

Western Sydney Airport Climatological Review



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Western Sydney Airport Climatological Review

Executive summary

A detailed climatological assessment was carried out for the area around the proposed location of the Western Sydney Airport. Since a previous study was carried out in 1996, data availability has improved. The study focussed on data from the Automatic Weather Station (AWS) at Badgerys Creek that was installed in 1995, supplemented by other stations:

- Badgerys Creek AWS one minute wind and rainfall data, three hour wind data and daily temperature and rainfall data (December 1995 to 2014);
- Camden Airport AWS ten minute (August 2010 to October 2014) and halfhourly (May 1995 to 2014) visibility data were used to study visibility and fog in the area;
- RAAF Base Richmond AWS ten minute (April 1995 to January 2014) visibility and fog data used for comparison; and
- Sydney Airport AWS one minute and data rainfall and ten minute and halfhourly visibility data were used for comparison.

The main findings of the study were:

- Fog events at Camden airport, and most likely at Badgerys Creek, were found to be significantly more frequent than at Sydney Airport;
- Fog in the area can occur at all times of the year and can last for extended periods;
- Heavy rainfall events may be more likely at Badgerys Creek than Sydney Airport;
- Badgerys Creek receives less rainfall on average than Sydney Airport;
- Heavy rainfall events are more likely to occur between November and March, peaking in February;
- The dominant wind direction at Badgerys Creek is south westerly in all seasons. Wind direction is more constant in autumn and winter than in spring and summer; and
- Winds tend to reach peak strength around 0500 UTC and are weakest from 1000 to 2100 UTC.

1 Introduction

1.1 Background

Badgerys Creek, the location of the proposed Western Sydney Airport, is located in Greater Western Sydney, 45 km from the coast, at an elevation of 81.2 m above sea level, near the Great Dividing Range (see Figure 1.1). As such, it has a significantly different climate to Sydney airport, which is closer to the coast and at sea level. The occurrence of fog, prevailing wind directions and summer temperatures would be expected to be significantly different at the Badgerys Creek site than at Sydney Airport.



Figure 1.1 Map of the Sydney basin, with the locations of Sydney and Camden, RAAF Base Richmond and Badgerys Creek AWS marked

Earlier reporting (Report No. SSU96-8 – see references) on the climate of the Badgerys Creek area was hampered by the limited observations that had been taken near the proposed airport site. The number and quality of observations recorded at the site has since been improved by the installation of an Automatic Weather Station (AWS) in 1995, which has provided considerable data. This has allowed the climate of the site to be described in more detail in this report, drawing on the AWS observations and those from several other sites in the area. This report describes the relevant climate characteristics of Badgerys Creek. The average rainfall, temperatures and winds are given, along with the observed ranges of these variables and some information on the occurrence of extreme rainfall and wind speed as well as the potential frequency of fog.

1.2 Site selection and information

An AWS was installed at the Badgerys Creek site in October 1995, providing measurements of wind speed and direction, rainfall, temperature, pressure and humidity. The AWS is located on open grassland/farmland and has not been moved since its installation. The original AWS was upgraded in April 2011 to a newer model. In addition, the anemometer at the site has been replaced on two occasions in the course of normal site maintenance. Changes in instrumentation can lead to inhomogeneities in the site record; however, these potential inhomogeneities have not been investigated in this report as they are expected to be negligible.

The AWS at Badgerys Creek does not have the capability to determine visibility and cloud. Instead, instrumentation at Camden Airport has been used as a representative site for these parameters, being the closest available site and with a similar climatology. Camden Airport is less than 20km to the south of Badgerys Creek and is a similar altitude and distance east of the Great Dividing Range.

1.3 Data availability

One-minute, three hourly and daily data recorded by the Badgerys Creek AWS are used in this report (with the exception of visibility and cloud). Data at Badgerys Creek are available from December 1995 to present. Each data set has good completeness and is therefore considered reliable. See Appendix A for a metadata summary and data availability listing for Badgerys Creek.

Cloud and visibility data for this report were sourced from Camden Airport. Data at Camden Airport is available in 10 minute increments from August 2010 to October 2014. The four year record of 10 minute data at Camden is too short to determine climatic trends, so half-hourly data (available from May 1995 to present) has been used in some analyses. See Appendix A for a full metadata summary for the Camden Airport site.

1.4 Data quality

High resolution data types, such as the one-minute data used in this report, are subject to only basic automated quality control. This is due to the high volumes of data recorded. Automated checks include consistency checks, rapid change checks and checks against extremes. Three hourly and daily data are also subjected to a range of automated quality control checks.

Some additional manual quality control has been carried out on the data in this report, generally to remove obvious erroneous values. See each section for details of any quality control performed.

