Adelaide Airport irrigation project

Financial and economic analysis

Prepared for:
SA Water Corporation

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MWH now part of Stantec

Revision	Description	Author		Quality Check		Independent Review	
0.1	TOC and data requirements	Elsie Mann					
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1.0	Final version addressing client review comments	Barrie Griffiths Dean Lanyon		Elsie Mann			

Table of Contents

LIST OF TABLES

LIST OF FIGURES

1. Introduction

SA Water and Adelaide Airport Limited (AAL) have undertaken a trial to test the potential for heat mitigation through irrigation at Adelaide International Airport. The trial, which has been running for two summer periods, has demonstrated the potential for irrigation to reduce air temperatures. If applied to the maximum possible extent across the airside area, the reduced air temperatures and potential to grow and harvest a saleable crop are anticipated to have numerous flow on benefits which are both direct (to the airport) and indirect (to airlines operating at the airport, employees and visitors).

SA Water has engaged MWH, now part of Stantec, to undertake a high-level financial and broader economic analysis related to the theoretical expansion of the trial to cover the approximately 200 hectare area available for irrigation and harvesting of lucerne at the airport.

This analysis is intended to support SA Water and Adelaide Airport Limited (AAL) in their decision on whether to invest in the expansion of the irrigated area. It is acknowledged that the analysis undertaken involves numerous assumptions. These assumptions are clearly outlined in the sections below. The overall objective of the assessment is to provide an indication of the order of magnitude of costs and benefits that might arise from an expansion of the irrigation activities. It is expected that further, more detailed data gathering, analysis and research will be required to develop a formal business case for the proposed project.

It is acknowledged that the trial being undertaken by SA Water and AAL is unique, and has potential broader applications to other settings such as public open space and other commercial facilities.

2. Base Case and Future Option

To properly quantify the benefits associated with a project of this nature, it is important to understand the base case, and the future options, to ensure that the change resulting from the future options can be clearly defined. To this end, this section summarises our understanding of the base case and future options based on discussions with SA Water and AAL staff.

2.1. Base Case

The base case assumes:

- No irrigation of the airside area
- Site management required to comply with aviation safety regulations and reduce the risk of bird strike (weed and vegetation management)

2.2. Future Option

The future option includes:

- Installation of irrigation system to cover approximately 200 Ha of airside area.
- Supply of Class B water from Glenelg Wastewater Treatment Plant.
- Growth and harvesting of lucerne on the irrigated area.

Key assumptions for the financial analysis agreed with SA Water and AAL at the start of the project include the following:

- Approximately 200 Ha is available for irrigation and crop production, excluding those areas that are inaccessible, e.g. proximate to the runways or slated for development in the near term.
- Existing vegetation management staff can be trained to undertake the lucerne management and harvesting. Lucerne harvest management that minimises the non-irrigation period during lucerne drying should be considered.
- All crop management and harvesting activities that may increase bird activity to occur during flight curfew hours.
- Water is supplied to AAL irrigation system at the appropriate flow rate and pressure (cost to SA Water to provide this is not in the scope of the analysis but is assumed to be accounted for in the cost of water).
- The irrigation system will consist of a mix of lateral move irrigators, overheads and pop-up sprinklers as required to suit proximity to runways
- Irrigation is most likely to occur from November to March each year but will largely be driven by climate conditions with the expected annual application rate of 6-7 ML/ha

2.3. Financial and Economic cost and benefits considered

Both the financial and economic analyses have been carried out for the future option compared to the base case. The financial analysis included both costs and revenue for the crop growing proposal. The economic analysis included both a qualitative and quantitative assessment for the benefits gained. The quantitative assessment was restricted to those benefits most likely to flow from the expected temperature reduction due to the irrigation and crop growing proposal.

Table 1 summarises the main considerations of the financial and economic assessments carried out for both the base case and future option.

Table 1: Financial and Economic considerations

Option	Financial	Economic - Quantified	Economic - Qualified
Base case	Cost of current airfield management to aviation safety standards and to minimise bird strike	Not assessed independently. The base case informs assessment of the change resulting from the future option	
Future option	Cost of growing lucerne (establishment, recycled water, harvesting etc.) vs sale value of lucerne.	Potential airline benefit due to reduction in temperature	Environmental e.g. soil erosion, air quality Social e.g. airside comfort for workers, use of recycled water Cooling towers

3. Financial Analysis

The financial analysis focuses on tangible costs and benefits, including capital, operations and maintenance costs, as well as any direct and indirect revenue/benefit resulting from the future option compared to the base case. The financial analysis focuses on the tangible costs and benefits derived from the management and use of the airside (no public access) land surrounding the built environment and defined aeroplane traffic pathways. Less than half of the airside area is maintained by Adelaide Airport limited (AAL) to limit weed infestation, vegetation growth (height) and bird activity. The remainder is essentially unmanaged with the exception of mowing (to conform to aviation safety regulations). A possible future option is to convert part of the airside area to irrigated lucerne production. Description and assumptions associated with the base case and future option are outlined in the following section. Please refer to Appendix B for the full financial analysis.

Development of an investment proposal in line with Treasury Instruction 17[1] comparing multiple future options is beyond the scope of this engagement and is not the outcome of this analysis. For the purpose of this report the net present value (NPV) has been determined over 25 years using a discount rate of 5.06% as provided by SA Water. Any financial benefit from depreciation of capital equipment has been based on a diminishing value at a rate set by the Australian Tax Office[2] at a company tax rate of 30%.

3.1. Base Case

The base case refers to the current management of the land surrounding the built environment and defined movement areas totalling 421 hectares (Appendix A). Costs associated with the base case relate to labour, capital costs for equipment and operating costs. An indirect benefit is associated with the depreciation of the capital equipment.

Labour

According to AAL[3] the management of the airside area requires a full FTE at a total cost of $120,000 annually including on-costs.

Capital costs

Capital equipment required is associated with mowing and herbicide/pesticide spraying for weed and insect control. It is assumed that both the mowing and spraying is undertaken using a 66 kW tractor with a 57 kW power take-off (PTO) that is capable of supporting a three point linkage slasher and boom spray. The capital cost of these items is assumed to be $35,000 for the tractor, $10,000 for the slasher, and $7,000 for the boom spray. All equipment

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[1] Department of Treasury and Finance 2014, *Best practice guidelines for assessment of public sector initiatives*, Government of South Australia

[2] https://www.ato.gov.au/Forms/Guide-to-depreciating-assets-2016/

[3] email Stephanie Bolt AAL 23/06/2017

is depreciated on a 10% diminishing value. For the purpose of this financial analysis all capital equipment is assumed to be purchased in year 1.

Operating costs

To manage weed growth and insect activity it is assumed there will be a total of four operations per year across the entire 421 hectares for herbicide/pesticide spraying (two per year) and mowing (two per year). Spraying is assumed to apply 1.2 L of herbicide/pesticide per hectare at a cost of $12/L. Each mowing and spray operation is assumed to cost $2.99/ha, which includes costs associated with fuel, filters, oil, tyres, batteries and maintenance of the tractor. These values have been selected based on a review of several publically available agricultural operational budgeting sheets.

3.2. Future Option

The future option refers to the use of some of the land area for irrigated lucerne production using class B recycled water supplied by SA water. Allowing for required setbacks from the defined movement areas and built environment, a total area of 187 hectares could be used for irrigated lucerne production (Appendix A). Costs associated with irrigated lucerne production relate to labour, capital infrastructure costs for irrigation and crop management, harvesting and operation costs. A further cost is associated with the maintenance of the area not under irrigated lucerne production as in the base case.

Unlike the base case there is the direct benefit from the sale of the lucerne hay as well as the indirect benefit associated with the depreciation of the capital equipment and irrigation infrastructure.

Labour

It is assumed that the labour requirement to maintain the airside area and manage the irrigation and contractors for the irrigated lucerne area will increase to 1.25 FTE at a total cost of $150,000 annually including on-costs. It is assumed that this 25% increase in labour cost will cover additional tasks to monitor and manage wildlife hazards.

Capital and infrastructure costs

Capital equipment required is associated with the mowing and herbicide/pesticide spraying as with the base case. No additional capital equipment will be required for the irrigated lucerne as it is assumed that contractors will be used for all necessary operations (see Operating and maintenance costs). There will be a requirement for irrigation infrastructure. It is assumed that the recycled water will be supplied at the required pressure to the property boundary of the Adelaide Airport. Whilst the method of irrigation has not been designed it is expected to involve a combination of methods including lateral move and fixed sprinklers. Given the potential for access restrictions and tunnelling requirements the cost per hectare is assumed to be on the higher end of irrigation installations costs. Hence, irrigation design and installation for 187 hectares is assumed to cost $2.448 million, or approximate $13,000/ha.

All equipment and infrastructure is depreciated on a 10% and 20% diminishing value, respectively.

Operating and maintenance costs

Operating costs associated with maintaining the airside areas not under lucerne production is assumed to be the same as the base case despite the smaller managed area of 245 ha.

Operating costs associated with the production of irrigated lucerne across the 187 ha include the following:

- Lucerne establishment;
- Herbicide and pesticide application;
- Fertiliser application;
- Harvesting and transporting baled lucerne;
- Recycled water supply; and,
- Soil testing.

