Adelaide Airport Stormwater Irrigation Trial – determining the multiple benefits of irrigated vegetation

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A two year trial has been established at the Adelaide International Airport to study the possible temperature reductions that can be achieved through irrigation of open space. The irrigation area is 3.5 hectares with a number of control sites located around the irrigated zone. The area is irrigated with stormwater that has been captured and stored using the adjacent aquifer storage and recovery (ASR) scheme. The aim of the trial is to quantify the temperature differences and use this data to examine the energy (in cooling towers) and fuel savings (during aircraft take-off) that can be achieved at the airport, as well as capturing information on other benefits such as the improved aesthetics, reduction in erosion, influences on bird risk and potential primary production of crops. Data from the first season of the trial is presented in this paper. The average temperature difference between the irrigated and unirrigated area was 2.4 degrees, with a range of less than 1 degree to 3.8 degrees. As observed in other studies, the maximum difference in temperatures between the irrigated and unirrigated area did not necessarily occur on the hottest days. Further analysis of the data will occur following the second season of irrigation, however the data obtained to date is promising and may be useful to other airports where a lack of summer rainfall can present risks to airport operations.

Key words: urban cooling; airport irrigation

1. INTRODUCTION

A wide range of investigations have occurred throughout cities to quantify the Urban Heat Island (UHI) impacts with a view to develop methods to reduce these impacts through a number of mitigation strategies (O'Malley *et al*, 2014). Green infrastructure has been one such mitigation strategy that is being supported in many developed countries as it offers many additional benefits including improved aesthetics, activation of open space to encourage social interaction and physical/mental health improvement, increased property values, and improvements in air quality (Harlan and Ruddell, 2011). The one critical aspect with this method of intervention is the need for water to sustain the health of the vegetation.

Whilst water is required to sustain vegetation health, there are financial implications in many cities associated with the application of water, particularly those in climates that have hot dry summers, such as a typical Mediterranean climate (Vardoulakis *et al*, 2013). These climate types generally equate to an excess of rainfall and hence available water for vegetative growth during winter months and a deficit of water during late spring, summer and early to mid-autumn.

Adelaide is renowned for being a hub for managed aquifer recharge (MAR), specifically using the aquifer storage and recovery (ASR) method of MAR (Dillon *et al*, 2010). With more than 30 ASR schemes operating around Adelaide, the majority of which are used to store stormwater, a significant proportion of urban run-off is captured prior to be discharge to the marine environment. Different end uses are being investigated, including the contribution that this captured stormwater can make to liveability and supporting green open space and green infrastructure in the areas connected to the ASR network.

The Adelaide Airport stormwater ASR scheme has been in operation since May 2015. Stormwater is harvested from the adjacent Brownhill Creek and injected into the Tertiary 2 (confined sedimentary) aquifer located 200 metres below the ground surface. Although this creek is a major watercourse of the Adelaide Plains, it is an ephemeral creek which only flows during the wetter periods of the year (generally between May and August). Without the ASR scheme, the stormwater would only be available during the wetter period of the year when the creek is flowing. SA Water has an EPA licence to inject 300ML of stormwater per year from the creek into the T2 aquifer, via 4 bores, and an approval to extract 270ML/yr from these bores following injection.

Every major city has an airport. Airports require large swathes of land to act as buffers between airport activities and the surrounding industrial and residential land uses. The main purpose of the buffer land is to ensure safety and security for airport activities, and to reduce the public exposure to high levels of noise (Freestone and Baker, 2010). This buffer land must be managed in a way that does not impede airport operations, including mitigating the risk of bird strike, flooding and the generation of dust. Modifying the way that this buffer land is managed requires significant evidence to satisfy the airport operator, the airline operators and the civil aviation regulators (Stevens, 2012).

1.1. The Trial

A two year trial was established at the Adelaide International Airport in November 2015 to enable the quantification of the benefits associated with irrigating open space using stormwater from the SA Water ASR scheme. The trial is a collaborative project between SA Water and the operators of the airport, Adelaide Airport Limited (AAL). SA Water's interest in the trial is to investigate the extent to which irrigated broad acre vegetation can reduce air temperature, and to quantify the associated financial benefits. If the trial continues to be supported by both organisations and the outcomes are viable, both financially and environmentally, the scheme may be expanded across the entire airport using recycled water, blended with the stormwater as required to manage salinity.

1.1.1. Aims and objectives

The overall aim of this trial is to quantify the cooling that is achieved through irrigation of vegetation in the otherwise unusable land around a major airport and to identify the associated benefits. This is a "proof of concept" trial.

The specific objectives of the trial are to:

- Measure the temperature across an irrigated area and an unirrigated area, and determine the persistence of the cooler air downwind of the irrigated area;
- Estimate the energy savings that could be achieved in the cooling tower in the airport passenger terminal and the aeroplane fuel savings (during take-off) that could be achieved through the reduction in air temperature during hot periods of the year; and
- Assist with the secondary trial (vegetation trial) undertaken by AAL using different types of vegetation to address issues such as minimising the risk of attracting birds to the airfield; and
- Examine any additional environmental benefits that may be achieved through the use of stormwater for open space irrigation.

In addition to the main objectives described above there is an interest in investigating how the outputs and findings from this trial could be used to demonstrate the benefits (and develop the business case) for expansion of the irrigation of open space. This may include neighbourhood parks, sports fields, picnic areas and larger unused open land parcels.