Further information about the observations and quality control can be found on the Bureau's website at <u>http://www.bom.gov.au/climate/data-services/about-data-observations.shtml</u>

2 Wind

Wind data used for the following analyses (with the exception of the averages and extremes discussed in section 2.1) are observations taken at Badgerys Creek at 10 minute intervals. Wind speed is the average wind speed in the last 10 minutes, wind direction is the average direction of the wind in the last 10 minutes, and gust is the highest maximum 3 second gust in the last 10 minutes. The direction associated with the wind gust is the average wind direction in the last 10 minutes. It should be noted that this is not necessarily the direction from which the gust came. Data used are from 4 December 1998 to 18 November 2014. The analyses discussed in this report are presented by season as there is very little change between the months within each season. However, monthly analyses are included in Appendix B.

The monthly mean wind speed averages, discussed in section 2.1, have been calculated using three hourly observations from 1996 to 2014 for January to July averages, 1996 to 2013 for August to October averages and 1995 to 2013 for November and December.

A comparison with Sydney airport has not been undertaken. Wind conditions between the two locations are significantly different due to the influence of the sea breeze at the more coastal location of Sydney Airport.

2.1 Monthly wind averages and extremes

Mean wind speeds at Badgerys Creek are relatively consistent throughout the year, ranging from 5 to 7 knots, with a slight increase in the mean wind speed from July through to February (See Table 2-1). The strongest wind gust ever recorded at the site was 56 knots on 24 September 2006, from a north-northwest direction. Wind gusts of 35 knots or higher have been recorded during every month of the year, generally ranging in direction from north-northwest through to south-southwest (See Table 2-1).

Table 2-1 Monthly wind statistics for Badgerys C	Creek AWS (67108) in knots and degrees true
--	---

	January	February	March	April	May	June	July	August	September	October	November	December
Mean wind												
speed (knots)	6	6	5	5	5	5	6	6	7	6	6	6
Maximum wind												
gust speed												
(knots)	52	35	43	38	39	44	43	49	56	49	48	55
Maximum wind												
gust direction												
(° true)	286	205	222	230	263	274	223	262	352	299	197	233
Maximum wind	24	19	25	6	16	28	10	1	24	1	2	
gust date	January	February	March	April	May	June	July	August	September	October	November	4 December
	2004	2012	2009	2006	2009	2014	2005	2008	2006	2013	2003	2003

2.2 Wind speed and direction by season

Data has been displayed using a wind rose. The wind rose illustrates the main 8 wind directions and attributes a percentage occurrence of winds within a set speed range. The addition of the different speed ranges in one direction makes up one 'arm' of the wind rose. The wind roses in Figure 2.1 show the mean wind speed and direction at Badgerys Creek for each season.

The predominant wind direction at Badgerys Creek in all seasons is south-westerly. Westerly and north-westerly winds are in the minority, with the frequency of north-westerly winds being less than 5% in all seasons except spring. The spread of wind directions is more uniform in summer and spring, with most directions recording a frequency of at least 10% in these seasons (the only exception being north-westerly winds). In winter and autumn the domination of the south-westerly wind is more apparent with frequencies of 35.5% and 33.6% respectively. Wind speeds in each speed bracket have been recorded in each direction.



Figure 2.1 Wind roses showing mean wind speed and direction for each season at Badgerys Creek

2.3 Wind gust by season

The histograms in Figure 2.2 show the frequency of occurrence of wind gust strength in each season. The gusts described are the maximum three second gust in the ten minutes prior to the observation. The histograms show the highest frequencies of wind gust strength are from 4-13 knots and display very similar patterns in each season.



Figure 2.2 Frequency (%) of wind gust strength in each season (maximum 3-second gust in previous 10 minutes)

The wind gusts were found to be between 0-4 knots stronger than the 10-minute mean wind speed most of the time. Wind gusts between 4-13 knots stronger than the mean wind speed occurred around 25% of the time, with slight seasonal variations (about 30% in summer and 20% in spring). Wind gusts at Badgerys Creek more than 13 knots or more than 20 knots stronger than the mean wind speed are rare (0.15% and 0.05%, respectively).

2.4 Wind speed by hour of day by season

The box plots below show the average variation in wind speed across the day. Note that as wind speed is a highly variable parameter, the range of wind speeds is quite broad.



Figure 2.3 Box plots showing mean wind speed by hour of the day at Badgerys Creek for each season

Figure 2.3 shows that diurnal variation in wind strength is similar throughout the year. The wind speed generally reaches a peak at around 05 UTC, before easing. Lowest wind speeds are generally recorded during the night, with the minimum usually being reached around 10 UTC remaining at a minimum until around 21 UTC. In summer there is a second drop in wind speed around 19 UTC, before it begins to increase at 21 UTC.