It is assumed that activities associated with crop establishment, fertiliser and pesticide applications, harvesting and transport will be conducted using a contractor. The cost of lucerne establishment is based on the work of Lattimore (2008) and is estimated to be $272/ha. It is expected that the lucerne crop will need to be re-established, on average, every six years. Contractor rates for lucerne harvesting and transport were provided by SA Water[4]. Mowing and raking were set at $85/ha/cut with baling and transport set at $65/t. The annual application of fertiliser and pesticides were also set at $55/ha for contractor spreading. It is assumed that these contractor rates are applicable when site access is restricted to curfew hours.

The annual cost of fertiliser to maintain crop nutrient balance was a function of crop yield with application varying between 200 and 400 kg/ha at a cost of $315/t for low and high yielding lucerne, respectively. Herbicide and pesticide annual costs were provided by SA Water and set at $116/ha. It was also assumed that no gypsum was applied to counter the potential sodicity development caused by the recycled water with an average sodium adsorption ratio of 6.9. If annual application of gypsum is required this would be an additional cost of $70/ha inclusive of contract spreading.

The amount of recycled water used was also a function of lucerne yield. It is assumed that the cost of the supply of suitably pressurised recycled water to the boundary of the Adelaide airport by SA Water will cost $200/ML. It is expected that the lucerne crop will yield an average of 19 t/ha with a potential range between 15 and 25 t/ha. No soil assessment has been undertaken to gauge the yield potential of the site.

The application of recycled water requires the testing of the soil chemistry to monitor and manage any deterioration in soil conditions that might impact crop production. An allocation of $4,000 has been allocated annually for the sampling and testing of soil samples. No account has been made for any amelioration activities as a result of these tests such as the application of gypsum to combat potential sodification of the soil.

Maintenance of the irrigation infrastructure is assumed to be 2% of capital cost annually.

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[4] email Greg Ingleton SA Water 21/06/2017

Revenue

The price received for the baled lucerne can vary between $200 and $350/t depending on market conditions. For the purpose of this assessment it has been assumed that the average sale price for the lucerne is $275/t with an average yield of 19 t/ha. Yield during lucerne re-establishment is set at 70% of the expected yield (Moot, et al., 2012).

Given that there is a risk associated with lucerne yield estimates, this financial analysis assesses three yield scenarios of 16, 19, and 22 t/ha representing low, medium and high yield forecasts, respectively. For the low, medium and high yields the annual irrigation application rates were 5.4, 6.4 and 7.4 ML/ha, respectively (Appendix C). The corresponding number of cuts per year were 5, 6 and 7 for the low, medium and high yield.

3.3. Financial analysis outcomes

Based on the default assumptions outlined in sections 3.1 and 3.2 the introduction of lucerne production to 187 ha provides a financial advantage over the current management practice (base case). The NPV over a 25 year period shows at least a $1 million advantage relative to the NPV of the base case (Table 2). The likely outcome of lucerne production is a little under $1.8 million benefit to AAL. Whilst there is a significant upfront expenditure due the installation of irrigation infrastructure this cost is expected to be neutral after 9 years compared to the on-going cost associated with current management but could vary between 7 and 12 years, depending on yield outcomes (Figure 1).

Table 2: Impact of lucerne production on NPV ($'000) over 25 years compared to the base case (current management)

Yield	NPV	Relative NPV
Base case	-$1,961	$0
16 t/ha	-$945	$1,016
19 t/ha	-$163	$1,798
22 t/ha	$620	$2,581

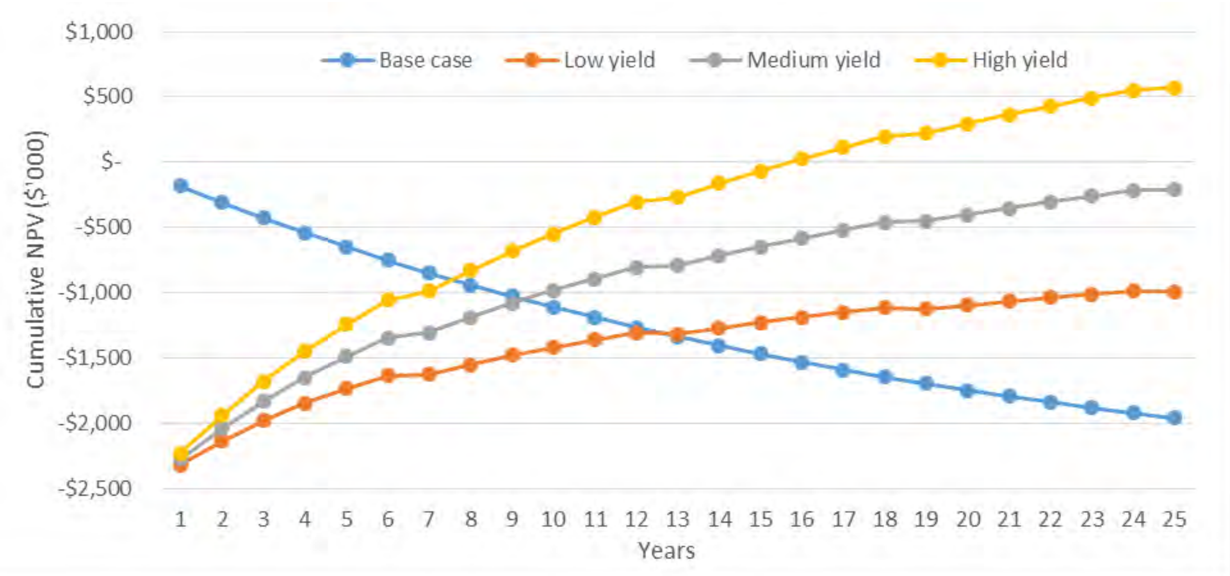

Figure 1: Time series comparison of NPV ($'000) over 25 years between the base case (no change) and the introduction of lucerne production for three yield levels

3.4. Sensitivity analysis

Impact of lucerne sale price

Lucerne sale price can vary markedly and is dependent on seasonal conditions and market demand. As shown in Figure 2 the benefit of lucerne production is quickly eroded when the sale price for lucerne falls below $250/t. Conversely, the benefit of lucerne production escalates for lucerne prices above $275/t. This sensitivity to sale price is expected given that the revenue stream is dominated by the sale price for the lucerne. AAL would need to consider long term contracts at a set sale price to help maintain a stable benefit from lucerne production. The cost of a sales agent or time required to negotiate lucerne sales have not been included in this assessment.

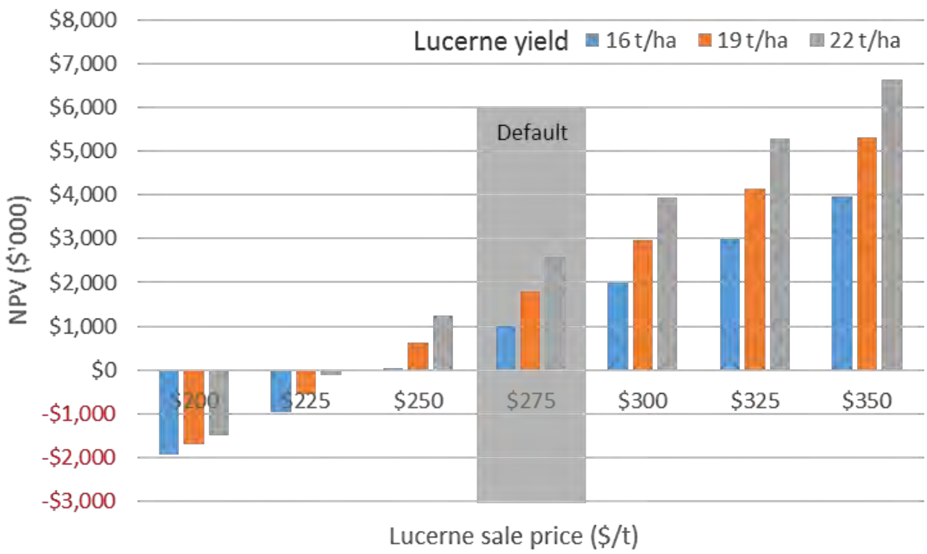

Figure 2: Sensitivity of NPV ($'000) over 25 years to changes in lucerne sale price relative to the base case

Impact of the Cost of recycled water

There is the potential for SA Water to change the sale price of the recycled water. The cost of recycled water used in agribusiness in Australia typically ranges between $300 to $500/ML, but can be as high as $2000/ML, depending on its use. However, the impact of a change in recycled water cost on the benefit of lucerne production is less pronounced compared to the impact of the sale price of the lucerne produced. The introduction of lucerne production retains a marginal benefit over the current management even with a 50% increase in the default recycled water charge expected by SA Water (Figure 3). The water costs contributes a portion of the overall operational cost of lucerne production, hence, the reason why the lower sensitivity compared to the lucerne sale price.