A secondary trial by AAL is examining the growth and survival of different vegetation species both within and adjacent to the irrigated area. This involved planting 5 species, some of which were already present at the site and some (such as lucerne and other grasses) that were new to the site. The vegetation trial also examined other aspects of the selected species including their attractiveness to different bird species and the potential maintenance costs (mowing frequency, weed control etc.). As this was a separate component to the irrigation trial, and was managed through AAL, this aspect of the airport work is not discussed further in this paper.

1.2. Methodology

The methodology outlined below describes the first phase of the trial, namely the field work. The second phase of the trial, the assessment of the potential benefits such as fuel and energy savings and bird risk reduction will be addressed at the end of the trial in autumn 2017.

1.2.1. The site

The key criteria for the site were (i) to be near the stormwater ASR distribution network, (ii) at least 100 metres from the main runway, (iii) away from other temperature influences (buildings etc.) and (iv) suitable to contain a four hectare irrigation area with a surrounding unirrigated control area.

The specific site is shown in Figure 1. Note the south west to north east orientation of the trial plot designed to take advantage of the predominant south westerly wind direction that occurs at this site (as does the airport's main runway).

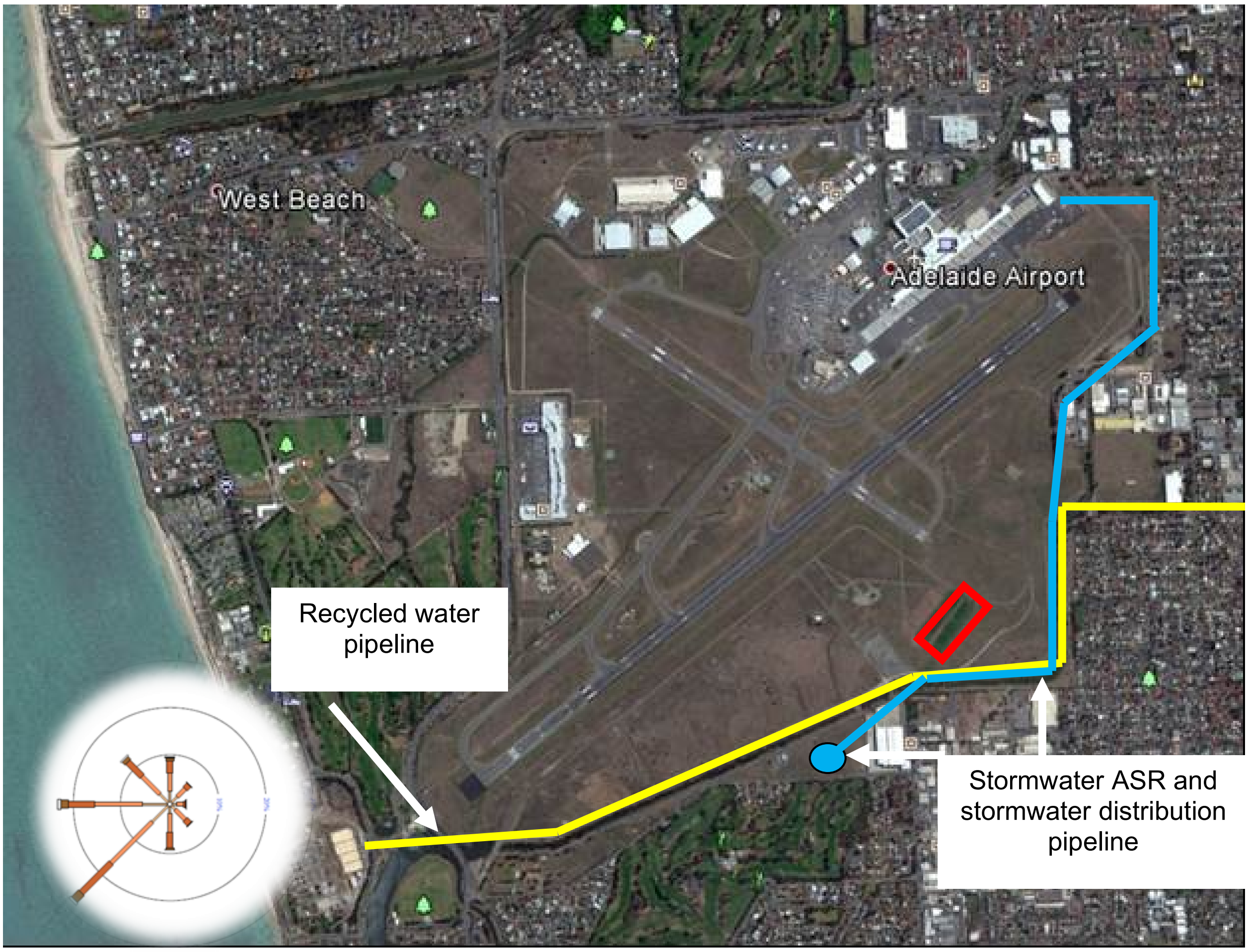

Figure 1. Showing the irrigation trial site in relation to the airport land parcel. The inserted wind rose indicates the dominant wind direction year round, including summer months.