2.5 Wind gust by hour of day by season

The plots below show the variation in wind gust strength throughout the day. Due to the highly variable nature of the wind, the range in gust strength is quite broad. Strong gusts have been recorded at all hours of the day and night.



Figure 2.4 Box plots showing mean gust strength by hour of the day at Badgerys Creek for each season

Figure 2.4 shows that the diurnal variation in wind gust strength is similar across all seasons, and is also similar to the diurnal variation in average wind speed (Figure 2.3). The wind gust strength generally reaches a peak around 05 UTC, before easing to a minimum around 12 UTC. Lower gust strengths continue during the night before picking up again around 21 UTC.

3 Rainfall

The rainfall climatologies for Badgerys Creek and Sydney Airport are examined together to enable comparison of the two locations.

The mean and median monthly rainfalls for each month of the year are shown for the two sites in Figure 3.1.

For Badgerys Creek the average number of times a threshold rainfall value is equalled or exceeded for each month of the year is also shown in Figure 3.3. The number of days in which the threshold value is equalled or exceeded is also shown in Figure 3.4.

The results show similar rainfall patterns on average from November to March at the two sites. For the months from April to October Badgerys Creek has a lower monthly mean and monthly median rainfall than the Sydney Airport site.

3.1 Rainfall data availability

Rainfall data is available from AWS gauges enable rainfall to be measured to time intervals down to one-minute using a Tipping Bucket Rain Gauge (TBRG).

TBRG gauges record rainfall automatically and continuously. However the quality of the data can sometimes be inferior to that from daily rainfall gauges due to instrument malfunction, interference of the instrument due to environmental effects (for example leaves or flying debris), tampering by humans or animals, the need for regular calibration, and measurement errors under certain conditions (such as very heavy rainfall).

The Badgerys Creek site has had an AWS installed since October 1995, with oneminute rainfall data available since December 1998. The Sydney Airport site has rainfall data available from an AWS which was installed in December 1998. As a result, these sites only have a relatively short record for one-minute rainfall data of about 16 years. A requirement was made, for the purpose of this analysis, that less than 25% of data be missing in a month for it to be a valid month and therefore included in the analysis.

One-minute rainfall data from the Badgerys Creek (67018) and Sydney Airport sites (66037) are available from December 1998 to November 2014. This matching period record enables a comparison of rainfall between the two sites.

The AWS data was screened for obvious errors. The errors detected were spurious spikes in the one-minute data. The screening involved searching for values that exceeded 5 mm over a one-minute duration. For each detection, the 24-hour 9 am to 9 am accumulated rainfall from the AWS was compared with the 9 am to 9 am daily value either at the same site (for Sydney Airport) or with 9 am to 9 am daily values at nearby sites (for Badgerys Creek). Each detection was then manually quality controlled. This method of quality control is only expected to detect gross errors in the data.

3.2 Rainfall climatology

3.2.1 Mean and median monthly rainfall

Basic statistics such as the mean and the median can provide useful information about the rainfall climatology. The mean describes 'normal' or 'average' conditions at a location. The median is more useful when there is high variability. The mean is more sensitive to the presence of outliers than the median. Large differences between the mean and the median indicate skewness in a distribution where there are relatively more very high or very low observations.

The mean and median monthly rainfall at Badgerys Creek (67108) and Sydney Airport (66037) using AWS data from 1999 to 2013 are shown in Figure 3.1.



Figure 3.1 Monthly mean and median rainfall from Sydney Airport and Badgerys Creek AWS

Comparison of the mean and median monthly rainfall for the two sites shows similarities in the months between October and March with highest mean monthly rainfall in February most likely arising from convective activity in the inland trough over eastern Australia which is common at the time of year. Between April and September the mean and median monthly rainfalls tend to be consistently lower at the Badgerys Creek site compared with Sydney Airport. This is likely to be due to the more inland location of Badgerys Creek which is less exposed to the prevailing maritime onshore flow in the cooler months.

Rainfall at both Badgerys Creek and Sydney airport varies significantly from year-toyear. Much of this variability is due to large-scale climate variations, with El Niño – Southern Oscillation being the most important. Figure 3.2 shows the standard deviation of rainfall at the two stations for each month of the year, using monthly rainfall totals from 1996-2014. It can be seen that, as with mean rainfall, variability from year-to-year is greater at Sydney airport than at Badgerys Creek. Also, the greatest year-to-year variability is seen in summer at Badgerys Creek but in winter at Sydney airport.



Figure 3.2 Interannual standard deviation of monthly rainfall at Badgerys Creek and Sydney Airport AWS

3.2.2 Rainfall exceeding a threshold value

A rainfall intensity of 6 mm per 1 hour over a duration of 60 minutes (as a sliding window) was selected as a threshold value for heavy rainfall events. The average number of events exceeding that value in each month of the year was calculated from the AWS data for Badgerys Creek and Sydney Airport. The results are shown in Figure 3.3.