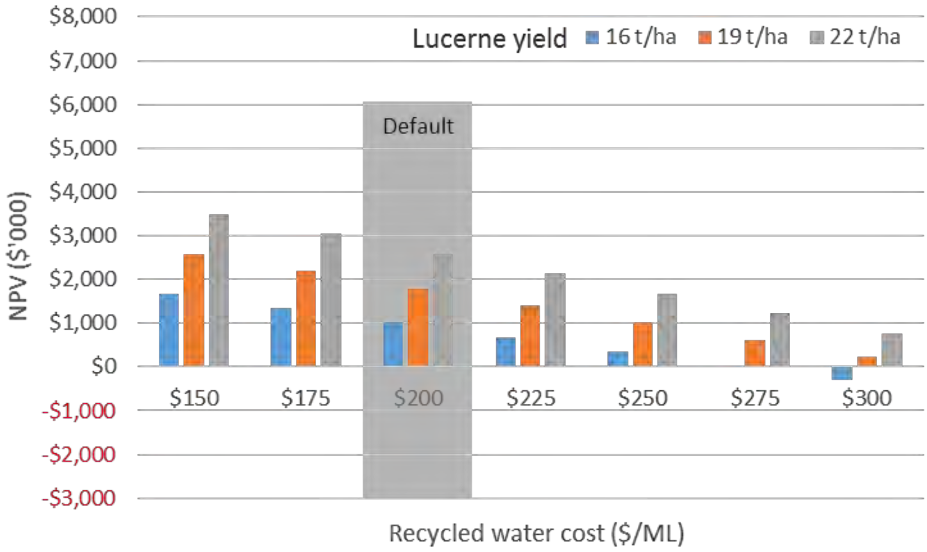

Figure 3: Sensitivity of NPV ($'000) over 25 years to changes in recycled water cost ($/ML) relative to the base case

Impact of discount rate

The high upfront cost of the irrigation infrastructure can result in a high sensitivity to the discount rate applied. For this assessment the discount rate has assumed to be 5.06%. The potential range of discount rates would be expected to be no greater than 2% either side of the assumed rate. The impact of this range in discount rates on NPV is summarised in Table 3. For all scenarios the introduction of lucerne production remains beneficial compared to the current management practice (base case). For the expected lucerne yield the benefits range between $1.3 to $2.8 million for the 25 year assessment period.

Table 3: Sensitivity of NPV ($'000) over 25 years to changes in discount rate relative to the base case

Yield	3.06%	5.06%	7.06%
16 t/ha	$1,676	$1,016	$533
19 t/ha	$2,642	$1,798	$1,179
22 t/ha	$3,610	$2,581	$1,827

Recovery of infrastructure costs from third parties

There is the potential to recover the cost of the irrigation infrastructure development from third parties based on the economic benefits associated with irrigated lucerne (see section 4). Whilst the upfront cost of the irrigation infrastructure might be accommodated by AAL, third parties can be charge annually for the associated benefits. For this assessment it is assumed that the full irrigation infrastructure cost is recouped from third parties based on an annual fixed charge for 25 years.

The benefits of lucerne production under a infrastructure cost recovery scenario is significant with the expected lucerne yield showing a NPV benefit of $3.3 million over 25 years compared to the current management (base case). This compares to $1.9 million without infrastructure cost recovery.

Table 4: NPV ($'000) to changes in discount rate relative to the base case

Yield	NPV	Relative NPV
Base case	-$1,961	$0
16 t/ha	$427	$2,388
19 t/ha	$1,208	$3,169
22 t/ha	$1,992	$3,953

4. Economic Analysis

The economic analysis has identified, and where possible quantified, indirect economic impacts that might accrue to airport customers, operators and businesses that use the airport, from the proposed future option outlined in Section 2. While the financial analysis has assessed the direct benefits of the lucerne production and harvesting, the economic analysis has focussed on the potential benefits that flow from a reduction in air temperatures due to irrigation and crop growth. Lucerne is known as a high water use crop, with corresponding high evapotranspiration rates and hence has a higher potential to contribute to temperature reduction compared to other crops or ground cover.

4.1. Irrigation trial outcomes

The trial undertaken by SA Water and AAL has demonstrated the potential for irrigation to reduce air temperatures. Figure 4 shows the frequency of measured reduction of air temperature between irrigated and non-irrigated areas during the first summer irrigation period of January to April 2016. Whilst the average air temperature difference between irrigated and non-irrigated areas for the airport trial was 2.4 degrees Celsius, there were many hotter days when the temperature differential exceeded 3 degrees.

During the first year of the trial (from where this data was generated) the majority of the irrigation area did not have a good cover of vegetation, due to continuous spraying and site preparation of 75% of the trial area. It is assumed that this temperature differential would have been more significant for more days over the trial area had lush vegetation cover been established.

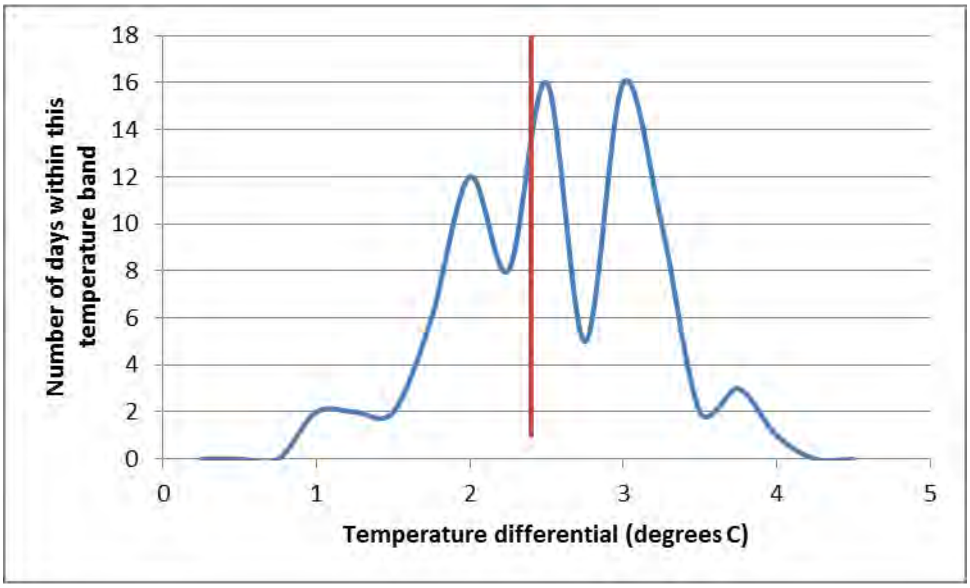

Figure 4: Temperature Differential January 2016 to April 2016

Data for the second irrigation trial period (summer 2016/17) was not available to be included at the time of writing this report. A number of studies around the world have shown that irrigation will reduce average air temperatures by over 3 degrees Celsius and reduce air temperature by more than 4 degrees of the maximum daily temperature in some studies (Lobell & Bonfils, 2008) (Lobell, et al., 2008) (Sproken-Smith, et al., 2000) (Zhu, 2012) (Mahmood, et al., 2013).

For the purposes of the economic analysis, it has been assumed that a 4 degree air temperature reduction can be expected as a result of irrigation and growth of lucerne, and that this air temperature reduction can be expected to be translated to the runways and terminal building areas. Although this value is at the higher end of the observed data from 2015/16, as previously mentioned this data was collected when there was little to no vegetation in the irrigated area. The abovementioned literature supports the potential for higher air temperature reductions. The assumption of 4 degrees degree air temperature reduction was agreed to be suitable for this high level analysis which is primarily focused on understanding the likely magnitude of economic benefits.

4.2. Economic assessment process

The economic analysis has been undertaken with the following steps:

- Define base case and future option
- Identify impacts and their associated costs/benefits
- Qualitative description/screening of costs and benefits
- Quantification of significant costs and benefits
- Valuation of costs and benefits
- Aggregation of results

The definition of the base case and future option is outlined in Section 2. The following sections summarise the outcomes of the remaining steps of the economic analysis.

A more detailed presentation of the economic analysis is contained in Appendix D.

4.3. Impact assessment

The following potential benefits were identified by SA Water and AAL at the start of the project:

- Cost benefit as a result of reduced air temperature for cooling towers at the terminal building
- Aircraft fuel savings due to reduced air temperature on and above the runway on take off
- Additional savings for the airport or airline operators (possibly through payload increases, reduced air-conditioning demand)
- Revenue from crop generation
- Improved visual amenity
- Thermal comfort for airside workers
- Reduced air temperature for surrounding residents

A brainstorming exercise was undertaken to identify additional impacts (both positive and negative) to include in the economic assessment. Combining these efforts, a list of expected impacts associated with the proposed future option compared to the base case have been identified and are presented in Table 5, summarised under the three broad categories of Economic, Environmental, and Social benefits.

Qualitative assessment of identified impacts

The benefits in terms of revenue from crop generation is addressed through the financial analysis. The assessment of benefits related to the air conditioning systems has been reviewed by the project team, and is discussed further below.

To assist with the assessment of impacts and associated benefits for airline operators, SA Water engaged Aviation Projects to identify, quantify and determine the likely monetary value of these benefits. The outcomes of Aviation Projects' assessment has informed the selection of benefits which have been quantified as part of the overall economic assessment.

It should be noted that this assessment has not included a range of green space benefits that could be considered (e.g. enhanced property values, improved amenity, improved mental health, etc.). Much of the data regarding the benefits of green space relate to space which is accessible to be used for recreation, or which is in close proximity to offices and homes. The study area being considered in this assessment is not accessible to the public, and is surrounded by major traffic corridors. As such, the benefits typical identified with development of green space are not expected to be significant in this case.