1.2.2. Irrigation equipment

A key selection criterion for the irrigation system was the need to use a temporary system that could be removed if the trial presented unacceptable risks by attracting birds or other unforeseen circumstances. The irrigation system selected was two Monsoon Hose Reel Irrigators operating in parallel along the trial area (see Figure 2). Water was supplied via a pipeline from the existing stormwater ASR scheme. Whilst this system had a comparatively low capital cost it did require a higher amount of labour (and hence operating costs) compared to other more automated systems.

Figure 2. Showing the cannon and reel components of the irrigation system

With the pressure available from the ASR distribution system pump station the cannon sprinkler head had a radial throw of around 37 metres. The irrigators were equipped with a 250 metre hose reel which enabled an irrigation coverage of just over 3.5 hectares.

Due to the potential risk of attracting birds to the airport the irrigators were only operated during the mandatory Adelaide Airport aircraft curfew period between the hours of 11pm and 6am. Both irrigators were operated together, and were capable of irrigating half of the plot each night. The irrigation cannons were pulled out (i.e. reset) every second day during the week, and occasionally on weekends during hot periods.

Irrigation commenced in mid-December 2015 and continued until the end of April 2016, applying a total of 24ML across the 3.5 hectare site. Teething problems with the irrigators resulted in uneven frequency of irrigation during the first two months of the trial, however these were addressed with the resulting irrigation control being 95% effective during the last half of the irrigation season.

1.2.3. Monitoring sensors and equipment

Temperature sensors were used to log the *in situ* temperature across both the irrigated and unirrigated areas. The sensors used were the Hobo Pro v2 temperature and relative humidity sensors. These were each placed in a custom made solar radiation shield that was constructed as per a solar radiation shield manual developed by Davis Instruments Corp (1998). They were constructed out of 8 melamine cereal bowls with the sensor placed horizontally within the array.

A total of 43 sensors were originally installed (see Figure 3 below), however issues with the mounting structure caused 7 of these to have repeated failings of the mounting structure, which for air crash safety reasons, were designed to collapse easily under lateral pressure. The sensors and solar radiation shields were placed at a height of approximately 1.2 metres above the ground surface. The sensors were configured to take a temperature and RH reading every 5 minutes. Sensor data was manually downloaded monthly and stored on a PC for later analysis.

Additional monitoring was undertaken of soil moisture content and also for general weather data, using Sentek Drill and Drop soil moisture probes (60cm TriSCAN), and 2 Davis Vantage Vue Pro 2 weather stations. As shown in Figure 3 below, the soil moisture probes and the weather stations were placed both within and outside the irrigation area.

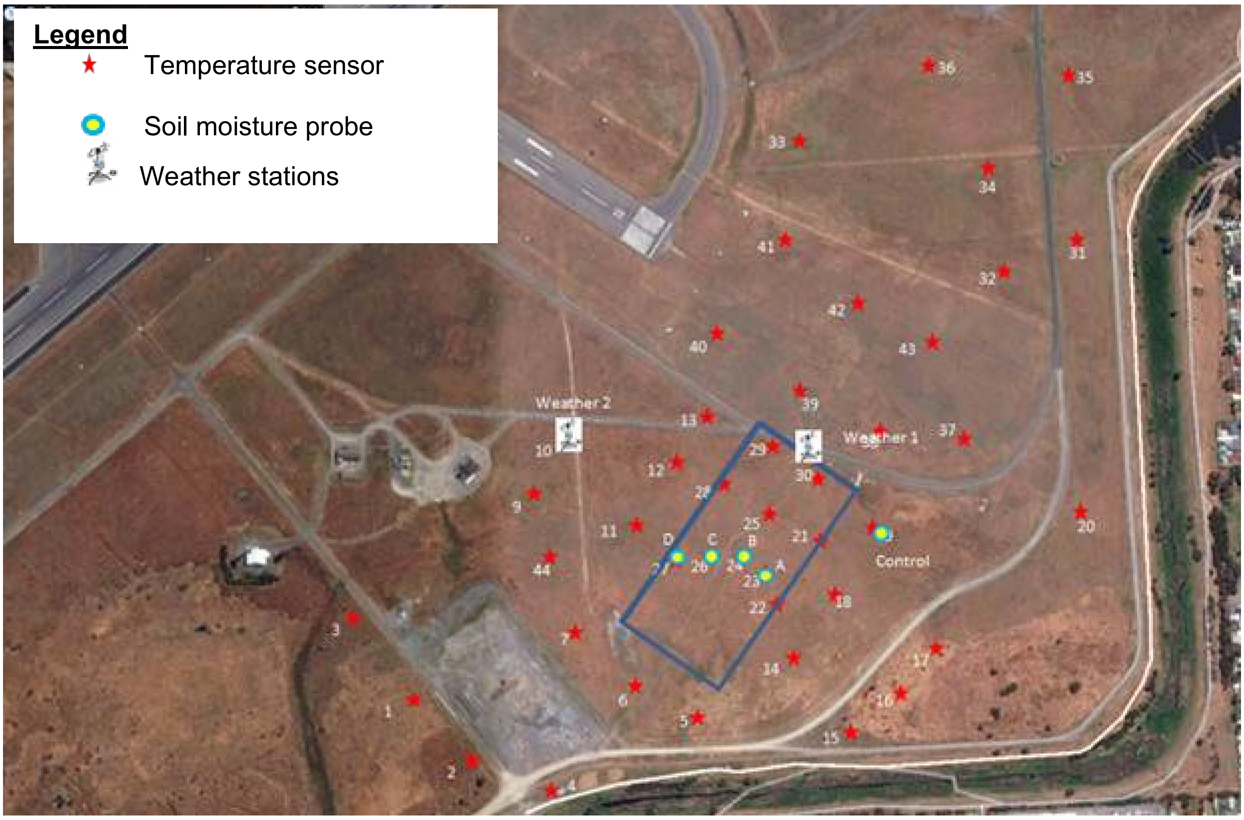

Figure 3. The location of the monitoring equipment (the irrigation area is located within the blue rectangle)

2. RESULTS

The main objective of this trial was to quantify the temperature difference that could be achieved through the application of stormwater to increase evapotranspiration in the irrigation area. The following section highlights the initial temperature results.