The average number of days in each month on which at least one exceedance was recorded were also calculated (Figure 3.4).

The results show a similar pattern to the number of records shown in Figure 3.3 with a higher number of days recorded during November to March due to higher convection activity. In the cooler months, May to October, the number of days of intense rainfall is lower due to the lack of convective activity and the more inland location.

Boxplots of the data in Figure 3.3 and Figure 3.4 are shown in Figure 3.5 and Figure 3.6. These provide additional information indicating the variability in the number and days of exceedances. Also shown are the mean conditions. The boxplots show that the variability and median of number and days of exceedances is higher at Badgerys Creek in the months of November to March. Although the median number of days is lower, variability remains high for the months of April to June and then drops off between July and September.

The comparison of Badgerys Creek rainfall with that at Sydney Airport is consistent across all the parameters investigated: the mean, median, variability and occurrence of rainfall extremes are similar at the two stations from October to March, but in the other months all are lower at Badgerys Creek than at Sydney airport. Badgerys Creek receives less rain, it is less variable from year-to-year, and 6 mm per hour events are less frequent than at Sydney airport from April to September. The exceptions are early and late summer, with Badgerys Creek experiencing more mean rainfall and exceedance events in November and February.



Figure 3.3 Average number of events equalling or exceeding 6 mm/hr over a duration of 60 minutes for each month of the year



Figure 3.4 Average number of days in each month with a least one event equalling or exceeding a rainfall intensity of 6 mm/hr over a 60-minute duration



Figure 3.5 Average number of occurrences per month with rainfall intensity >= 6 mm/hr over a 60-minute duration



Figure 3.6 Average number of days per month with at least one occurrence of rainfall intensity >= 6 mm/hr over a 60-minute duration

4 Temperature

4.1 Monthly average temperature and extremes

The monthly temperature statistics presented in this report have been calculated using all years of record (December 1995 to November 2014, inclusive). Individual monthly averages were only included in the calculation of the overall statistics if that month had at least 21 days of temperature data. A comparison with Sydney Airport has not been undertaken. Conditions between the two localities will be quite different due to the influence of the sea breeze at the more coastal location of Sydney Airport.

4.2 Maximum temperature averages and extremes

January is the warmest month on average at Badgerys Creek (mean maximum temperature of 29.9°C), and July the coldest month (mean maximum temperature of 17.3°C) (Figure 4.1).

The highest temperature ever recorded at the site was 45.8 °C on 18 January 2013 and the lowest maximum temperature 10.5 °C on 13 July 1997 (Table 4-2)

Seasonally, mean maximum temperatures range from 28.8 °C in summer, to 18.1 °C in winter (Table 4-3).



Figure 4.1 Mean monthly maximum temperature and maximum temperature extremes at Badgerys Creek AWS (67108) in °C

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Mean maximum													
temperature	29.9	28.5	26.7	23.9	20.7	17.8	17.3	19.3	22.8	24.8	26.5	28.1	23.9
Lowest mean													
maximum													
temperature	26.8	25.4	25.0	21.4	19.4	16.2	15.4	17.1	21.2	22.1	23.5	23.7	23.1
Year of lowest													
mean maximum													
temperature	2000	2008	2012	2008	2000	2007	1998	1998	2010	2003	1999	2011	2008
10th percentile	26.9	26.4	25.3	22.5	19.8	16.8	16.7	17.8	21.6	22.8	25.0	25.9	23.3
90th percentile	31.2	31.1	27.7	25.3	21.9	19.0	18.1	20.3	24.3	27.2	29.1	29.9	24.5
Highest mean													
maximum													
temperature	32.8	31.2	29.6	26.0	22.3	19.4	18.8	21.1	25.3	27.5	30.1	31.2	24.6
Year of highest													
mean maximum		1998,											
temperature	2009	2004	1998	2005	2007	2004	2005	2009	2013	2013	2009	2005	2013

Table 4-1 Monthly maximum temperature statistics for Badgerys Creek AWS (67108) in °C

Table 4-2 Daily maximum temperature extremes for Badgerys Creek AWS (67108) in °C

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Highest													
temperature	45.8	42.6	40.0	34.6	27.9	25.2	25.4	28.8	34.8	37.2	41.9	42.5	45.8
Date of highest	18	11	13	8	3	14	22	23	29	14	20	17	18
temperature	January	February	March	April	May	June	July	August	September	October	November	December	January
	2013	2004	1998	1998	2007	2004	2009	2012	2000	2006	2009	2009	2013
Lowest maximum													
temperature	20.1	18.1	17.9	16.5	12.3	11.4	10.5	11.8	13.9	14.7	13.1	16.5	10.5
Date of lowest	3	14	21	28	28	30	13	22	4	18	22	23	13
maximum	January	February	March	April	May	June	July	August	September	October	November	December	July
temperature	2010	2009	2000	2008	2002	2006	1997	2008	2005	2004	1996	1995	1997