Table 5: Benefits Analysis of Irrigation at Adelaide Airport

Item	Measure	Likely Impact	Comments	Quantified Yes/No
Economic (due to temperature change)	Auxillary Power Unit	High	Reduction in fuel consumption as a result of less time running the APU.	**Yes,** dependent on compliance with standard operating procedures (SOPs)
	Engine de-rate	Low	Engine overhaul costs delayed due to reduction in engine RPM. Will vary across individual airlines.	**No**. Benefits expected, but data specific to each airline and difficult to quantify.
	Reduction in fuel flow at take off	Med	Less fuel used during take-off during 10 minute take-off thrust. This is fairly consistent for most temperature ranges.	**Yes**
	Tyres and Brakes	Low	Reduction in landing distance leading to reduced breaking requirements and more time between replacements.	**No.** Cost benefits expected, but data specific to each airline, difficult to quantify.
	Payload and Range	High	Only quantified potential fuel savings. Alternative of increase in payload likely to have greater effect but information not available to determine the value of this benefit.	**Yes**, considering extra range only which is assumed to translate to fuel savings
Environmental	Soil Erosion	Low	Reduced with benefit of minimising dust (aircraft safety)	**No**
	Flooding	Low	Minor increase in risk of flooding due to soil saturation.	**No**
	Soil quality	Negligible	Expect to improve over time but not significant.	**No**
	Air quality	Negligible	Some potential improvement in local air quality as a result of additional planting but not significant considering distance to local residents	**No**
	Water quality	Negligible	Reduced sediment but increase in nutrients. Overall neutral effect.	**No**

Item	Measure	Likely Impact	Comments	Quantified Yes/No
Social	Airside comfort	Low	Potential temperature reduction means increase airside worker comfort. (Reduction at crop site may not be fully translated to airside worker comfort but still a positive)	**No**
	Harvesting at airport	Low	Opportunity to apply to other airports. Reputational benefit for both AAL and SA Water.	**No**
	Use of recycled water	Low	Use of recycled water from Glenelg WWTP.	**No** but part of the financial assessment
	Harvesting/Site Management	Low	Increased complexity compared to current site management of weeds and grass cutting only. Need for specialised contractors assumed with restricted access times and security clearances.	**No** but part of the financial assessment
	Noise & disruption	Low	Some nuisance for harvesting operation at night time every 2 months (min 2 nights)	**No**

Note: please refer to the report from Aviation Projects (Appendix E) for more detail on the benefits accruing to airline operators.

Air conditioning system impact assessment

SA Water and AAL had identified a possible benefit of reduced air temperature would be a reduction in energy consumption for the airport terminal cooling system.

Energy consumption for the airport terminal cooling system is made up of three key elements:

- Cooling tower fans
- Circulation pumps
- Chillers

Based on data provided by AAL, the estimated annual energy consumption and associated cost of each of these components of the cooling system is shown in Table 6. Please refer to Appendix F for the full calculations.

Table 6: Estimated energy consumption and running costs for the air-conditioning system

Appliance (count)	Annual energy usage kWh/yr	Annual cost ($)
Cooling Tower Fans (3)	218,453	$34,275
Pumps (11)	1,510,790	$237,043
Chillers (3)	4,500,122	$706,069
Total	**6,229,364**	**$977,387**

Key assumptions:

- Terminal 1 open from 4am - 11pm
- Total floor space 70,000 m2
- Estimated electricity tariff: 15.7 c/kWh
- VSDs installed on all fans / pumps

The focus of this analysis is to quantify energy savings that could be expected as a result of a reduction in air temperature external to the building. There was an expectation that a 4 degree drop in external temperature resulting from the crop irrigation, and associated evapotranspiration, would have benefits for the cooling system.

A reduction in external temperatures could be expected to reduce the overall load on the cooling system (i.e. may reduce run time of fans and pumps). However the magnitude of this energy saving is difficult to quantify, would require a number of assumptions, and is likely to be offset by other system parameters.

It can be seen from Table 6 that the chillers represent the main component of energy consumption for the overall system. The major driver of chiller efficiency is the wet bulb temperature. Any drop in the air temperature due to the effects of evapotranspiration from irrigation would lead to a proportional increase in the humidity of the air. The likely net result would be that the wet bulb temperature would not significantly alter. This would mean that the power requirement to run the chillers would also not change.

To understand the potential order of magnitude cost benefit that would result from a reduction in wet bulb temperature, an assessment has been undertaken assuming a four degree air temperature reduction resulting in a 3.2 degree reduction in wet bulb temperature, with humidity staying constant at 50%. In this scenario, the energy savings would be 144,000 kWh over the 6 month irrigation period. This would result in a total saving in the order of $22,500 per year based on an electricity tariff of 15.7 c/kWh. Given that this reduction in wet bulb temperature is not expected to result from irrigation activities, this saving has not been included in the final benefit summary.[5]

4.4. Quantitative assessment of impacts

The potential impacts that would result from the expected temperature reduction of four degrees (due to the irrigation and production of lucerne) identified in Table 5 have been quantified in terms of the resulting benefit and the monetary value of each benefit. There were only three areas that were identified as being suitable for this type of assessment based on the information provided by Aviation Projects (see Appendix E for more details). These areas were:

- Savings in the fuel costs and maintenance of the auxiliary power unit
- Fuel savings due to reduced air temperature on and above the runway on take off
- Fuel savings due to reduced air temperature in the range of the aircraft.

The key assumptions of this quantitative assessment were:

- A four degree drop in temperature translated to all areas.
- The potential airline operator cost benefits used were based on those provided by Aviation Projects in their report 7 August 2017.
- Appropriate Standard Operating Procedures (SOPs) to be in place.

The potential estimated cost benefits are contained in Table 7 below. This quantitative assessment shows that there are total potential benefits to the airlines of over $1,000,000 each year.

[5] There are opportunities for energy and water consumption savings through measures such as upgrades to monitoring and control systems, or changes to operational parameters (thermostat settings). These energy and water savings do not a result from air temperature reduction from irrigation, and hence have not been included in the benefits summary presented. This information can be viewed in Appendix F.

Table 7: Quantitative assessment of impact of 4 degree[1] Celsius air temperature decrease

Item	Quantity p.a.	Unit value	Benefit p.a. $ '000s [3]	NPV at 5.06% $ '000s
Auxiliary Power Unit - Reduction in fuel consumption and maintenance	5,086 flight [2]	$69 per flight	$351	$4,916
Reduction in fuel at take off - Reduction in fuel consumption	169,430 litres of fuel	$0.50 per litre	$85	$1,186
Increase in range of aircraft - Reduction in fuel consumption	1,793,590 litres of fuel	$0.50 per litre	$897	$12,563
Total			**$1,333**	**$18,667**

[1] Analysis based on ambient temperatures at Adelaide Airport for the period 01 Jan 1985 to 25 Jan 2013.

[2] Number of aircraft movements per annum was based on current data supplied to Aviation Projects by AAL and contained in Aviation Projects' Report (Appendix E). Future increase or decrease in movements per annum has not been accounted for in the NPV calculation.

[3] Detailed breakdown of calculations are contained in Appendix D Economics Benefit Analysis.

It should be noted that all the estimated cost benefits presented in Table 7 represent the maximum potential. It should also be noted that for ease of analysis and understanding only B737 (narrow body domestic flights) have been assessed. However this type of aircraft represent 94% of the total aircraft movements and approximately 85% of the costs.

Figure 5 below shows a graphical representation of the proportion of the total potential cost benefits. This shows that the savings in fuel due decrease APU burn, taxi, landing and reserve fuel at lower temperatures represents nearly 70% of the total potential benefits.

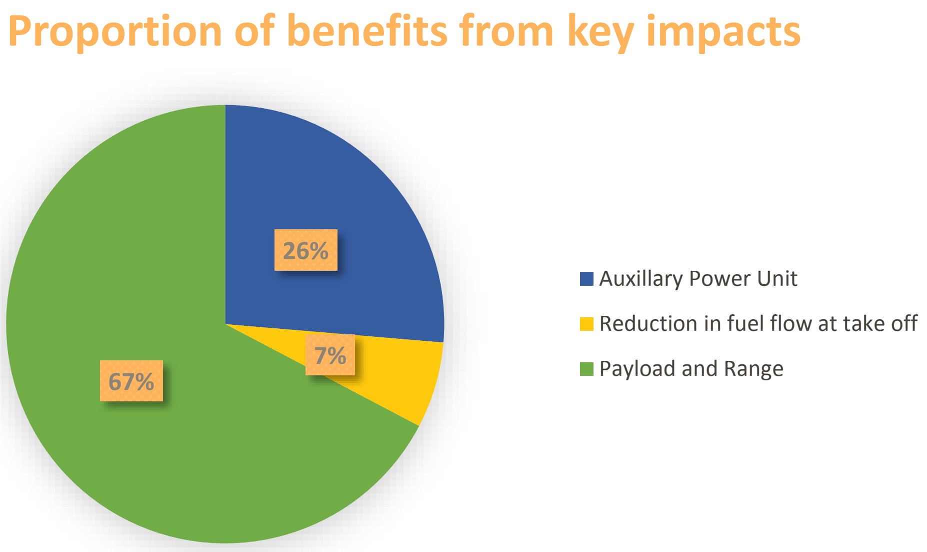

Figure 5: Proportion of quantified benefits

4.5. Sensitivity to key assumptions

Discount rate

The analysis has assessed sensitivity to a variation in discount rate used in the NPV calculation, using the same discount rates applied in the financial analysis (7.06% and 3.06% respectively). Over the 25 year NPV analysis period, the total cost benefit calculated ranges from $15 million to $23 million.

Sensitivity to other parameters

The benefits shown in Table 7 are the potential benefits to the airline operators due to a reduction of four degrees in the surrounding air temperature. The likelihood and magnitude of benefits would be sensitive to:

- Four degrees not being achieved at the irrigation site (reduction in potential benefit).
- The reduction in air temperature at the irrigation site not being fully translated to runway or gate in the case of the APU (reduction in potential benefit).
- SOPs not being fully adhered to for the APU (reduction in potential benefit).
- SOPs being developed to increase payload (increase in potential benefit as the average fuel saving per flight has been estimated to be $33 which could be translated to one extra passenger).

