HOW TO COOL A CITY – JUST ADD WATER

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KEYWORDS

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ABSTRACT

Increased urban intensification, coupled with increasing temperatures due to climate change, is impacting on liveability in urban environments. The need to reduce the impacts of urban heat islands is therefore becoming more apparent and understood globally (Alavipanah, et al, 2015).

There are numerous approaches to mitigate the urban heat island effect, including adaptive urban design and planning of the built environment, and managing urban surfaces, specifically through development of vegetated areas (Mancebo, 2018).

At SA Water, our vision is "World class water services for a better life". Using water effectively to achieve urban cooling enhances liveability in our community. SA Water has undertaken investigative projects, as part of the Liveability program, designed to demonstrate that an integrated approach to outdoor water use provides multiple benefits, at multiple scales, to the community. These projects fall into three main areas: residential cooling, public open space irrigation management and monitoring air temperatures of irrigated and unirrigated open spaces.

The main outcome of the projects was to gain local evidence from around Adelaide and some regional centres in South Australia, with a view to improving the value placed on private and public green open space, to inform and influence behaviour change in the community and ultimately improve community resilience and the liveability of our cities and towns.

INTRODUCTION

It is acknowledged that cities and urban areas experience higher than normal air temperatures as a result of the urban heat island effect, when compared to the surrounding rural areas (Alavipanah, et al, 2015). It is also clear that the summer temperature is increasing in many locations around the world, especially in Australia (CSIRO, 2015). The combination of increased urban density, plus the impacts of a warming climate will make some cities uninhabitable in the future unless the impacts from urban heat islands can be mitigated (Mancebo, 2018).

A wealth of research has been conducted on the methods to reduce the impacts of the urban heat island. These include building and city design, alternative materials for road construction, and the strategic placement of 'green infrastructure' (Morrison, 2019).

'Green infrastructure' is a term used to describe healthy vegetation such as trees, parks, green walls, and general green open spaces.

Green infrastructure helps cool the urban environment via two mechanisms. Firstly, trees provide shade from direct sunlight, which reduces the air temperature within the shaded zone of the tree. Secondly, the combination of evaporation from the soil plus transpiration from the vegetation releases moisture into the air, which cools the air (Harlan and Ruddell, 2011).

The most important element to ensure that evapotranspiration, being the combination of evaporation and transpiration, occurs is the presence of water in the soil (Lobell, et al, 2008). The water needs to be in volumes that enable it to move to the surface, via capillary action, to enable evaporation The water also needs to be accessible to plant roots.

From work previously undertaken by SA Water, there is a correlation between air temperature and residential outdoor water use. Unfortunately, the air temperature peak occurs prior to the peak in outdoor water use, demonstrating that the average resident has a reactive approach to irrigating to maintain plant health during hot periods, rather than a proactive approach which would see irrigation occurring one or two days prior to a hot period (a hot period being two or more consecutive days above 35^{o}C). The latter would result in the vegetation being resilient during the hot period, more of the applied water reaching the root zone prior to evaporating, and hence more effective use of outdoor water for maintaining vegetation health.

In most areas with a Mediterranean climate there is minimal rainfall over the summer months (Vardoulakis, et al, 2013). As such, non-native vegetation usually struggles to remain healthy and actively transpiring without irrigation during this drier period of the year.

There is often concern about the sustainability of using drinking water to irrigate public and private open space, trees and other forms of green infrastructure. These areas may provide an opportunity to use alternative water sources (recycled water, stormwater, groundwater) where available. However the infrastructure costs required to get alternative water to large public open spaces is often prohibitive, leaving drinking water as the only viable option for irrigation.

The investigative projects addressed in this paper began in late 2018. The individual projects were designed to demonstrate the value of using water to keep green infrastructure healthy and active during the warmer months. As drinking water is used on the majority of the locations being investigated, the challenge was to demonstrate the value of using drinking water for irrigation purposes.

The target areas to investigate were schools and council parks, (which represented the public open space realm), the residential sector - specifically people's front and backyards - and outdoor public events. These areas each had a tailored approach to answer a series of questions, and determine the benefit for our customers, community and our shareholder, being the South Australian government. The projects, with the exception of the Airport cooling project (which commenced in December 2015) began in December 2018 and continued throughout that summer as additional participants and sites were identified. Our project was successful over the 2018/19 summer and was expanded for the 2019/20 summer, to capture further evidence to support a potential staged roll out of techniques identified through the project.