	Summer	Autumn	Winter	Spring
Mean maximum temperature	28.8	23.7	18.1	24.7
Lowest mean maximum temperature	26.0	22.9	16.5	22.8
Year of lowest mean maximum temperature	2011	2003, 2008	1998	1999
10th percentile	26.6	23.0	17.5	23.1
90th percentile	29.9	24.3	18.8	26.1
Highest mean maximum temperature	30.9	24.6	19.3	27.0
Year of highest mean maximum temperature	1997	2006	2005	2002

Table 4-3 Seasonal maximum temperature statistics for Badgerys Creek AWS (67108) in °C

4.2.1 Minimum temperature averages and extremes

On average the coolest minimum temperatures are experienced at Badgerys Creek during July, where the mean minimum temperature is 4°C. The warmest minimum temperatures generally occur in February, with a mean minimum temperature of 17.2°C (Figure 4.2).

The lowest temperature ever recorded at the site was -4.5 °C on 12 July 2002 (Table 4-4) and the highest minimum temperature 23.9°C on 3 February 2011 (Table 4-5). Seasonally, mean minimum temperatures range from 4.7°C in winter to 16.5°C in summer (Table 4-6).



Figure 4.2 Mean monthly minimum temperature, and minimum temperature extremes at Badgerys Creek AWS (67108) in °C

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Mean minimum													
temperature	16.9	17.2	15.1	11.3	7.3	5.4	4.0	4.7	7.7	10.3	13.6	15.2	10.8
Lowest mean													
minimum													
temperature	14.3	15.6	13.4	8.5	5.7	2.9	1.8	2.8	6.1	8.6	11.0	13.8	10.1
Year of lowest												· · · · · · · · · · · · · · · · · · ·	
mean minimum					2006,	2000,							
temperature	1997	2008	2005	1996	2012	2004	2002	2008	2012	2001	1999	1999	2008
10th percentile	15.8	16.2	13.7	9.6	5.8	3.6	3.3	3.3	6.8	9.1	12.1	14.1	10.2
90th percentile	18.0	18.1	16.0	12.5	8.6	6.9	4.9	6.4	8.6	11.5	14.9	16.1	11.3
Highest mean													
minimum													
temperature	18.2	18.2	17.3	13.0	10.3	7.6	5.7	7.8	9.5	11.7	15.4	16.3	11.6
Year of highest													
mean minimum										1999,			
temperature	2006	2010	2000	2014	2003	2008	2010	1998	1998	2005	2009	2009	1998

Table 4-4 Monthly minimum temperature statistics for Badgerys Creek AWS (67108) in °C

Table 4-5 Daily minimum temperature extremes for Badgerys Creek AWS (67108) in °C

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Lowest													
temperature	8.2	8.5	6.4	-0.1	-1.1	-3.0	-4.5	-1.9	-0.5	2.2	5.3	6.6	-4.5
Date of lowest	8	18	31	23	31	30	12	10	5	8	3	7	12
temperature	January	February	March	April	May	June	July	August	September	October	November	December	July
	1997	1998	2008	2006	2005	2010	2002	2008	2003	1998	2003	2002	2002
Highest minimum													
temperature	23.2	23.9	22.8	20.5	17.9	13.8	12.8	14.4	16.7	18.6	23.8	23.6	23.9
Date of highest	27	3	17	6	6	4	10	30	23	23	22	23	3
minimum	January	February	March	April	May	June	July	August	September	October	November	December	February
temperature	2001	2011	2000	1999	1998	2008	2001	2007	2003	2013	2006	2000	2011

	Summer	Autumn	Winter	Spring
Mean minimum temperature	16.5	11.3	4.7	10.5
Lowest mean minimum temperature	14.8	9.8	3.3	9.5
Year of lowest mean minimum temperature	1999	2008	2000	2003
10th percentile	15.6	10.5	3.7	9.7
90th percentile	17.1	12.3	5.6	11.2
Highest mean minimum temperature	17.5	12.5	6.6	11.5
Year of highest mean minimum temperature	2009	1998, 2014	1998	2014

Table 4-6 Seasonal minimum temperature statistics for Badgerys Creek AWS (67108) in °C

5 Hydrometeorological information

5.1 Background information

Intensity Frequency Duration (IFD) charts show the probability of a rainfall depth or intensity for a particular duration.