2.1. Temperature data

Temperature and humidity data from 7/1/2016 to 11/4/2016 was analysed. Weather data was obtained from the Bureau of Meteorology website as there was some uncertainty about the calibration and resulting data obtained from the trial weather stations. Overall results from the temperature data along with other climatic conditions on that particular day are shown in Table 1 below.

Table 1. A summary of the results from all sensors

	Daily Max (°C)	Max temp difference (°C)	Evaporation (mm)	Relative Humidity @ 3pm (%)	Daily Rainfall (mm)
2/03/2016	33.8	3.7	7.4	43	0
7/03/2016	28.9	0.8	4.4	66	11.6
Average over entire period	29.6	**2.4**	7.2	46	1.1

The data in Table 1 shows that the largest difference between probes did not occur on the hottest day recorded during the study period, nor did the smallest difference occur on the coldest day during the study period. Whilst rainfall would be the likely cause of the small difference on the 7th March 2016, there were many other days when rain did not occur where temperature differentials were less than 1 degree. It should be noted that the number of rain days was 14 over the study period, however only half this number were days when greater than 1 mm of rain was recorded.

The average temperature difference over the study period was 2.4 degrees. On all days the lowest maximum temperature was recorded within the irrigation area, with the highest maximum temperature being recorded 250 metres downwind of the irrigation area, in a location with very little vegetative cover and large areas of bare earth.

The majority of days where a large temperature differential was recorded were warmer days (70% above 30 °C) and similarly the majority of days where the lowest differential was recorded were cooler days (90% below 30 °C). Analysis of the daily maximum temperature difference (between probes), wind (speed and direction), sunlight (and cloud cover), evaporation, humidity and rainfall concluded that there was no single factor or combination of factors that influenced the range of temperature differentials between the irrigated and unirrigated areas. This requires further investigation using a multivariate analysis approach, and a larger dataset over a greater period of time (planned to be conducted at the end of Phase 2 of the trial). One further aspect that requires further investigation is the influence of shortwave solar radiation, which will be captured during the second season of the trial.

The distribution of temperature differentials is shown in Figure 4 below. The red vertical line represents the average differential during the study period. While the average differential for the study period was 2.4 degrees, the majority of individual readings were above the average.

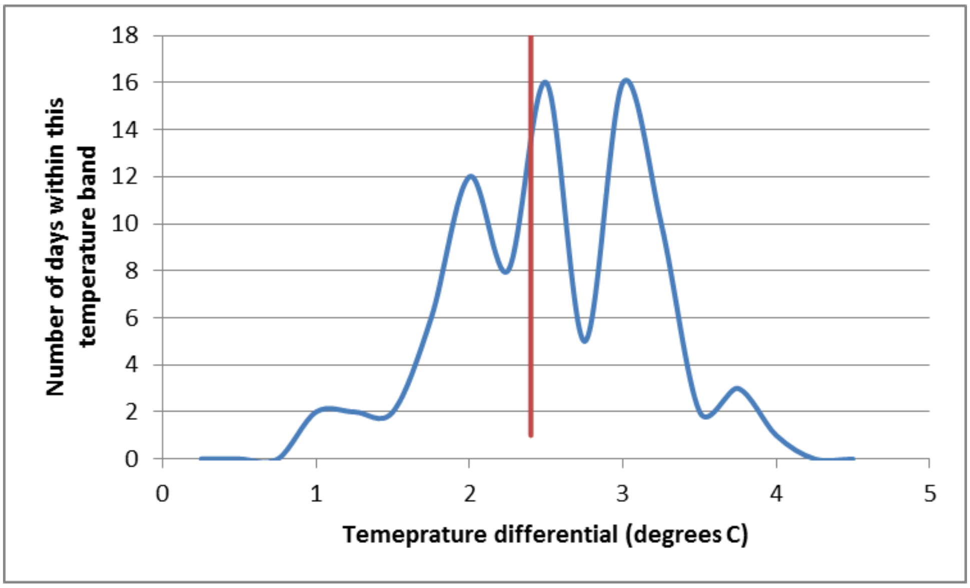

Figure 4. The distribution of temperature differentials during the study period.

To investigate the temperature differential across the irrigation area, two days were selected and assessed in detail, one being a hot day at the start of the study period and one being a mild day towards the end of the study period. Four sensors along a transect were used for this assessment, one upwind of the irrigation area, one in the middle of the irrigation area, one at the end of the irrigation area and one 80 metres downwind of the irrigation area. The following graphs show the temperature differential that was recorded across this transect for these particular days.

