.11	0.19	0.27	1.80
19-Sep	0.30	0.23	0.26	0.09	0.03	0.04	0.02	0.30
20-Sep	0.50	0.50	0.54	0.22	0.00	0.01	0.07	0.45
21-Sep	0.50	0.38	0.39	0.19	0.00	0.00	0.02	0.45
22-Sep	0.45	0.35		0.12	0.00	0.04	0.00	0.35
23-Sep	0.98	0.75		0.52	0.03	0.11	0.09	0.95
24-Sep	0.38	0.38		0.12	0.01	0.00	0.04	0.35

APPENDIX C-1. WEATHER DATA FOR THE INITIAL PROTOCOL

Date	Rainfall (cm)	Sol Rad (W/m^2)	Air Temp (^{0}C)	Rel. Hum (%)	Wind Speed (m/s)
21-Jul	0.00	306.5	20.7	77.6	1.4
22-Jul	0.00	249.6	18.7	80.2	1.4
23-Jul	0.00	322.2	17.7	78.0	1.3
24-Jul	0.00	331.9	19.3	72.5	1.2
25-Jul	0.00	320.6	19.0	75.0	1.4
26-Jul	0.00	299.0	16.7	83.5	1.2
27-Jul	0.00	317.9	17.7	81.2	1.3
28-Jul	0.00	302.3	18.5	81.0	1.2
29-Jul	0.00	300.8	19.0	80.6	1.3
30-Jul	0.00	291.4	19.7	79.2	1.4
31-Jul	0.00	307.1	20.3	76.7	1.5
1-Aug	0.00	316.8	19.4	77.7	1.5
2-Aug	0.00	310.5	19.2	75.6	1.4
3-Aug	0.00	312.2	18.5	74.9	1.4
4-Aug	0.00	259.8	18.8	73.6	1.5
5-Aug	0.00	195.2	18.7	78.9	1.3
6-Aug	0.00	198.8	18.4	80.6	1.2
7-Aug	0.00	268.8	17.3	76.6	1.2
8-Aug	0.00	303.9	18.7	77.6	1.5
9-Aug	0.00	287.1	18.9	79.8	1.5
10-Aug	0.01	231.9	18.6	80.6	1.3
11-Aug	0.00	287.0	17.9	79.9	1.4
12-Aug	0.00	308.0	19.5	74.7	1.4
13-Aug	0.00	305.8	19.2	75.0	1.4
14-Aug	0.00	305.8	20.2	69.3	1.6
15-Aug	0.00	296.2	23.2	61.0	1.1
16-Aug	0.00	289.5	21.7	71.3	1.2
17-Aug	0.00	284.2	19.7	78.4	1.2
18-Aug	0.00	285.8	19.4	78.8	1.4
19-Aug	0.00	290.3	19.6	74.5	1.5
20-Aug	0.00	278.6	19.4	75.1	1.4
21-Aug	0.00	244.3	18.4	78.8	1.3
22-Aug	0.00	275.5	18.7	78.0	1.4
23-Aug	0.00	275.9	18.0	79.7	1.2
24-Aug	0.00	291.7	19.2	75.9	1.3
25-Aug	0.00	291.4	20.0	74.4	1.3