IFDs are used in design of hydraulic structures and they are presented here to assess the significance of rainfall events.

IFDs are derived using statistical analysis of historical rainfall collected from rainfall gauges. The statistics at the rainfall gauges are 'regionalised' to incorporate information from other nearby gauges. The technique of regionalisation enables more robust estimates of design rainfall to be determined than the use of gauge data alone particularly where gauges have a relatively short record length. The IFD information is interpolated onto a regular grid with a spacing of 0.025 degrees latitude and longitude.

Comparing rainfall at the Badgerys Creek site and Sydney Airport, has shown that there are differences in the mean and median monthly rainfall for the two sites which arise from the slightly more inland location of Badgerys Creek implying less exposure to maritime easterlies in the cooler months compared with Sydney Airport. The IFDs presented for both sites in section 5.1.1 are similar because they are situated relatively close to each other and there are no mountain ranges between them.

Information regarding using an IFD to assess the significance of rainfall events is given in Appendix C.

5.1.1 IFDs for Badgerys Creek and Sydney Airport

The figures and tables on the following pages show the IFD curves and tables for Badgerys Creek (67108) and Sydney Airport (66037) respectively, using the new 2013 IFDs available at: <u>http://www.bom.gov.au/water/designRainfalls/revised-ifd/</u>

Table 5-1 IFD table for Badgerys Creek (67108)

Location

Label: Badgerys Creek Latitude: -33.8969 [Nearest grid cell: 33.8875 (S)] Longitude:150.7281 [Nearest grid cell: 150.7375 (E)



Table Chart

IFD Design Rainfall Depth (mm)

Issued: 18 December 2014

	EY		Annual Ex	xceedance	Probabil	ity (AEP)	
Duration	1EY	50%	20%	10%	5%	2%	1%
1 min	2.0	2.3	3.2	3.9	4.5	5.4	6.1
2 min	3.2	3.7	5.1	6.1	7.1	8.5	9.6
3 min	4.5	5.1	7.1	8.5	9.9	11.9	13.5
4 min	5.7	6.4	9.0	10.8	12.6	15.1	17.1
5 min	6.7	7.7	10.7	12.9	15.1	18.1	20.4
10 min	10.6	12.2	17.4	20.9	24.5	29.3	33.1
15 min	13.3	15.3	21.7	26.2	30.7	36.7	41.5
30 min	18.0	20.6	29.2	35.2	41.2	49.3	55.7
1 hour	22.9	26.1	36.5	43.9	51.3	61.4	69.5
2 hour	28.7	32.5	44.7	53.5	62.4	74.8	84.7
3 hour	33.0	37.1	50.8	60.6	70.7	84.7	96.0
6 hour	42.6	47.9	65.2	77.8	90.8	108.9	123.6
12 hour	56.4	63.7	87.7	105.1	122.9	147.8	167.8
24 hour	74.9	85.7	120.7	145.8	171.4	207.0	235.4
48 hour	96.3	111.6	161.9	197.7	233.9	284.0	324.0
72 hour	108.3	126.3	185.3	227.3	269.9	328.8	376.1
96 hour	115.8	135.2	198.7	244.1	290.4	354.4	406.3
120 hour	120.7	140.8	206.0	253.0	301.1	367.8	422.6
144 hour	124.2	144.3	209.5	256.7	305.4	373.2	429.6
168 hour	126.6	146.6	210.5	257.0	305.5	373.3	430.4



IFD Design Rainfall Depth (mm)

Issued: 18 December 2014



Figure 5.1 IFD curves for Badgerys Creek (67108)

Table 5-2 IFD table for Sydney Airport (66037)

Location Label: Sydney Airport (66037) Latitude: -33 9465 [Nearest arid (

Latitude: -33.9465 [Nearest grid cell: 33.9375 (S)] Longitude:151.1731 [Nearest grid cell: 151.1625 (E)] NSW Sydnes Canberra ACT VIG ©2013 MapData Services Pty Ltd (MDS), PSMA

Table Chart

6 hour

12 hour

24 hour

48 hour

72 hour

96 hour

120 hour

144 hour

168 hour

IFD Design Rainfall Depth (mm)

Issued: 18 December 2014

Annual Exceedance Probability (AEP) EY Duration 50% 20% 10% 5% 2% 1% 1EY 5.7 1 min 2.4 2.6 3.4 4.0 4.5 5.2 2 min 4.0 4.4 5.6 6.5 7.3 8.4 9.2 3 min 5.5 6.0 7.8 9.0 10.2 11.7 12.9 11.4 4 min 6.8 7.6 9.8 12.9 14.8 16.3 5 min 8.1 8.9 11.7 13.5 15.3 17.6 19.3 10 min 12.7 14.1 18.5 21.5 24.3 28.0 30.8 15 min 15.8 17.6 23.1 26.8 30.3 34.9 38.4 30 min 21.6 24.1 31.5 36.5 41.3 47.5 52.2 47.1 67.8 1 hour 28.2 31.2 40.7 53.3 61.6 2 hour 36.0 39.8 51.9 60.3 68.5 79.6 88.2 104.4 80.3 93.8 3 hour 41.7 46.1 60.4 70.4