This paper highlights the outcomes of the individual projects, holistic linkages from each of the areas of interest, and demonstrates the numerous benefits associated with the projects within the Liveability program.

METHODOLOGY

Our overarching Liveability program initially had six individual projects as its components, being:

1. Residential cooling project
2. Cooling the community project
3. Smart irrigation project
4. Cooling our people project
5. Remote communities project
6. Airport cooling project

Of these, the majority of work undertaken to date has focused on the first three projects on the list. The Cooling our people and Remote Communities projects are still under development and are considered to be extensions of the work being undertaken in the first three projects. The Airport cooling project is currently awaiting funding and support to expand the irrigation area at Adelaide airport. There has been considerable interest for that project from both interstate and international airports, with early discussions about implementing the methodology occurring with a few of these airports. As such, this paper does not contain any additional information of the last three projects listed above.

Residential cooling project

This project gathers information about techniques that reduce the air temperature around the home, improve the aesthetics of a lawn and garden and reduce energy usage. It was also designed to influence a behavioural change in participants by demonstrating the benefits of using water in a more informed manner. In addition, the use of an outdoor misting system enabled residents of a home to be outside for longer on warm to hot days, thereby reducing their air conditioner use.

A call out was made to invite around 100 of our people to participate in the project, known as 'Keeping it Cool'. Each person was given a kit, which included:

- A seven metre misting system,
- A digital thermometer with an indoor and outdoor station
- A small flow meter
- A soil moisture probe

The participants were given instructions on how to use the equipment and given access to information on how to get the most from their outdoor water use, via presentations, simple videos and fact sheets.

In exchange for the equipment the participants agreed to give us information about the characteristics of their home (its location, orientation, construction and yard type), plus their water and electricity use. They were also asked to document their experience and observations from implementing the suggested actions, and whether this has changed their outdoor water use habits.

This project was first run from December 2018 to April 2019, with the participants asked to record their findings in a spreadsheet and submit it at the end of the period. This proved to be an inefficient method for recording observations and so during the second year of the project, an app was developed to enable participants to more easily record and report observations in a structured and timely manner. The app has six key questions:

1. Action(s) taken (multiple choice)
2. Why these actions were taken (multiple choice)
3. Time the participant and/or family members spent outside
4. Observed temperature reduction
5. Time air conditioner was turned off/down
6. Happiness factor

Questions 3 to 6 are answered via moving a point on a slide bar, to accurately provide data on the outcomes of their actions. Through the answers to these six questions we can ascertain the following:

- Actions/changes in behaviour most attractive to the different participants
- Reasons they chose a certain action
- Effectiveness of their action(s)
- Reductions in electricity use achieved through the action(s)
- How satisfied they were with the outcomes, and therefore how likely they are to change their behaviour based on the effort and the result.

The information from the app, plus comments and additional observations from participants, was logged and interrogated to determine the overall outcome and inform future stages of this project.

Cooling the community project

This focuses on two different approaches to outdoor cooling with water. The first involves the deployment of misting systems at major outdoor events in Adelaide. The second approach is the installation of more than 200 air temperature sensors across open spaces in urban areas.

Misting at major events

This activity involves installing simple hardware-bought misting systems at outdoor events and/or venues. The initial installation occurred at a commercial venue, being the Adelaide TreeClimb Adventure Park in the Adelaide Parklands. Approximately 80 metres of misting system was placed on the railing around the launch pad area of the adventure park. The misting set up is a semi-permanent installation, removed during the cooler months of the year, with the venue staff operating the system according to the conditions of the day.

The success of this initial installation led to the deployment of misting systems for several major annual events on the Adelaide calendar such as the Tour Down Under international cycle race, the Superloop Adelaide 500 touring car race, the major music festival WOMAD, and several smaller events.

The installations form a component of SA Water's sponsorship of these events. It also provides an opportunity to demonstrate and document the extent of outdoor cooling that can be achieved, with the hypothesis being that attendees will then replicate this in their own homes.

Monitoring air temperature

This component involves the installation of more than 200 air temperature sensors in a variety of open spaces across the Adelaide metropolitan area and in some South Australian regional centres. The air temperature sensors are manufactured by Rising HF and are about the size of a 200ml juice box. They operate on the LoRa WAN network at a frequency of 915MHz. The signal is sent back to either a public LoRa gateway, as part of The Things Network (TTN) or sent to a private gateway supplied by our project partner (Fleetspace).

Sensors were placed in irrigated and unirrigated parks located near each other, to enable a good comparison of the observed air temperature differences with the same climatic and geographical conditions. Sensors were also placed in carparks, streetscapes and other locations that represented both cool and hot land uses.