It should be noted that the potential benefit for tyres and brakes and the delay in engine de-rating have not been quantified due to the lack of reliable data. However both of these would represent additional areas of benefit to the airline operators.

5. Go/No Go Risks

As part of this study a number of go/no go risks were identified that could influence the viability of the proposed future option. These include:

1. Increased risk of bird strike
2. Increased risk of foreign object debris (but more likely a reduction in dust generation).
3. Increase fire risk during either the crop growing or harvesting phases
4. Perception that lucerne or other crops grown within the environs of the airport would not be as marketable if sold as animal fodder.

5.1. Increased risk of bird strikes

Numerous publications recommend increasing height and density of ground vegetation as a strategy to reducing bird strike risk as information indicates that 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). The Australian Airports Association state that encouraging a dense vegetation cover across airport land is a practice that has been in place in the United Kingdom since the 1960's and is now common on Australian airports, as a method to reduce the major bird strike species (Australian Airport Association, 2015). Adelaide Airport has instituted a long grass policy however, due to limited management inputs and environmental conditions its implementation across the site has had limited success.

Although the irrigation of lucerne would provide increased height and density of ground vegetation for periods of time, the sowing, growth and harvesting of lucerne has the potential to increase bird activity with exposed soil and seed, increased insect activity and access to biota possibly attracting birds during the process.

The potential increase in risk associated with bird strike would need to be further investigated and strategies for managing a potential increase in risk such as sowing or harvesting management practices, developed. This management could have a significant effect on the financial viability of the proposed lucerne production and harvesting and may lead to consideration of alternative crops such as sorghum, and alternative end uses of these crops such as biofuel generation.

5.2. Foreign object debris risk

AAL has identified that a change in foreign object debris (FOD) risk may result from this project. Further investigation of the current factors contributing to FOD risk, and the impact of the proposed future option on these factors is required. In terms of dust generation, irrigation and crop growing would likely lead to a potential benefit in terms of lowering the amount of dust generated. However during harvesting there is the potential to increase the FOD risk. Both the potential risks and benefits would need to be considered further and strategies developed for managing any potential increase in risk prior to embarking on the proposed future option.

5.3. Increased fire risk

It is thought that a well irrigated crop would not increase the fire risk compared to the existing open grassland and weeds that are currently managed in the base case. However, during lucerne harvesting the cut lucerne is left to dry for three to five days before bailing and collection. The concentration of dried lucerne hay in windrows increases the fire risk. There is also the potential for windy conditions to disperse the dried lucerne hay which can further increase the fire risk.

5.4. Marketability of crop

There may be a perception that crops grown adjacent to consistent aeroplane activity may be more contaminated than crops grown in a more rural setting. If the lucerne is sold as animal fodder this may affect the marketability of the crop and therefore its resale value.

The financial and economic assessments have not quantified the impact of these risks. AAL would need to consider these key risks and others to determine the viability of investing in the proposed future option.

6. Summary

The financial analysis shows that the 'high yield' scenario is likely to generate a profit for AAL. However, all three scenarios show that the outcome of growing irrigated lucerne will have a net financial benefit to AAL when considering the current operating costs to maintain the airside area.

The economic analysis has identified potential for indirect financial benefits from the expected reduction of the air temperature and also environmental and social benefits from the irrigation by recycled water and crop growing activity. The most significant benefits identified are those that would accrue to the airline operators. The magnitude of these likely benefits would provide justification for AAL to recover some or all of the cost of the infrastructure through a levy or similar economic instrument.

The likely outcome of lucerne production is a little under $2 million benefit to AAL over a 25 year period. If AAL is able to recover the cost of the irrigation infrastructure development from third parties, the future option is expected to be profitable under all yield scenarios. The economic assessment indicates a potential benefit to airline operators at the airport on the order of $1 million per annum.

The risks associated with increased wildlife attraction and FOD need to be considered further in a more detailed risk assessment. The process of lucerne planting, slashing and baling could be managed in a way that will not then present a new bird strike, FOD or safety risk but this could have a significant effect on the financial viability of lucerne as the proposed crop.

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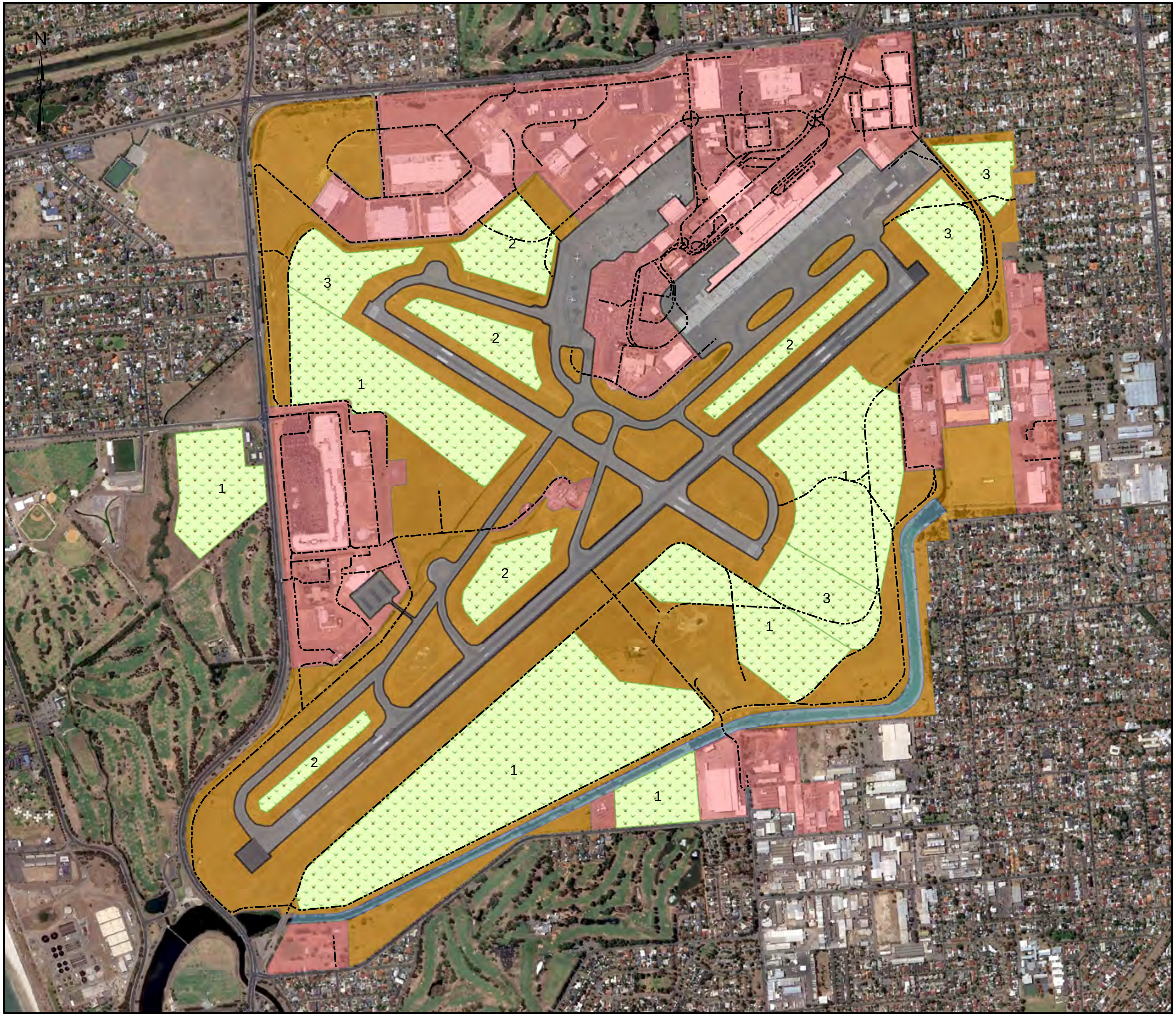
APPENDICES

Appendix A Airport land use and irrigation areas



Adelaide Airport

Landuse areas

CLIENT: SA Water

PROJECT:
83504012
Airport Economic Evaluation

DATE: 27/06/2017

DRAWN BY: DL

APPROVED BY: SL

FILE NAME:
P:\Projects\SA Water\ENGINEERING SERVICES PANEL\83504012 - Airport Economic Evaluation\40 Technical\40.11 GIS\02. Workspaces

Legend

- Airport roads
- Potential irrigation areas

Land use type

- Aeroplane traffic
- Built environs
- Managed landscape
- Waterway

0 90 180 360 540 720 Metres

1:18,000 @ A4

MWH
BUILDING A BETTER WORLD

Appendix B Financial Evaluation

Please refer to *APPENDIX B_Airport Irrigation Financial Evaluation Final*.*xlsx* for full calculation details.

Appendix C Crop Irrigation Demand

Crop irrigation demand for lucerne is determined using a daily water balance model based on climate conditions, crop evapotranspiration, and assumed soil physical conditions. The model is based on Allen et al (2006).