APPENDIX C-2

Date	Rainfall (cm)	Sol Rad (W/m^2)	Air Temp (^{0}C)	Rel. Hum (%)	Wind Speed (m/s)
26-Aug	0.00	297.8	22.4	60.6	1.4
27-Aug	0.00	283.7	28.1	37.3	1.8
28-Aug	0.00	287.0	22.9	65.6	1.2
29-Aug	0.00	281.3	20.4	77.8	1.4
30-Aug	0.00	286.1	21.3	61.6	2.0
31-Aug	0.00	274.0	18.2	78.8	1.5
1-Sep	0.00	193.6	17.0	80.9	1.1
2-Sep	0.00	239.7	17.9	77.8	1.3
3-Sep	0.00	267.0	17.9	74.0	1.3
4-Sep	0.00	244.7	15.3	77.8	1.2
5-Sep	0.00	276.9	18.4	59.4	1.4
6-Sep	0.00	281.2	21.8	38.9	1.2
7-Sep	0.00	279.9	22.8	42.0	1.1
8-Sep	0.00	267.4	24.5	42.8	1.0
9-Sep	0.00	251.1	24.7	56.0	0.9
10-Sep	0.00	227.9	25.7	50.5	0.8
11-Sep	0.00	173.6	23.1	66.4	0.9
12-Sep	0.00	165.3	23.2	65.6	1.0
13-Sep	0.01	196.0	20.7	76.6	1.0
14-Sep	0.03	115.4	19.6	84.2	1.0
15-Sep	0.00	68.2	15.8	81.2	1.2
16-Sep	0.00	255.8	17.5	66.0	1.6
17-Sep	0.00	255.7	20.4	57.2	2.3
18-Sep	0.00	255.5	24.8	40.9	3.2
19-Sep	0.00	254.1	24.6	41.5	1.5
20-Sep	0.00	243.9	24.8	41.4	1.0
21-Sep	0.00	233.6	23.5	68.8	1.4
22-Sep	0.00	235.2	19.7	79.3	1.2
23-Sep	0.00	247.0	24.3	43.7	1.9
24-Sep	0.00	242.1	24.3	40.8	1.4
25-Sep	0.00	235.9	22.0	63.9	1.3

APPENDIX D-1. WATER LEVEL DATA FOR THE EXTENSION STUDY

Pool ID			2	6	8	9	10	11
Cover Type			Bubble	Control	LES B	LES A	LES A	LES B
Date	Remark	Side	Distance to water level (cm)					
19-Oct		S		7.4		6.8	7.9	8.3
		W		7.1	7.0	7.2	8.2	8.6
		N		7.8		7.4	8.3	8.4
		E		7.5	7.2	7.5	8.2	9.0
20-Oct		S		8.2		7.4	8.4	8.9
		W		7.8	7.8	7.8	8.7	9.2
		N		8.5		8.0	8.8	9.0
		E		8.2	8.0	8.1	8.7	9.7
21-Oct		S		8.7	10.5	7.9	8.8	9.3
		W		8.3	8.4	8.4	9.0	9.7
		N		9.1	10.8	8.5	9.2	9.5
		E		8.7	8.6	8.6	9.1	10.1
22-Oct		S		9.1	11.1	8.5	9.2	9.7
		W		8.7	9.0	8.9	9.4	10.1
		N		9.5	11.3	9.1	9.5	9.9
		E		9.2	9.1	9.2	9.4	10.5
23-Oct		S		9.5	11.6	9.0	9.5	10.2
		W		9.2	9.5	9.4	9.8	10.5
		N		9.9	11.8	9.6	9.9	10.3
		E		9.6	9.7	9.7	9.8	10.9
24-Oct	Before adding water to Pool 8	S		10.0	12.1	9.5	9.9	10.6
		W		9.6	10.0	9.8	10.1	10.9
		N		10.4	12.4	10.1	10.3	10.7
		E		10.1	10.3	10.2	10.2	11.3
	After adding water to Pool 8	S			3.7			
		W			1.6			
		N			4			
		E			1.8			
25-Oct		S		10.4	4.1	9.9	10.3	11
		W		10	2	10.2	10.5	11.3
		N		10.7	4.4	10.6	10.6	11.1
		E		10.4	2.2	10.6	10.5	11.7