Great effort was taken to ensure the sensors were placed in locations within the targeted site types that were relatively similar to each other. For example, most installations occurred in trees that had a consistent canopy cover, generally native species, at a height of around three metres above ground level, and on the southern side of the tree to reduce direct sunlight hitting the sensor.

The sensors were programmed to collect air temperature data every five minutes and upload this data to a software platform every 15 minutes. The data is displayed and updated on a map on the SA Water website. Website visitors can zoom into the temperature icon of a monitored location. A text box pops up when an icon is clicked showing temperature, along with a photo and information on the site.

This project provides information to the public regarding the temperature of their favourite park, to encourage visitation and get people out of the house on warm to hot days when they may normally sit inside with the air conditioner running. It also provides data on the air temperatures being generated from different land types under different management regimes. It is hoped that the data can be used by councils and open space managers to justify the use of water to provide green open space. We also anticipate data can inform better use of other sites that may have good infrastructure (such as playground equipment and toilets) but are not being used due to a lack of irrigation and hence higher temperatures.

Smart irrigation project

This project involves the use of hardware and software designed to inform irrigation scheduling for open space managers. The hardware consists of a smart water meter along with a soil moisture probe. A variety of different hardware combinations have been trialled over the past three years, with the main variation being the method of communication (3G, LoRa WAN or a proprietary network) and the subsequent cost to buy, install and operate the equipment. Information generated from this hardware is sent to our project partner, SWAN Systems (water and nutrient irrigation software). The software also receives input from the chosen Bureau of Meteorology station. The software can predict, based on these inputs, what irrigation is required during the following week to ensure that the turf and/or other vegetation receives the correct amount of water. The software has a budgeting function, which ensures irrigation volumes stay within or below budget for the irrigation season.

There are 25 sites currently involved in the project, which includes 14 councils and a few schools. Each site manager is given access to the software so they can view the suggested schedule for the coming week. Additionally, an SA Water project member copies the output graphs and provides to the site manager with minor commentary on what the data is suggesting for the week ahead. Open space managers can use the graph from the monitored parks to inform the irrigation schedule for other parks with similar soil types and geographical conditions.

RESULTS AND DISCUSSION

Results for each of the three projects and associated discussion on them follows. It should be noted a complete dataset of this summer and autumn across all projects is not currently available, as the time of writing this paper falls only midway through the warmer period of the 2019/2020 year.

Residential cooling project

The project attracted around 160 SA Water staff in total over its first and second years. Of the initial 100 people in the first year, 40 returned to participate again in the second year, joining the 63 new participants.

Due to the reporting method for the first year (hard copy recording of observations), most of the data related to the social components of the project, being level of satisfaction with the action and if this would influence any changes in people's outdoor water use behaviour. The data collected through the first period was summarised for each participant; noting that only some participants answered all the questions. Of note from the first year was the information on the reduction in people's electricity bills for the summer period, based on their spend for the previous summer. This is shown on the following graph.

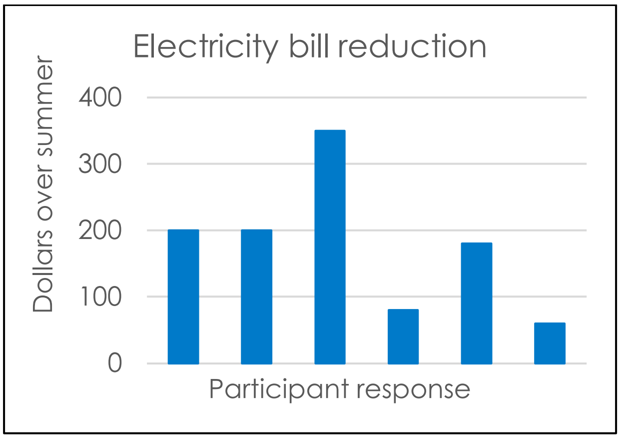

Figure 1. Reduction in electricity bills for six participants in year one.

There was a significant reduction in electricity usage from the six people who answered this question in the first year. The use of the app in the second year yielded a better response rate, with more structured data received, specifically about reduction in electricity usage associated with not running the air conditioner during periods when they would have used it, based on previous behaviours. This data will enable us to calculate an indicative electricity use reduction for each participant.