C.1 Climate

Climate information for Adelaide airport is required to determine crop irrigation demand. Daily rainfall, evaporation and temperature data are generally sourced from the Bureau of Meteorology (BOM) but the data is often incomplete. Complete daily weather data series are sourced from SILO[6] through a patch point query of a BOM weather station with the missing data filled using the interpolation method described by Jeffrey et al. (2001). Weather data for the Adelaide airport was obtained using weather stations 23034. Monthly climate averages over 47 years (1970-2016) are summarised in Table 8 with the annual 10th, 50th and 90th percentiles and minimum and maximum values shown in Table 9. Adelaide airport has an average annual rainfall of 446 mm and an expected annual pan evaporation of 1872. Average rainfall exceeds average pan evaporation in June only.

Table 8: Average monthly rainfall (R), pan evaporation (P) and potential evapotranspiration (ET_o) for the Adelaide Airport (1970 – 2016)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
R (mm)	19.0	17.8	23.6	35.0	49.7	58.0	59.9	50.9	46.8	37.0	23.5	24.4
P (mm)	276.9	234.0	194.8	125.7	80.5	56.6	61.6	83.8	117.7	171.2	214.3	254.6
ET_o (mm)	181.4	153.3	128.7	86.1	55.7	37.9	41.1	57.6	82.9	121.4	148.1	170.3

Table 9: The annual 10^{th}, 50^{th} and 90^{th} percentiles and minimum and maximum rainfall (R), pan evaporation (P) and potential evapotranspiration (ET_o) for Adelaide airport (1970 – 2016)

	Minimum	10^{th}	50^{th}	90^{th}	Maximum
R (mm)	234.6	325.2	441.6	580.2	730.8
P (mm)	1541.4	1708.1	1863.7	2074.2	2203.4
ET_o (mm)	1117.4	1210.3	1262.1	1333.6	1370.5

[6] https://www.longpaddock.qld.gov.au/silo/

C.2 Irrigation scheduling

It is assumed that the capacity of the irrigation systems are designed to deliver 15 mm per irrigation event. Irrigation is assumed to be initiated when part or all of the readily available water (RAW) of the soil profile has been depleted to maintain maximum transpiration rates of the crop. Soil water conditions drier than the RAW reduces the transpiration rate and growth of the crop. The depletion trigger for irrigation is known as the maximum allowable depletion (MAD). It is assumed that the MAD is equal to 15mm.

C.3 Soil water balance

The soil water balance determines the trigger of any irrigation event. This is calculated over the monitoring depth for irrigation. The target soil profile depth over which irrigation is managed is assumed to be 500mm depth. Since there is no soil information the soil profile is assumed to have a bulk density of 1.45 g/cc, drainable porosity of 10%, TAW of 14%$ and a RAW fraction of 50% with a subsoil permeability of 2.5 mm/day.

The soil water store can be expressed by:

$$\Delta SS = R_{eff} + I - F_a k_c ET_o - RO - D$$

where

ΔSS	=	daily change in stored soil water (mm)
R_{eff}	=	daily effective rainfall (mm)
I	=	daily irrigation amount (mm)
F_a	=	agronomy factor (-)
k_c	=	crop coefficient (-)
ET_o	=	daily potential evapotranspiration (mm)
RO	=	daily runoff (mm)
D	=	daily drainage of the soil profile (mm)

The daily change in soil water storage accommodates the saturation of the soil profile after heavy rain which drains through the soil profile base on the permeability of the subsoil (D). Runoff can also occur once the soil profile is saturated. Further, the rate of crop depletion of soil water below the RAW range is slowed through a water stress function which limits the maximum water depletion to the wilting point.

It is also recognised that not all rainfall is effective in replenishing soil water stores for crop use and some evaporates before it can be utilised by the crop and/or is intercepted by the canopy. For the purpose of this study, the first 5 mm of a rainfall event[7] is considered not effective after which any further rainfall is deemed effective. Only the first 5 mm is not effective for periods of consecutive daily rainfall events.

[7] A rainfall event remains continuous if consecutive daily rainfall remains greater than 0

The crop water use is determined using the crop coefficient and the potential evapotranspiration (ETo) as described by Allen et al. (2006). The coefficients for lucerne is given in Table 10. These crop coefficients are generally applicable in situations where crop performance is not limited by factors such as soil condition, grazing pressure and biomass removal. Hence, an agronomic factor (F_a), between 0 and 1, is applied to the crop water use calculations that will account for these agronomic impacts. Theoretical crop water use is based on an agronomic factor of 1 whereas experience suggests that lucerne harvesting reduces overall irrigation resulting in an agronomic factor of 0.8 (80% of theoretical crop water use). Further reductions in the agronomic factor are related to the impacts of soil conditions.

Table 10: Crop coefficient (k_c) used for lucerne to calculated crop water use (after Allen et al, 2006)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Lucerne	0.95	0.95	0.95	0.93	0.9	0.9	0.9	0.91	0.94	0.95	0.95	0.95

Taking the theoretical maximum lucerne yield to be 22 t/ha with an agronomic factor of 0.8 results in an average irrigation demand of 7.4 ML/ha. Given that yield is proportional to crop transpiration, yields of 19 and 16 t/ha result in an average irrigation demand of 6.4 and 5.4 ML/ha, respectively.

Appendix D Economic Benefits Analysis

Please refer to *APPENDIX D_Airport Irrigation ES Benefits – v8.xlsx* for full calculation details.

Summary

Future Option	Scheme Impacts	Quantity	Units	Value	Year impacts start	Year impacts end	Annual impact	NPV
Auxillary Power Unit	High	5,086	flights	$ 350,955	2017	2042	$ 350,955	$ 4,916,727
Reduction in fuel flow at take off	Med	169,430	fuel litres	$ 84,715	2017	2042	$ 84,715	$ 1,186,824
Payload and Range	High	1,793,590	fuel litres	$ 896,795	2017	2042	$ 896,795	$ 12,563,720
				$ 1,332,465	**p.a.**			**$ 18,667,271**

IMPACTS - QUANTITATIVE ASSESSMENT

Financial	Impact	Units	Quantity p.a.	$ Unit Value
Auxiliary Power Unit	High	flights	5,086	69
Reduction in fuel flow at take off	Med	fuel litres	169,430	0.50
Payload and Range	High	fuel litres	1,793,590	0.50

VALUATION					
Area of Valuation	**Impact**	**Value**	**Annual or one-off?**	**Valuation source**	**Comments and assumptions**
Auxiliary Power Unit	High	$ 350,955	Annual	Adelaide Airport Irrigation Trial - Aviation Aspects *AVIATION PROJECTS Version 1.0 Final Draft 7 August 2017*	Reduction in fuel and maintenace costs. Used B737 only which represents 94% of the flights assessed for 19% of the year when benefits gained.
Reduction in fuel flow at take off	Med	$ 84,715	Annual	Adelaide Airport Irrigation Trial - Aviation Aspects *AVIATION PROJECTS Version 1.0 Final Draft 7 August 2017*	Reduction in fuel costs measured kg/hr. Used B737 only which represents 94% of the flights assessed for 50% of the year when benefits gained.
Payload and Range	High	$ 896,795	Annual	Adelaide Airport Irrigation Trial - Aviation Aspects *AVIATION PROJECTS Version 1.0 Final Draft 7 August 2017*	Reduced fuel requirements (kg) Used B737 only which represents 94% of the flights assessed for 100% of the year when benefits gained.(Payload (kg) not assessed as may not be realised as need to make assessment before take off.)

Appendix E Aviation Projects Report

AUGUST 2017

IRRIGATION TRIAL – AVIATION ASPECTS

ADELAIDE AIRPORT

Prepared for SA Water

AVIATION PROJECTS

AVIATION PROJECTS

DOCUMENT CONTROL

Document Title: Adelaide Airport Irrigation Trial – Aviation Aspects

Reference: 080301-01

Release Date: 07 August 2017

Prepared by: K Tonkin

Reviewed by: R Corner

Released by: K Tonkin

Revision History: Release

Version	Description	Transmitted	Reviewed by	Date
0.1	First Draft	21 June 2017	Stantec	30 July 2017
1.0	Final	07 August 2017		

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TABLE OF CONTENTS

LIST OF TABLES

GLOSSARY

APU	auxiliary power unit
CASA	Civil Aviation Safety Authority
CASR	Civil Aviation Safety Regulations
OEM	original equipment manufacturer
RPM	revolutions per minute
RPT	regular public transport

1. INTRODUCTION

1.1. Situation

In order to determine the potential reduction in temperature at the Adelaide airport, and demonstrate the ability to extrapolate this temperature reduction to an energy reduction (related to the energy use of the cooling towers and potential fuel savings for aircraft) a trial has been underway to test the theory of heat mitigation through irrigation of a small site located south of the runway at the Adelaide International Airport. The trial has been underway for two years and a suite of data has been collected on the air temperature from within and around the trial site.

This is an iconic trial which aims to gain information required to support the business case for rolling this concept out to this and other airports. Every major city has an airport which contains large areas of buffer land. The use of this land does come with limitations, such as the need to ensure it reduces the risk of bird strike, and does not, at any stage, negatively impact on the operation of the airports core business, being the facilitation of air travel. To our knowledge no other trial of this type, specifically designed to reduce air temperatures, has been conducted at any national or international airport. The outcomes of this trial may also be transposed to other settings such as public open space within urban areas of Adelaide, to address the urban heat island effect and to provide other associated benefits to the community.

The next stage of this trial is to assess the data to determine what financial as well as a broader economic benefits could be obtained from the expansion of the trial, to encompass larger sections of the airside area of the airport. This includes potential fuel savings for aircraft during take-off, reduction of energy use of cooling towers in the airport passenger terminal, revenue from growing of suitable crops in the irrigation area etc. The cost of irrigation, crop production and maintenance needs to also be determined to enable a full financial and economic assessment of irrigating the entire airside area of the airport. Some of this data will be available from SA Water.