APPENDIX D-2

Pool ID			2	6	8	9	10	11
Cover Type			**Bubble**	**Control**	**LES B**	**LES A**	**LES A**	**LES B**
Date	**Remark**	**Side**	**Distance to water level (cm)**					
26-Oct		S		10.8	4.7	10.3	10.6	11.4
		W		10.4	2.6	10.7	10.8	11.7
		N		11.2	4.9	11.0	11.0	11.6
		E		10.9	2.8	11.1	10.9	12.2
27-Oct	Before adding water	S		11.2	5.3	10.7	11.0	11.8
		W		10.8	3.3	11.1	11.2	12.1
		N		11.5	5.5	11.5	11.4	12.0
		E		11.3	3.4	11.5	11.3	12.6
	After adding water to Pools 6, 8, 9, 10 and 11	S		4	0.5	3.6	1.2	3.5
		W		3.6		4.1	1.5	3.9
		N		4.4	0.6	4.3	1.6	3.7
		E		4.1		4.5	1.5	4.4
28-Oct		S		4.4	1.1	3.9	1.5	3.7
		W		4		4.3	1.9	4.2
		N		4.8	1.3	4.6	2	3.9
		E		4.5		4.7	1.9	4.7
29-Oct	Windy day- Skipped readings	S						
		W						
		N						
		E						
30-Oct		S		5.7	3	4.9	2.8	4.9
		W		5.3	0.9	5.3	3.1	5.2
		N		6.1	3.3	5.6	3.2	5
		E		5.7	1.1	5.7	3.1	5.7
31-Oct		S		6.3	4	5.5	3.2	5.5
		W		6	1.9	5.9	3.5	5.8
		N		6.7	4.2	6.2	3.6	5.6
		E		6.4	2.1	6.3	3.5	6.2
1-Nov		S	6.7	6.9	4.8	5.9	3.6	6
		W	6.3	6.5	2.7	6.4	3.9	6.2
		N	6.8	7.3	5	6.6	4	6.1
		E	6.9	6.9	2.9	6.7	3.9	6.7

APPENDIX D-3

Pool ID			2	6	8	9	10	11
Cover Type			**Bubble**	**Control**	**LES B**	**LES A**	**LES A**	**LES B**
Date	**Remark**	**Side**	**Distance to water level (cm)**					
2-Nov		S	6.7	7.2	5.4	6.1	3.8	6.2
		W	6.3	6.8	3.4	6.5	4.1	6.5
		N	6.8	7.6	5.7	6.8	4.2	6.3
		E	6.9	7.3	3.5	6.9	4.2	6.9
3-Nov	Before adding water		5.1	5.8	4.3	4.7	2.6	4.7
			4.7	5.5	2.2	5.1	3.0	5
			5.3	6.2	4.5	5.5	3.1	4.8
			5.3	5.9	2.4	5.5	3.0	5.5
	After adding water to Pools 6 and 9	S		3.4		3.3		
		W		3		3.7		
		N		3.8		4.0		
		E		3.5		4.2		
4-Nov		S	5.3	3.9	5.1	3.7	3.3	5.1
		W	4.9	3.6	3.1	4.1	3.5	5.4
		N	5.5	4.3	5.4	4.4	3.6	5.2
		E	5.5	4.0	3.3	4.5	3.6	5.9
5-Nov		S	5.5	4.7	6.2	4.2	3.9	5.6
		W	5.1	4.3	4.1	4.7	4.1	5.9
		N	5.7	5.1	6.4	4.9	4.2	5.7
		E	5.7	4.7	4.3	5.0	4.2	6.4
6-Nov		S	5.7	5.4	7.2	4.7	4.3	6.1
		W	5.3	5.0	5.0	5.1	4.5	6.4
		N	5.9	5.8	7.4	5.4	4.6	6.3
		E	5.9	5.4	5.1	5.5	4.6	6.9
7-Nov		S	5.9	6.3	8.3	5.5	5.1	6.8
		W	5.5	5.9	6.1	5.9	5.3	7.1
		N	6.1	6.7	8.5	6.2	5.4	7.0
		E	6.1	6.3	6.2	6.3	5.4	7.6
8-Nov		S	6.2	6.8	9	5.8	5.4	7.2
		W	5.8	6.5	6.8	6.3	5.7	7.5
		N	6.4	7.2	9.2	6.6	5.8	7.3
		E	6.4	7	6.9	6.7	5.7	7.9