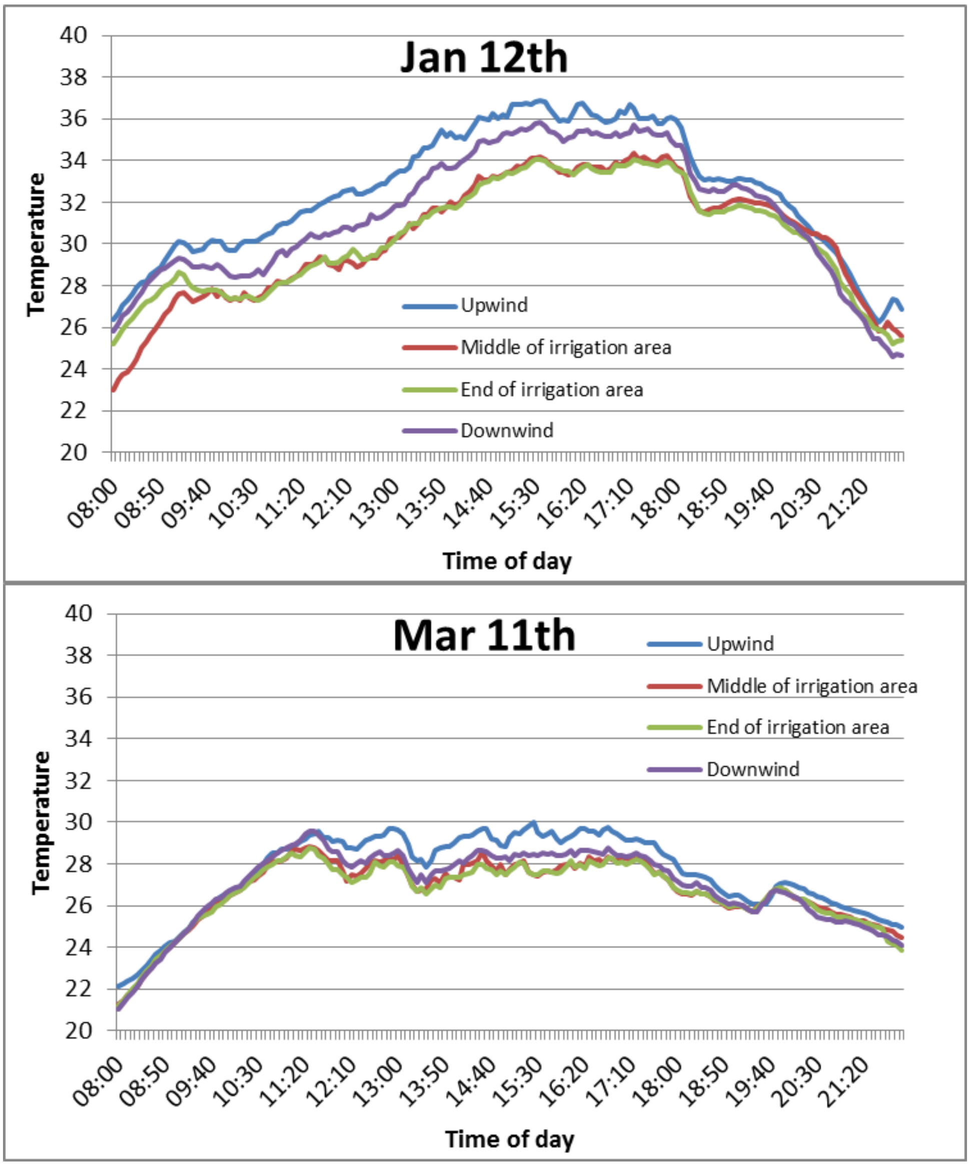

Figure 5. The temperature across a transect through the irrigation area on 12 January 2016 and 11 March 2016

It is clear from these plots that there is a substantial difference in air temperature across the site. Although there is only limited persistence of the cooler air, as shown by the downwind temperature being less than the upwind temperature, the area of influence from the evapotranspiration within the irrigation area does not extend more than around 100 metres from the irrigation area. This is evident in the temperature contour images below (Figure 6).

These images were generated using the temperature recorded at 3.30pm on each day (during the warmest period of the day). There was also a slight south westerly sea breeze occurring on both days at this time (blowing from bottom left corner to upper right corner of the images).

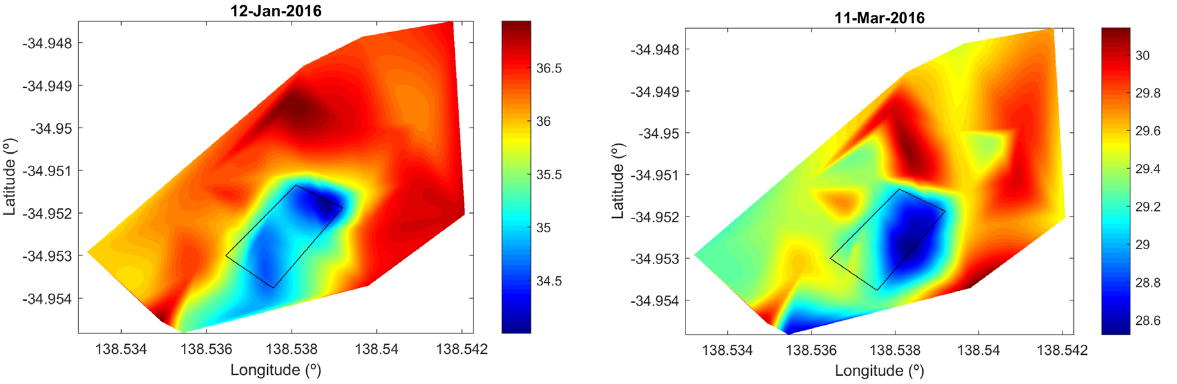

Figure 6. Temperature contours across the trial site on 12 January 2016 and 11 March 2016