1.2. Scope of Work

The scope of work is to provide inputs to the economic modelling activity by scoping and describing, to the extent possible within the nominated timeframe and budget, the quantum of potential benefits that have been identified in relation to aircraft operations:

1. Identification of aircraft fuel savings related to certain air temperature reductions on and above the runway (assuming the influence of the irrigation-induced temperature reductions extend vertically within the confines of the airport). This will include three categories of aircraft, being dual propeller (SAAB) aircraft, domestic carriers (Airbus A320 and Boeing 737) and larger international aircraft (Boeing 777 and 787 Dreamliner) – Note – it is acknowledged that this is a difficult component of the assignment, however it is a very important one. If information is difficult to find for all classes of aircraft, the use of information from the domestic carriers only will suffice;
2. Additional savings for the airport or airline operator (e.g. payload increases, reduced demand on air conditioning while at the gate etc.); and
3. Comment on, but not necessarily quantify other benefits that could be realised through a reduction of air temperature of 4 degrees.

1.3. Approach to task

The following actions were to taken to undertake the study:

1. Review client material;
2. Liaise with the lead consultant in relation to structure and format of inputs;
3. Research relevant documents and information available in the public domain;
4. Identify and liaise with aircraft operators that will be able to provide meaningful information within the time available;
5. Consolidate the findings of the study in an appropriate format for the lead consultant to incorporate in the overall scope of work; and
6. Respond to requests for clarification as required.

1.4. Stakeholders

The following stakeholders were consulted and/or considered in the preparation of this plan:

- Aircraft operators and other tenants and aerodrome users; and
- Adelaide Airport (aircraft movements data).

1.5. Client material

The following client material was received/consulted in the preparation of this review:

- SA Water, Request for Quotation – Services, Economic Assessment for the Adelaide Airport Irrigation Trial, received 25 May 2017.

1.6. References

References used or consulted in the preparation of this report include:

- Aeronautical Information Package; including AIP Book and En Route Supplement Australia effective 25 May 2017;
- CASA, Civil Aviation Safety Regulations (CASR) 1998, Part 139—*Aerodromes;*
- CASA, Manual of Standards Part 139—*Aerodromes*, Version 1.14: January 2017; and
- other references as noted.

2. ANAYLSIS

2.1. Basis of analysis

The following aircraft have been evaluated:

- Boeing 737 – representative of narrow body regular public transport (RPT) jet aircraft used for short-haul domestic transport;
- Airbus A330 - representative of wide body RPT jet aircraft used for medium-haul domestic and international transport (limited data only); and
- Boeing 777 – representative of wide body RPT jet aircraft used for long-haul international transport.

The following areas of benefit have been evaluated:

- Reduction in Auxiliary Power Unit (APU) fuel use;
- Reduction in APU maintenance;
- Reduction in aircraft engine maintenance;
- Reduction in take-off fuel;
- Reduction in aircraft brake and tyre maintenance;
- Increase in aircraft payload; and
- Increase in aircraft range.

2.2. Auxiliary Power Unit

The APU is a small jet engine located in the aft fuselage of an RPT aircraft. It is primary used while the aircraft is on the ground to provide:

- Airconditioned air to maintain the temperature in the aircraft cabin at a comfortable level for passengers during boarding and disembarkation;
- Electrical power for cabin lighting, galley power, in-flight entertainment and other aircraft systems; and
- Pneumatic air to start the aircraft engines.

Typically, airports are equipped with an external electrical source (ground power) which provides the necessary electrical needs of the aircraft. This is used until the APU is started and used in its place.

As the APU is a jet engine it burns fuel while operating, aircraft operators minimise the use of the APU to save fuel and reduce maintenance costs (calculated as a function of hours in use). The decision on when to start the APU is based on the ambient temperature at the airport. When the ambient temperature is below 21°C, the APU remains off until 5 minutes prior to pushing back from the gate. For normal aircraft operations, this results in between 30-40 min (short-haul), 60-90 min (medium-haul) and 90-150 min (long-haul) of fuel and maintenance savings between flights. Refer to Table 1 and Table 2.

Table 1 Cost of APU use per aircraft type

Aircraft	*Fuel cost per hour*[1]	*Maintenance cost per hour use*[2]	*Total*
B737	$67	$51	$118
A330	$137	$60	$197
B777	$228	$74	$302

Table 2 Potential savings per aircraft type

Aircraft	*Time between flights*	*Savings*	*Savings per day*
B737	30 – 40 mins	$59 - $79	$236 - $316
A330	60 – 90 mins	$197 - $296	$394 - $592
B777	120 – 150 mins	$604 - $755	$604 - $755

[1] Source: Index Mundi. Price (AUD$1.90 per US gallon and SG = 0.79) as at May 2017

[2] Source: Indicative figures published in OEM operations and aircraft performance manual suite

An analysis of the ambient temperatures at Adelaide Airport for the period 01 Jan 1985 to 25 Jan 2013[3] showed the temperature was between 21°C – 25°C for 19%[4] of the time each calendar year. Refer to

Table 3.

Table 3 Potential annual savings per aircraft category

Aircraft Category	*Movements per year*	*Savings per year*
Narrow Body (Short Haul)	26,770	$300,000 - $401,800
Wide Body (Medium Haul)	875	$32,750 - $49,210
Wide Body (Long Haul)	805	$92,380 - $115,475
Total Annual Benefit		$425,130 - $566,485

[3] Source: Bureau of Meteorology - Aerodrome Climatological Summary - Model E

[4] Summed percentage of temperature for the period 0600 Local to 2300 Local (ADL Airport operating hours)

2.3. Engines

As for the APU, engine maintenance is a function of use. Unlike the APU which runs at a constant speed (RPM), engines run at variable RPM with the highest being at take-off. Accordingly, engine maintenance is determined on hours of use with credit given for reduction in take-off RPM (engine de-rate). The greater the de-rate and the more often it is employed extends the time between maintenance cycles. Additionally, as RPM is reduced the fuel flow reduces.

By example, the cost of engine overhaul for the B737 engine after 27,000 flight hours is USD $2.7M[5]. This typically includes operating at maximum take-off thrust for periods up to 10 minutes. Engine manufacturers permit operators to increase the number of flight hours before inspections, maintenance and/or overhaul when engine de-rate has been used. The greater the de-rate and frequency of use, the greater the benefit. Exact monetary benefit is commercial-in-confidence for each operator. Given the order of magnitude of overhaul cost, any reduction or deferment of these expenses is significant. Refer to Table 4.

Table 4 Engine RPM (N1) reduction per aircraft type[6]

Aircraft	*N1 at 25°C*	*N1 at 21°C*	*Total N1 Reduction*
B737	95.40	94.76	0.64
B777	106.00	105.28	0.72

It is informative to note that the temperature bands immediately lower and higher than the target range showed identical results. It is also worth noting that the three temperature bands in the range from 16°C to 30°C are the highest overall percentages[7] and account for greater than 50% of total ambient temperatures. Refer to Table 5 and Table 6.

Table 5 Engine RPM (N1) reduction per aircraft type - Lower Band[8]

Aircraft	*N1 at 20°C*	*N1 at 16°C*	*Total N1 Reduction*
B737	98.80	98.16	0.64
B777	105.10	104.38	0.72

Table 6 Engine RPM (N1) reduction per aircraft type - Higher Band[9]

Aircraft	*N1 at 30°C*	*N1 at 26°C*	*Total N1 Reduction*
B737	100.30	99.66	0.64
B777	106.90	106.18	0.72

[5] Source: SGI Aviation – IATA Cost Conference 2015
[6] Source: OEM operations and aircraft performance manual suite
[7] Source: Bureau of Meteorology - Aerodrome Climatological Summary - Model E
[8] Source: OEM operations and aircraft performance manual suite
[9] Source: OEM operations and aircraft performance manual suite

A reduction in take-off N1 also results in a reduction in fuel flow. Take-off fuel flows are very high and can be at this level for up to 10 minutes. The following table shows the fuel flows in the target temperature band and the fuel saving from a 4°C temperature reduction. Refer to Table 7.

Table 7 Fuel saving from engine RPM (N1) reduction per aircraft type[10]

Aircraft	*Fuel Flow at 25°C*	*Fuel Flow at 21°C*	*Total Fuel Saving per hour*
B737	8,525 kg/hr (95.40 N1)	8,468 kg/hr (94.76 N1)	57 kg/hr
B777	21,204 kg/hr (106.00 N1)	21, 060 kg/hr (105.28 N1)	144 kg/hr

At 10 minutes of take-off thrust, this results in between 10 kg (B737) and 24 kg (B777) fuel saving for each departure. Given that a 4°C temperature reduction has the same effect on N1 across over 50% of temperature variation the following table shows the fuel savings possible. Refer to Table 8.

Table 8 Potential annual fuel savings for reduced take-off thrust

Aircraft	*Movements per year*	*Savings per year*
Narrow Body (Short Haul)	26,770	$85,000
Wide Body (Long Haul)	1680	$12,800
Total Annual Benefit		$97,800

[10] Source: Indicative figures published in OEM operations and aircraft performance manual suite

2.4. Tyres and Brakes

Ambient temperature has an effect on the stopping distance of landing aircraft. For every 5°C reduction in temperature landing distance decreases by 25 – 35m[11] for all categories of aircraft in both dry and wet runway conditions. This reduction in landing distance allows the pilot to use reduced braking to leave the runway at their required/desired exit. Reduced braking means less wear and tear on tyres and brakes, thus extending their life and reducing maintenance cost.