APPENDIX D-4

Pool ID			2	6	8	9	10	11
Cover Type			Bubble	Control	LES B	LES A	LES A	LES B
Date	Remark	Side	Distance to water level (cm)					
9-Nov		S	5.5	6.1	8.5	5.2	4.8	6.4
		W	5.1	5.8	6.3	5.7	5.0	6.8
		N	5.7	6.6	8.7	5.9	5.2	6.5
		E	5.7	6.6	6.5	6.1	5.1	7.1
10-Nov	Before adding water	S	5.6	6.4	8.9	5.3	4.8	6.5
		W	5.3	6.1	6.7	5.7	5.0	6.9
		N	5.9	6.9	9.1	6.0	5.2	6.7
		E	5.9	6.5	6.9	6.1	5.1	7.3
	After adding water to Pools 2,6, 8, and 11	S	3.3	3.6	4.1			4.7
		W	3	3.3	2.1			5
		N	3.6	4	4.4			4.9
		E	3.7	3.8	2.2			5.5
11-Nov		S	3.6	4.1	4.8	5.7	5.2	5.1
		W	3.2	3.9	2.8	6.1	5.4	5.6
		N	3.9	4.6	5.0	6.4	5.6	5.3
		E	3.9	4.2	3.0	6.5	5.5	5.8
12-Nov	Windy day - Skipped readings	S						
		W						
		N						
		E						
13-Nov		S	4.3	6.1	7.4	7.3	6.6	6.4
		W	4.1	5.9	5.4	7.7	6.8	6.9
		N	4.8	6.6	7.6	8.0	7.0	6.6
		E	4.8	6.2	5.6	8.2	6.9	7.1
14-Nov		S	4.5	6.5	7.6	7.5	6.8	6.7
		W	4.2	6.4	5.5	8.0	7.1	7.1
		N	4.9	7.0	7.7	8.3	7.2	6.8
		E	4.9	6.6	5.7	8.4	7.1	7.4
15-Nov	Windy day- Skipped readings	S						
		W						
		N						
		E						
16-Nov		S	4.5	6.6	7.9	7.5	6.8	6.7
		W	4.3	6.5	5.8	8.0	7.1	7.0
		N	4.9	7.0	8.0	8.3	7.2	6.8
		E	4.9	6.6	5.9	8.4	7.1	7.5

APPENDIX E. WEATHER DATA FOR THE EXTENSION STUDY

Date	Rainfall (cm)	Sol Rad (W/m^2)	Air Temp (^{0}C)	Rel. Hum (%)	Wind Speed (m/s)
19-Oct	0.00	169.9	18.1	73.4	1.8
20-Oct	0.00	193.6	18.5	66.7	1.6
21-Oct	0.00	189.1	17.0	75.4	1.2
22-Oct	0.00	172.5	14.7	86.0	1.0
23-Oct	0.00	181.9	16.6	79.4	1.0
24-Oct	0.00	159.6	19.3	66.4	0.9
25-Oct	0.00	126.1	16.8	75.8	1.1
26-Oct	0.00	186.1	17.7	68.4	1.0
27-Oct	0.00	147.2	20.6	62.6	1.2
28-Oct	0.00	162.0	18.8	72.1	1.9
29-Oct	0.00	174.3	19.0	54.5	2.0
30-Oct	0.00	173.5	20.6	36.6	1.4
31-Oct	0.00	171.9	20.1	59.6	1.3
1-Nov	0.12	168.4	17.5	80.2	1.2
2-Nov	1.60	35.8	11.0	92.7	0.9
3-Nov	0.00	159.0	12.0	75.6	1.2
4-Nov	0.00	169.5	13.2	54.8	1.6
5-Nov	0.00	155.9	15.0	49.5	1.8
6-Nov	0.00	163.2	16.8	37.5	3.6
7-Nov	0.00	166.3	13.0	59.4	1.0
8-Nov	0.93	161.0	13.7	79.4	1.1
9-Nov	0.15	107.8	10.0	86.0	0.9
10-Nov	0.01	140.2	12.0	63.4	2.1
11-Nov	0.00	163.7	14.0	51.4	4.2
12-Nov	0.00	158.0	14.8	49.9	4.7
13-Nov	0.00	158.8	13.6	56.6	2.0
14-Nov	0.32	157.2	13.2	67.3	1.0
15-Nov	0.66	76.3	9.4	80.2	1.4