There are several noteworthy aspects in these images. First, on both images there is a cooler area in the bottom of each image which was evident on many days, as recorded at the four sensors in this area. It is likely this is due to the creek and riparian area which is located just outside of the trial site. Second, there is a high temperature area to the north east of the irrigation area, outside of the area of influence. This is an area with little vegetation cover and large areas of bare earth. On all images from the study period this area is warmer than all other areas around the study site. Third, it is clear from the images that the area of influence does not extend far from the irrigation area. This may be due to the relatively small size of the irrigation area, coupled with the overwhelming warmth generated from the bare ground cover to the north east of the irrigation area. Although the majority of days had a south westerly wind at 3.30pm, the few days where the wind was from the north did not differ from those presented above.

2.2. Soil moisture data

Soil moisture was recorded from 5 probes across the site, with 4 being within the irrigation area and one located outside of the area. Figure 7 shows data from one of the probes within the irrigated area (top line) and data from the “control” probe outside of the irrigation area on the bottom.

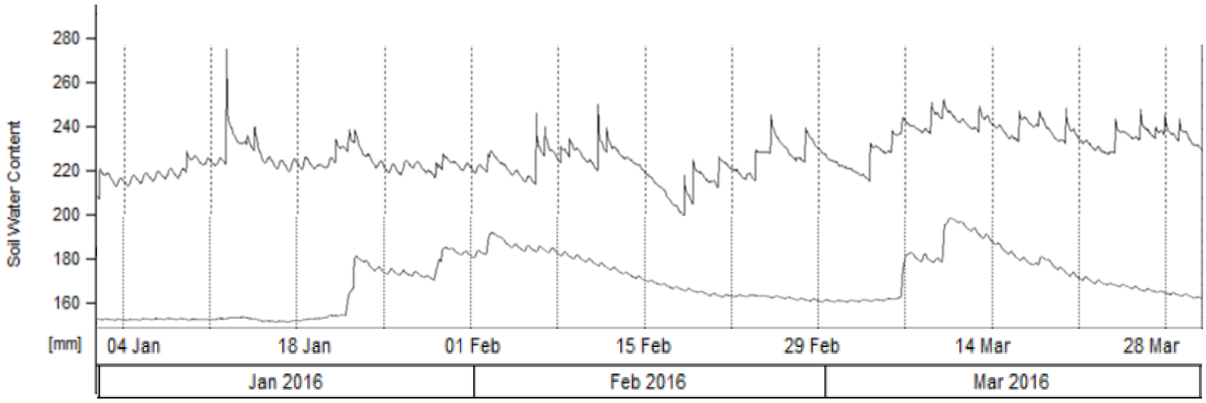

Figure 7. Soil moisture probe readings for the irrigated (top) and non-irrigated (bottom) area.

From this soil moisture data it is clear that there was a significantly greater volume of moisture in the soil in the irrigation area when compared to areas that were not irrigated. The three major rain events that can be seen in the control (bottom) line were unusual for this time of the year. In fact the rainfall during the study period was 40% higher than the average rainfall for this time of the year.

Figure 8. Showing the change in vegetation coverage after 3 months of irrigation.

Regardless of the above average rainfall during the study period, the vegetation outside of the irrigation area was dormant during the majority of the study period. Figure 8 illustrates the improvement, aesthetically and from the temperature reductions discussed above from the application of stormwater in this environment.

2.3. Thermal images

A series of thermal images were taken at the end of the trial period to assess the surface temperatures and identify the difference between irrigated and unirrigated surfaces. The thermal images below were taken on a cloudy day toward the end of the study period. The air temperature at the time was around 28 ^{o}C.

The first image in Figure 9 shows the surface temperature difference between the irrigated and unirrigated areas. The actual surface temperature difference was 5 ^{o}C which is above the 2.6 ^{o}C air temperature difference that was recorded on that day from the nearby temperature sensors.

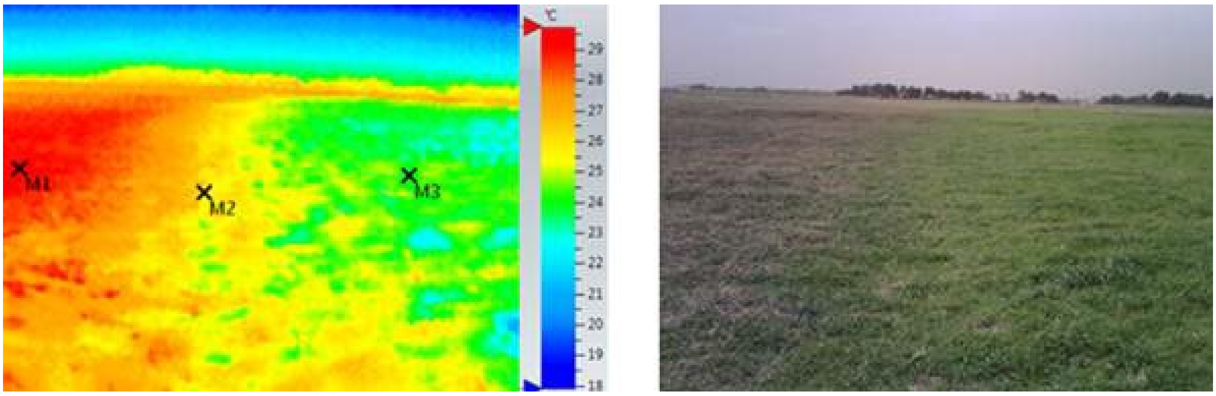

Figure 9. Thermal images showing the surface temperature difference between the irrigated and non-irrigated area.