Data to date shows that, on average, the participants are using their air conditioner for two and a half hours less on a hot day, and up to five hours less for some participants. A ballpark calculation was conducted, using the following assumptions, to compare the annual operating cost of an air conditioner as opposed to a seven metre misting system. These assumptions are:

- It costs $0.80/hr to operate an average air conditioner (medium size split system, powered from the grid),
- Air conditioners and misting systems would be turned on when the temperature exceeds 30°C,
- There are 60 days per year when the air temperature exceeds 30°C in Adelaide.

Table 1. A comparison of the cost to run an air conditioner versus a misting system

	Cost per hour	**Average use** (2.5h/day)	**High use** (5h/day)	**Cost per year** (average use)	**Cost per year** (high use)
Air con	$0.80	$2.00	$4.00	$120	$240
Mist	$0.07	$0.18	$0.35	$11	$21

From this ballpark calculation it is clear that an air conditioner can cost up to an order of magnitude more to operate when compared to a seven metre misting system. There are numerous other factors that would influence the use of one over the other, such as a lack of an outdoor entertainment or living area and hence the inability to install and operate a misting system. The main reason to show this data is to demonstrate that there is a cost effective alternative to air conditioning, especially for those in the low socio-economic portion of our community that may not be able to afford or operate an air conditioner.

From the data collected to date during the second year of the trial, the following graphs show the main action that was taken by the participants in response to a hot day. It should be noted that the average temperature on the days when observations were logged was in excess of 37°C.

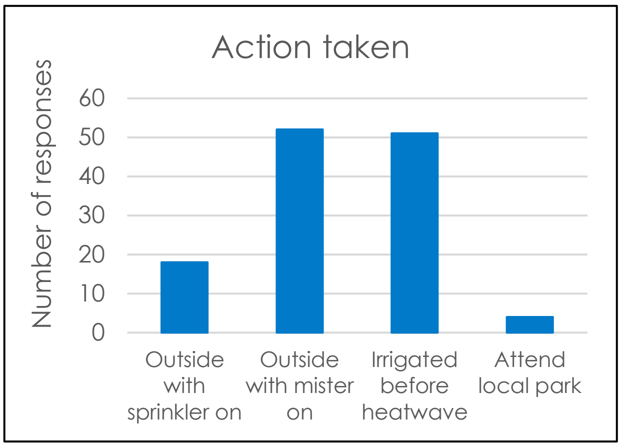

Figure 2. Actions people took on a hot day.

From this information the most popular responses were firstly that people prepared their garden and lawn via irrigation leading up to the hot weather period, and secondly, liked to sit outside with a misting system operating during the hot period. The main reason why this action was taken is shown in Figure 3, below.

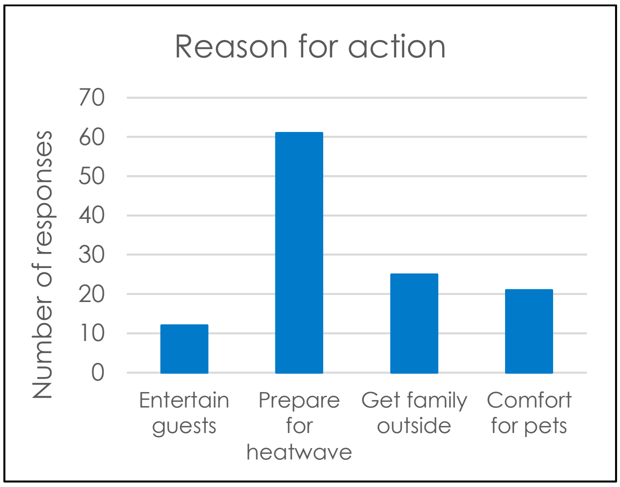

Figure 3. Reasons why people took the specific action.

Most participants were undertaking action to prepare for a hot period (termed "heatwave" in the app but actually relates to a hot period of two or more days). Watering before the hot period will improve irrigation efficiency, reduce air temperature around the home, and influence vegetation resilience leading up to and during the hot period. As mentioned earlier, most responses were logged on days when the temperature was above 37°C. This implies that our participants were conscious of the approaching hot weather and acted prior to and during the heat to reduce the air temperature around their homes.

As one of our main outcomes of this project is about influencing a change in people's outdoor water use habits, a specific question for both years of the project relates to the Happiness factor – whether the participant was satisfied with the action(s) they undertook and the subsequent outcome of them. People had three options in answering this question: Happy, Neutral or Not Happy. Responses are shown in Figure 4.

Figure 4. The Happiness rating for the action and outcomes by the participants.