A consequential benefit may also be provided to the airport and other aircraft. Reduced landing distance may mean the difference between allowing the aircraft to exit the runway at an intermediate taxiway rather than continuing to the next. The less time landing aircraft occupy the runway means reduced waiting time for subsequent departing aircraft or following landing aircraft. Less time equals less fuel burn.

[11] Source: OEM operations and aircraft performance manual suite

2.5. Payload and Range

There are a number of limits to which an aircraft must adhere. Maximum weight is a primary limit and a major element of safety. A pilot must prioritise between:

- the amount of fuel to carry – sufficient for the flight;
- the amount of payload (passengers and cargo) – more payload equals more revenue; and
- the maximum weight permissible for the flight – either aircraft maximum structural take-off weight and/or maximum performance weight (primarily dictated by runway length, ambient temperature and obstacles surrounding the airport).

The amount of fuel required for a flight is the sum of:

- APU fuel;
- Taxi fuel;
- Flight fuel;
- Approach and landing fuel;
- Regulatory minimum reserve fuel; and
- Weather and/or traffic holding fuel (if required)

At lower temperatures, less fuel is required for APU burn, taxi, landing and reserve fuel. This allows the pilot to use this additional fuel capacity for flight (fly longer distance) or holding (wait longer to enable landing at desired destination rather than divert to an alternate airport). Conversely, the pilot may use the reduced fuel requirement to add more payload and increase the revenue for that flight.

Temperature is proportional to volume and inversely proportional to density.[12] That is, as temperature decreases, volume decreases and density increases for a given mass – in this case fuel. Think of a balloon filled with air. If you heat the air inside, the air expands (increased volume – less dense), if you cool it, it shrinks (decreased volume – more dense).

This is important to understand as air density has a profound effect on the thrust produced. The volume of the air flowing through the engine is relatively fixed for any particular RPM by the size and geometry of the inlet duct system. But since the thrust is determined by mass, not the volume of air, any increases in its density increases the mass and thus the thrust. For any given weight, the amount of thrust required is constant, therefore, a lower RPM and thus fuel flow is required.

Maximum structural take-off weight is usually only an issue for long flights and affects all categories of aircraft when the intended flight is at or near the range limit of the aircraft. In this situation, the amount of fuel required is fixed which then limits the payload capacity. The less fuel (expense) required equals more payload (revenue).

[12] Source: Charles' Law, also known as Law of Volumes

Maximum performance take-off is improved as temperature decreases. There are two primary benefits:

- Less runway required for a given weight. As runway length is fixed the pilot can:
  - Use reduced engine thrust (N1) for take-off (less fuel used and reduced maintenance required); or
  - Use higher thrust to out-climb obstacles; and
- Greater fuel and/or payload capacity for a given runway length.

The following table illustrates how a reduction in 4°C relates to fuel savings being realised as either greater payload or greater range. For simplicity, 50 kg (B737), 125 kg (A330) and 200 kg (B777) of fuel is used as a representative amount. The relationship between fuel versus payload/range is close to linear. Refer to Table 9.

Table 9 Fuel saving relative to payload and range per aircraft type[13]

Aircraft	*Payload (kg)*	*Range (NM)*
B737	415	12
A330	670	12
B777	445	12

[13] Source: OEM operations and aircraft performance manual suite

3. SUMMARY

Reduced ambient temperature has multiple benefits to aircraft operators. Benefits include:

- Reduced fuel usage;
- Reduce maintenance costs; and
- Greater payload and range capability.

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Appendix F Cooling Towers Analysis

Please refer to *APPENDIX F_1_CT energy and water consumption calcs_AAL.xlsx* and *APPENDIX F_2_Chiller Energy Savings_AAL.xlsx* for full calculation details.

Chillers energy analysis

No. Appliances	Power Usage (kW)	Load Factor (%)	No. uses per day (hours)	Days per year	Annual energy usage per chiller (kWh/yr)	Annual cost per chiller ($)	
3	309	70%	19	365	4,500,122	$706,069	
	289.224	70%	19	365	4,212,114	$660,881	Reduced energy consumption with 4°C reduction
					288,008	$45,188	Difference, 1 chiller at 4°C reduction
Indicative annual total reduction					864,023	$135,565.26	Difference, 3 chillers at 4°C reduction
					432,012	$67,783	Over 6 months

Key assumptions		
Terminal 1 open from 4am - 11pm	19	365
Three levels; Total floor space (m2	70,000	Per AAL
Estimted electricity tariff (c/kWh)	$0.1569	
VSDs installed on all fans / pumps	70%	

Cooling Tower Fan and Pump Energy Analysis

Appliance	No. Appliances	Power Usage (kW)	Load Factor (%)	No. uses per day (hours)	Days per year	Annual energy usage kWh/yr	Annual cost ($)
Cooling Tower 1							
L Cooling Tower fan	1	15	70%	19	365	72,818	$11,425
Cooling Tower 2							
L Cooling Tower fan	1	15	70%	19	365	72,818	$11,425
Cooling Tower 3							
L Cooling Tower fan	1	15	70%	19	365	72,818	$11,425
Pumps							
PCHWP 00-01	1	5.5	90%	19	365	34,328	$5,386
PCHWP 00-02	1	5.5	90%	19	365	34,328	$5,386
PCHWP 00-03	1	5.5	90%	19	365	34,328	$5,386
SCHWP 00-01	1	55	70%	19	365	266,998	$41,892
SCHWP 00-02	1	55	70%	19	365	266,998	$41,892
CCWP 02-01	1	30	70%	19	365	145,635	$22,850
CCWP 02-02	1	30	70%	19	365	145,635	$22,850
CCWP 02-03	1	30	70%	19	365	145,635	$22,850
HHWP 02-01	1	30	70%	19	365	145,635	$22,850
HHWP 02-02	1	30	70%	19	365	145,635	$22,850
HHWP 02-03	1	30	70%	19	365	145,635	$22,850
					Indicative annual total	**1,729,242**	**$271,318**

Key assumptions		
Terminal 1 open from 4am - 11pm	19 Hours	365 Days
Three levels; Total floor space (m2)	70,000	Per AAL
Estimted electricity tariff (c/kWh)	$0.1569	
VSDs installed on all fans / pumps	70%	

Cooling Tower Fan and Pump Opportunities

Opportunities	Est. Saving	Indicative Capital Cost($)	Electricity savings (kWh/yr)	Electricity cost savings ($/yr)	Payback periods (yrs)	Key assumption
Installation of electricity sub-meters to monitor energy consumption: To manage and monitor the operation and performance of a cooling tower successfully the inputs and outputs of the system need to be measured and recorded. The best method to obtain such information is by the installation of sub-meters. To achieve energy savings the following items should be metered: • Cooling tower fan energy consumption. • Cooling tower pump energy consumption. With this data a cooling system operation can be optimised (through ensuring fans and pumps aren't operating unnecessarily / outside of hours etc.) which in turn will yield cost saving [1]. [1] https://www.airah.org.au/Content_Files/BestPracticeGuides/BPG_Cooling_Towers.pdf	5%	$42,000	86,462	$13,566	3.1	Installation of sub-meters on eleven (11) pumps and three (3) cooling tower fans
Installation of variable speed drives (VSDs): A variable speed drive (VSD) is a system for controlling the rotational speed of a motor and works by controlling the frequency of electrical power supply to the motor. VSDs can reduce the energy consumption of equipment motors significantly and are considered best practice. Typically a 10% reduction in motor speed will provide a 27% energy reduction. Currently the three (3) x 5.5 kW single stage primary chiller centrifugal water pumps (PCCWP) associated with the cooling tower system run at a constant speed despite any variability in the recirculating water load. The pumps can be controlled via discharge pressure sensor to maintain the required flow rate by reducing the speed thus energy consumption. It has been estimated that the installation of a VSD will result in a 5% speed reduction (i.e. a 14% power reduction).	20%	$9,000	22,886	$3,591	2.5	At 90% load the electricity usage for the three pumps is estimated to be in the vacinity of 102,984 kWh/yr and the annual electricity cost is ~$16,160 assume that if VSD are installed on the three pumps it would equate to the pumps operating at approximately 70% load. At 70% load the three pumps will consume 80,099 kWh/yr at ~$12,570 annum. Thus the potential energy and cost savings are a subtraction of the two load conditions.
Reduce the Cooling load Reducing the load on the cooling system in the form of changing the set perimeter zone temperature as a one degree (1°C) change can result in a 5.4% energy saving [1] and a three degree (3°C) temperature increase will reduce water consumed by approximately 15% [2]. Load reduction can be made by not cooling excessively or un-necessarily, for example seasonal temperatures should be considered and ideally the load on air conditioning cooling towers can be reduced by setting thermostats to 25°C in summer and 20°C in winter. [1]http://www.sharegreen.ca/pdf/Semi-Finalist-Submission/Mark_DesJardine_University_of_Western_Ontario.pdf [2]http://www.ecoefficiency.com.au/Portals/56/factsheets/genmanufacture/00976%20M2%20Cooling%20tower.pdf	5.4%	$5,000	93,379	$14,651	0.3	Indicative capital cost associated with technicians adjusting set-point parameters and trialing the outcomes.
Total	**30.4%**	**$56,000**	**202,727**	**$31,808**	**1.8**	