The actual surface temperatures at the 3 markers across the thermal image were 29.3 ^{o}C in the unirrigated (red) area, 25.9 ^{o}C in the transitional (yellow) area and 23.9 ^{o}C in the irrigated (green) area.

One further interesting aspect to the surface temperature assessment was the difference in surface temperature of a bitumen road compared to the bare earth on the side of the road and in the unirrigated area (see Figure 10).

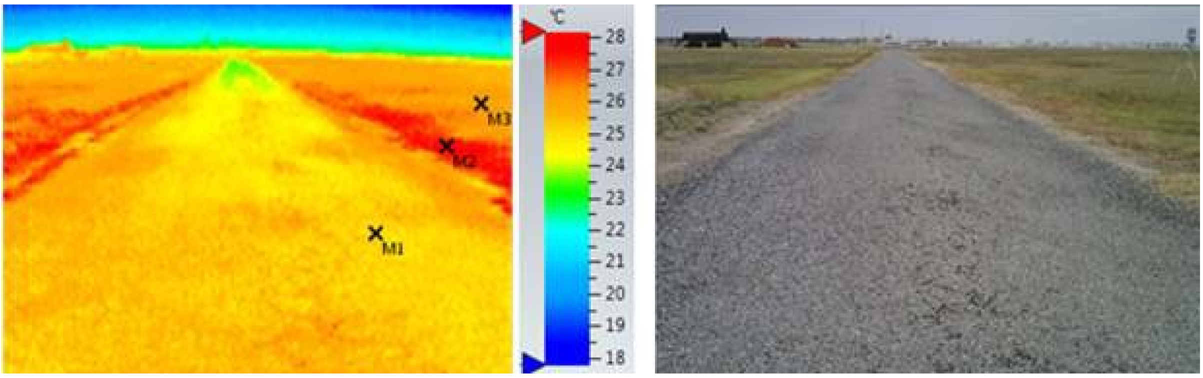

Figure 10. Showing the temperature difference across the road, bare earth and unirrigated area

It is interesting to note the temperature difference between the road, the bare earth and the unirrigated area. The road is actually 3 ^{o}C cooler than the bare earth. Airports have large areas of bitumen, albiet mostly darker than the road used in this image, however it is a good comparison with the potential heat generated from the bare earth.

3. DISCUSSION

The initial results of the study show irrigation of open space results in a consistent and significant reduction in air temperature. The overall average temperature difference of 2.4 ^{o}C is less than original estimates however the relatively high number of days where this difference exceeds 3 ^{o}C is encouraging. A number of similar studies (Lobell and Bonfils, 2008, Lobell *et al*, 2008, Sproken-Smith *et al*, 1999, Zhu, 2012, Mahmood *et al*, 2013), including large scale investigations of regional air temperature reduction achieved through irrigation, achieved comparable results. These studies also found little correlation between the difference in daily maximum temperatures and the extent of the cooling effect from irrigation, with the results being around 2 to 4 ^{o}C each day, regardless of the maximum temperature of that day (Lobell *et al*, 2008). It is assumed that this is a function of achieving the maximum evaporation-influenced cooling and also reaching the maximum cooling that can be achieved through transpiration (as a function of plant physiology).

Further investigation is planned on the influence that the unirrigated open space (containing minimal vegetative cover) has on both the temperature difference that was recorded in the irrigation area and also the persistence of the cooler air when moving beyond the boundary of the irrigation area. To assess this, in the second season of the trial the number of temperature sensors around the boundary of the irrigation area and in linear transects moving away from the irrigation area into the non-irrigated space will be increased. This will provide a finer resolution of the interaction of both the cooler air from the irrigation area and the warmer air from the non-irrigated areas.

A quantitative assessment of the financial and non-financial benefits will be conducted once the experimental field work phase is completed in 2017. Indicatively these benefits include the energy reductions that can be achieved in the cooling towers in the airport passenger terminal, and also the fuel savings that can be achieved during aeroplane take-off due to the cooler, denser air. There are many factors that influence both these potential benefits, including the change in humidity as a function of irrigation, and the vertical extent and persistence of the irrigation-induced cooler air temperature. Further data will be obtained during the second season of this trial to enable greater quantification and hence more accurate assessment of the financial benefits related to energy and fuel savings.

3.1. Other benefits

The additional benefits that were also investigated during this first assessment of data are discussed below. This is the preliminary assessment with further data and analysis to occur during and after the second season of monitoring.