Over 73 per cent of the responses recorded a "Happy" outcome from the action that was taken. Of the four responses registering an "Unhappy" outcome, these related to the impacts of the moisture from the misting system or the lack of effectiveness of the misting system. Both issues were directly related to the location and set up of the misting system.

The main outcome that can be extrapolated from the responses of the 163 participants over the two year project is that people need to be informed about what actions they can take leading up to and during hot periods. The other significant result identified is that people can reduce their electricity costs, and at the same time be able to maintain their garden and lawn health through this more informed approach.

Cooling the community project

There are two components to this project, the first being misting at events, and the second being monitoring air temperature in outdoor open spaces.

The misting at events has resulted in one semi-permanent installation and installations at several major events as outlined earlier. No actual temperature reduction data has been obtained to date from these deployments due to several factors. The most common issue during the first year of deployment was the lack of time to undertake monitoring. Many systems were set up and removed either on the same day or the following day. During the second year, no installations have occurred, when writing this paper, where the temperature has exceeded 30°C due to the below average temperatures during mid-January to mid-February. However, we have anecdotal information, being that benefits of misting were directly demonstrated to around 30,000 people who attended the events and took refuge from heat under the misting systems. Further data will be gathered at upcoming events.

The management team at the TreeClimb Adventure Park decided to cancel their hot weather policy because of the misting system's benefits, which previously had been that the premises would not operate on days over 40°C. As the misting system reduced the air temperature to well below 40°C around the central launch area of the venue, it remained open through the eight days above 40°C during the first year of operation. The management team stated they were very surprised by the benefit obtained from a relatively cheap misting system.

The monitoring of air temperature has been very successful. To date more than 240 sensors are producing live data on our website. There are numerous examples of outdoor spaces being 7°C above and 3°C below the Bureau of Meteorology (BoM) observation for that exact time. The following images show these differences in locations within close proximity to each other.

Figure 5. Two sensors in the same park show a significant temperature difference.

The data in Figure 5 shows that one sensor, close to the irrigated area, is 6°C cooler than the sensor located near the artificial turf area. The BoM air temperature for that location was 30°C at the time of this data capture, which is 3°C warmer than the irrigated area and 3°C cooler than the artificial turf.

Another image, taken at a time when the air temperature was 32°C is presented next.

Figure 6. Two sensors in the close proximity showing a significant temperature difference.

The sensor in the irrigated area is 2°C cooler than the BoM air temperature at the time, with the sensor in the unirrigated area being 3°C warmer than the BoM temperature and 5°C warmer than the irrigated area.

The following image was captured when the BoM temperature was 31°C.

Figure 7. A sensor in an industrial estate.

The temperature in this industrial estate is 12°C higher than the BoM temperature; particularly concerning given that at the same time some parks were 12°C lower than the industrial estate. This is a perfect example of the significant impact that a built, unirrigated, unvegetated environment has on temperature compared to an irrigated and vegetated environment.

One further example relates to the different land surfaces in an urban park.

Figure 8. Three sensors in the same park showing a significant temperature difference.

This is Victoria Square in the Adelaide's central business district. The 5°C temperature difference can be attributed to the high volume of concrete located near the northern 36°C sensor.

There are two significant outcomes being delivered from this data. The first is that the public can easily access and understand the temperature in different locations, enabling them to decide if they should venture out on a hot day, and where they should go to be cooler. The second outcome is that this data can be used to inform urban planning and design decisions as it shows the actual temperature associated with different land use types and management regimes.

Smart irrigation project

Our software partners, SWAN Systems, have stated that water savings of more than 20 per cent have been achieved in agricultural deployments. The longest user of this software for our project is Adelaide High School. They have quoted water savings of over 15 per cent for an urban oval. They have also stated that the software outputs, including the data from the soil moisture probe, have provided significant comfort to their grounds staff during hot weather as they have confidence in the outputs.

From the 25 sites monitored during the 2019/20 irrigation season, a wealth of data was collected to show the benefits of using this approach to manage irrigation for large open space. Whilst there were some issues related to communication problems because of the location of some soil moisture probes and smart meters, there was suitable and consistent data obtain from 14 parks, which is discussed below.

There was a distinct difference between the guidance from and response to the Swan outputs from the various open space managers. There are three categories of response that was observed, being open space managers that used the Swan outputs to inform their irrigation activities, those that continued as they normally would but also checked in with the Swan outputs to see how their scheduled compared to the Swan schedule, and those that did not take any notice of the schedule. Examples of the two extremes, being those that used Swan to inform the schedule, and those that did not follow Swan at all, are discussed below.