80.2

109.2

149.0

195.9

222.5

239.0

249.9

257.3

262.6

94.2

129.8

178.8

235.9

267.4

286.2

298.0

305.6

310.6

108.5

150.8

209.0

276.0

311.8

332.4

344.6

352.1

356.6

128.0

179.8

250.8

330.5

371.3

393.4

405.7

412.4

415.8

143.6

203.1

284.2

373.4

417.4

440.1

451.9 457.7

460.0

60.3

80.4

107.3

138.8

157.3

169.5

178.1

184.6

189.6

54.2

71.6

94.4

121.0

136.8

147.4

155.1

161.0

165.7

Tasman



IFD Design Rainfall Depth (mm)

Issued: 18 December 2014



Figure 5.2 IFD curves for Sydney Airport (66037)

5.1.2 Seasonality of rainfall events more rare than 1EY

In section 3.2.2 the frequency and days of when rainfall events equalled or exceeded a threshold for each month of the year were explored. The threshold value chosen was 6 mm/hr over a 60 minute period. Table 5-1 and Figure 5.1 show that this threshold value has probability of occurrence of more than 1EY (Exceedances per Year), therefore it would be a relatively common event occurring more than once per year on average.

The analysis below considers if the threshold chosen were to be a rarer event of 1EY and 50% AEP. The 1EY and 50% AEP rainfalls for a duration of 60 minutes were obtained from the IFDs and the number of values equalling or exceeding these values for each month of the year were counted for each month using the AWS data. Results are shown in Figure 5.3 and Figure 5.4. The number of days for each month having at least one event was also counted for 1EY and 50% AEP thresholds and results are shown in Figure 5.5 and Figure 5.6.



Figure 5.3 Number of rainfall occurrences with at least 1EY rainfall depth over 60 minutes for each month at Badgerys Creek (67108) and Sydney Airport (66037)



Total number days with at least one event >= 1EY over 60 minutes for each month in 16 years





Figure 5.5 Number of rainfall occurrences with at least 50% AEP rainfall depth over 60 minutes for each month at Badgerys Creek (67108) and Sydney Airport (66037)



Total number days with at least one event >= 50 % AEP over 60 minutes for each month in 16 years

Figure 5.6 Number of days with at least 50% AEP rainfall depth over 60 minutes for each month at Badgerys Creek (67108) and Sydney Airport (66037)

The results show that at the Badgerys Creek site events with a probability of 1EY and rarer are more likely to occur between November and March. At Sydney Airport events of 1 EY and rarer do not show such a strong seasonal signal. The data also suggests that during the last 16 years events rarer than 1EY have occurred more frequently at Badgerys Creek than Sydney Airport, despite the two sites having similar mean rainfall and frequency of events receiving 6 mm per hour. However, this is not necessarily an indication that this pattern is likely to remain so. It could be a result of decadal scale rainfall variability.

6 Fog (visibility <1000m)

The AWS at Badgerys Creek currently does not have the capability to determine visibility and cloud. Instead, these parameters have been based on the instrumentation at Camden Airport. Camden Airport is less than 20km to the south of Badgerys Creek and is a similar distance to the east of the Great Dividing Range. Camden Airport has been identified by meteorological forecasters as the most representative site available for fog statistics.

Senior meteorologists experienced in forecasting for the Sydney Basin suggest that fog at Badgerys Creek is likely to occur more often than fog at Camden Airport. However without adequate instrumentation it is impossible to confirm the frequency of fog at Badgerys Creek.

Camden Tower operated by Airservices personnel is active between 2200 – 0800UTC and does not regularly report weather phenomena. It is impossible to verify the occurrence of all operationally significant fog events at Camden Airport without 24hr manual input because the instrument observing visibility reports shallow fog identically to deeper fog events. For the purposes of this section, fog will be said to have occurred when the visibility meter records a horizontal visibility below 1000m as a 10 minute average.

6.1 Camden Airport Monthly 10-minute visibility statistics

Data was available at Camden Airport in 10-minute increments.¹ Approximately 4.5% of the data set did not contain an observation of visibility and cloud due to numerous factors including maintenance and quality control. With a total of 222,488 observations in the data set it was assumed that the missing data was not statistically significant.