3.1.1. Aesthetics

It is clear from the images presented above that the application of irrigation water has vastly improved the aesthetics of the irrigated area during summer months when compared to the unirrigated areas. Adelaide has a Mediterranean climate with a very long dry warm periods extending from October through to April, inclusive. During the majority of time this trial was underway the unirrigated areas were brown with little vegetation remaining continuous green. The actual idea for this trial was borne out of the visual realisation that there is very little green in the landscape along the flight path between Melbourne to Adelaide during the dry months, and the thought that it would be aesthetically pleasing to descend into an airport that was a green oasis after traveling over the arid landscapes that exist in all directions from Adelaide airport. It was also hypothesised that this improved aesthetics for the “gateway to South Australia” could actually boost tourism. This would be difficult to quantify and as such is considered to be a non-financial and potentially intangible benefit if irrigation was expanded to encompass the entire airside area.

Figure 11 shows the airport during winter (left image) when rainfall influences vegetation growth, and in mid-autumn (right image) with the irrigation area clearly visible on the right image.

Figure 11. An aerial view of the airport (winter and summer), with the irrigation area indicated by the red arrow.

3.1.2. Erosion

One of the concerns related to the impacts of climate change is the increased intensity of summer rainfall events. The lack of vegetation around the airport could increase the likelihood of erosion during these summer storm events, which in turn leaves areas more vulnerable to further erosion from rainfall, wind and aircraft movement. The generation of airborne dust around an airport during high wind events is a risk for visibility and also for jet engines of the aircraft. It is clear from the irrigation area that the risk of erosion is minimal due to the extent of vegetative cover of the ground surface. This is another non-financial benefit of irrigating the entire airside area of the airport.

3.1.3. Vegetation trial

Whilst the vegetation trial is a separate component of this overall trial, some aspects of the vegetation trial are discussed to enable a general understanding of this component. Five different species were chosen as each contained one or more attributes that were attractive to the airport operators (AAL). These attributes included lack of bird attraction, good ground coverage, low maintenance and existing presence on the airport land. Two control areas were also established, one within and one just outside of the irrigation area to determine what species will grow without any type of intervention, and what will grow with the only treatment being the application of water. The vegetation was planted at the end of the study period and will be fully established during the second season of the trial. Surveys of bird activity and vegetation growth are undertaken regularly to provide a wide scope of information to enable the preferred species to be propagated if irrigation is expanded to the entire airside area in the future.

3.1.4. Crop production

One of the issues commonly raised when discussing the benefits of irrigating open space to improve the aesthetics and greenness of an area is the additional costs incurred by the land owner/operator due to the increased maintenance, namely increased mowing and weed control. To address this issue the project team decided to include a primary production crop in the vegetation trial component of this trial. Lucerne was chosen due to its characteristics such as a lack of seed head, thick vegetative growth, profitability (from the sale of lucerne hay) and it is not known to attract birds. The growth and response of lucerne in the vegetation trial will be closely monitored to enable quantification of the potential benefits of this crop, including the financial returns that could be made with full crop production across the airport. In a true circular economy sense, it is suggested that the profits from the sale of the lucerne could potentially be used to pay for the water that is required for the irrigation, with the water utility gaining a benefit through the sale of non-potable water and the airport gaining a benefit from the improved aesthetics, reduced erosion risk and reduced energy use (in passenger terminal cooling towers) and aeroplane fuel usage. Further, if this method was employed in other airports, particularly those in developing countries, crops for human and or animal consumption may be able to be grown in the airside buffer land, making full use of the buffer land to provide a benefit to the community whilst also providing all the other benefits to the airport operators and water provider.

3.1.5. Bird risk reduction

As mentioned, bird surveys have been conducted across the trial site including the irrigated and unirrigated areas. This is being compared to historical bird survey data to determine if certain species, or certain activities, or just the application of water impacts on the abundance of bird species, particularly those that pose the greatest risk to aircraft. From visual observations taken during site visits (not as part of the official bird surveys), the bird activity in the irrigation area decreased as the abundance of vegetation increased. This is in line with numerous publications on reducing bird strike risk through increasing the height and density of ground vegetation as this reduces the unimpeded view of foraging bird species on the ground, and also interferes with the ability of the bird to flap its wings for a quick response to a potential predator species (DeVault et al, 2013)

4. CONCLUSION

There are a number of benefits that can be realised from irrigating a large open space which highlight the wide scope of this type of intervention. The results of the first season of the trial are strongly encouraging with a consistent temperature difference observed between the irrigated and unirrigated areas of the trial site. While the overall average temperature difference was a modest 2.4 ^{o}C, on warm to hot days this temperature difference tended to be larger and could have a significant influence on the operation of the airport if the entire airside land was irrigated. It is also expected that full expansion of the irrigation area across the airside land would be likely to achieve a greater reduction in air temperature as the influence from the current warm unirrigated areas would be removed. In the second season of the trial the effects of irrigation on temperature will be further investigated in greater detail. The results will inform a quantitative assessment of the financial benefits and formulate a case study that can be used as a guide for other airports both national and international.

5. ACKNOWLEDGEMENTS

I would like to acknowledge the input of resources and support from both SA Water and Adelaide Airport Limited. Without this support the trial would not have got off the ground. Significant investment was made by both organizations. Thank you to my manager and my CEO, who both have shown support for my “fringe” ideas, and also staff from AAL and from Cooe, all of whom made the operation of this trial possible. I would also like to acknowledge the contributions from equipment suppliers such as Monsoon Irrigation and Sentek who provided significant after sales service to ensure that the equipment was calibrated for this unique application.

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