This first example shows how an irrigation schedule was influenced by the Swan outputs. During the first month irrigation was conducted as per normal historical scheduling, however for the second and third month the Swan outputs informed the irrigation schedule.

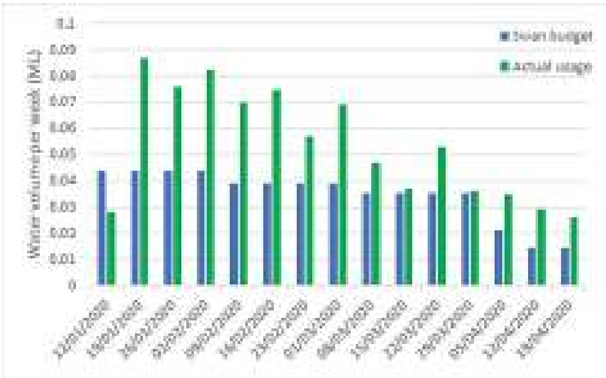

Figure 9. Water use changing as Swan is used to inform irrigation.

During the first month, a total of $1500 worth of water was applied to this relatively small park. During the second and third month, through the Swan outputs informing the irrigation schedule, water use was reduced to $500 worth of water applied each month. The average maximum temperature was within 1 degree between the first and second month, demonstrating this was not as a result of the weather cooling. Based on the trajectory of the first month of water use, the council saved an estimated $1400 of water for this park over the irrigation season.

The second example, at the other end of the response spectrum, shows water use at a sports oval. The irrigation schedule is programmed via a central control system, with a new schedule being programmed at the start of each week. On most occasions the Swan outputs were not used to inform the irrigation schedule.

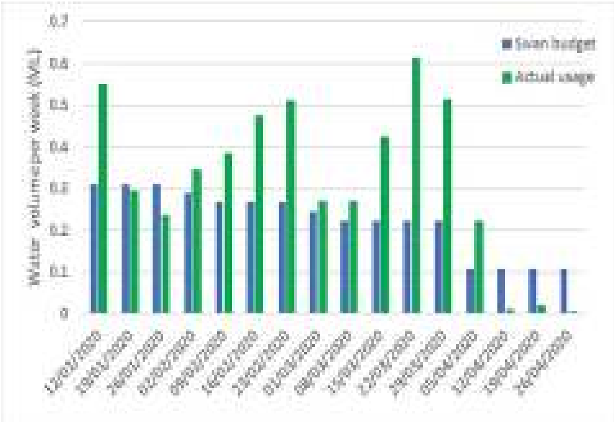

Figure 10. Actual water use is higher than that suggested by the Swan software schedule.

Each of the large peaks in Figure 10 demonstrates an additional water use of between $600 and $1,000 for that week. The additional water use for this oval equated to $7,500 for the 2019/20 irrigation season. A second park in this council area had a similar pattern of additional use of water.

The collated data from all the monitored parks across all participating councils showed that the average additional water use was just over 30% for the 2019/20 irrigation season. Extrapolated out across the entire Adelaide metropolitan area, this would equate to an optimisation opportunity that could provide an additional 1.7GL of water for other currently-unirrigated open spaces, and the subsequent benefit for the community through more green open space for recreation. This is now the focus for the next stage of the smart irrigation program, which involves the roll out of the commercial version of smart irrigation for councils, schools and other open space managers.

CONCLUSION

The expansion and densification of urban areas in developed countries, coupled with the impacts of a greater prevalence of extreme weather events, puts significant strain on our cities and towns and impacts the lives of the people who live, work and visit them.

As the climate dries there is a greater emphasis being placed on gaining the maximum value out of our existing water resources. The aim of our overarching Liveability program and the projects within it is to demonstrate that an integrated approach to outdoor water use provides multiple benefits, at multiple scales, to the community. The projects discussed are all important components of a holistic program of work to improve community resilience and the liveability of our cities and towns. By knowing when and where to water around the home, a resident can maintain the health of their garden and lawn, even in the driest summers. This not only improves the aesthetics of their home; it also reduces air temperature around the home. Combined with a simple misting system, residents can significantly cool their outdoor living areas and lower their electricity use. In additional to the residential sector, the ability to keep public open spaces green due to efficient and effective water use improves the value placed on these areas and increase their attractiveness and use by the community.

Greener residential yards coupled with green public open spaces can play an important role in reducing the overall impacts of urban heat islands. The methods used in our projects have demonstrated that you can cool a city, or parts thereof, by just adding water.

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