The remaining observations were analysed to obtain the number of days in which the visibility dropped below 1000m for a 10-minute period or more for each month. An average was calculated using the four years of data (refer to Figure 6-1), and a fourth order polynomial trend line has been superimposed on to the monthly averages. Associated with the average is a minimum and maximum to indicate the spread of data from year-to-year.

¹ Unless otherwise stated the 10 minute data for Camden Airport was analysed from 26 Aug 2010 to 18 Oct 2014.



Days with visibility <1000m

Figure 6.1 Monthly number of Days of Visibility <1000 m at Camden

The graph shows that short periods (ten minutes) of low visibility are common during the winter months, and can occur in every month of the year. It was calculated that for the 50 months studied the visibility dropped below 1000m over a 10-minute period at least once on 39% of days. Although short periods of reduced visibility can be of concern, generally they pose no large impact on airport operations.

6.2 Camden Airport hourly visibility statistics

Whilst 10-minute data is desirable for analysis of fog events, the four year record at Camden Airport is too short for climatic trends to be determined. Additional analysis has been completed on a longer period of 30-minute data to determine the percentage occurrence of visibility conditions below 800 m at each hour of the day for each month of the year. Camden Airport data from 1 May 1995 to 5 December 2014 (as recorded by the visibility meter) was used for this analysis (see Table 6-1).

Time(UTC)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0000	0.0	0.0	0.0	0.0	0.0	0.3	0.8	0.0	0.0	0.0	0.0	0.0
0100	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0
0200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0400	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0
0500	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3
0600	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
0700	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
0800	0.0	0.0	0.0	0.0	0.3	0.6	0.3	0.0	0.0	0.0	0.0	0.0
0900	0.0	0.0	0.0	0.0	0.0	1.7	2.0	0.0	0.0	0.0	0.3	0.0
1000	0.0	0.0	0.0	0.6	0.8	2.8	2.2	0.0	0.0	0.0	0.0	0.0
1100	0.0	0.0	0.0	0.9	1.9	4.8	5.0	0.3	0.3	0.3	0.0	0.0
1200	0.0	0.0	0.0	0.9	3.0	6.0	7.8	2.2	0.3	0.5	0.0	0.0
1300	0.3	0.0	0.8	3.5	6.8	10.8	9.8	4.4	0.8	1.3	0.6	0.3
1400	0.0	0.9	0.3	4.9	9.6	11.4	15.7	4.9	2.2	2.7	1.4	0.3
1500	1.2	0.3	3.2	10.4	10.7	16.6	16.8	7.5	4.5	3.0	2.5	0.9
1600	1.5	2.5	5.9	14.5	17.0	16.0	18.8	9.4	9.0	5.7	3.0	1.7
1700	1.8	3.1	9.9	18.0	19.5	14.9	21.8	11.9	10.5	8.9	6.1	3.2
1800	3.3	4.3	13.2	16.5	16.3	15.6	19.7	12.2	11.1	11.6	8.4	5.0
1900	4.9	5.6	14.9	20.0	15.7	14.7	22.2	13.2	14.7	13.2	8.4	5.6
2000	2.1	4.1	15.3	15.9	14.6	12.6	21.6	11.8	14.4	6.7	3.3	1.2
2100	0.3	0.6	5.6	10.1	14.5	11.0	16.9	11.3	3.7	1.1	0.6	0.6
2200	0.0	0.0	0.5	1.4	3.0	6.0	7.3	3.0	0.9	0.5	0.0	0.0
2300	0.0	0.0	0.0	0.3	0.6	1.7	2.0	0.8	0.0	0	0.0	0.0

Table 6-1 Table of percentage monthly occurrence of visibility <800m for each hour of the</th>day at Camden Airport

Table 6-1 shows that fog occurs more frequently during the late evening to mid-morning in winter months, particularly in July from 3am to 6am LST (1700-2000 UTC) when fog is reported on approximately one in five mornings. Whilst fog is not as prevalent in summer, fog is not uncommon in the early hours of the morning at Camden Airport. A statistical comparison between Camden Airport, Sydney KSA, Canberra Airport and RAAF Base Richmond for the months of June and July is illustrated in Table 6-2. All available data were included (Camden Airport –May 1995 to Dec 2014, Sydney Airport – Oct 1948 to Dec 2014, Canberra Airport –Jan 1985 to Dec 2014, and RAAF Base Richmond - 28 Apr 1995 to 27 Jan 2014).

	Camden Airport		Sydney	Airport	Canberr	a Airport	RAAF Base Richmond		
Time(UTC)	Jun	Jul	Jun	Jul	Jun	Jul	Jun	Jul	
0000	0.3	0.8	0.2	0.2	2.8	2.1	1.1	1.3	
0100	0.0	0.3	0.1	0.0	0.5	0.1	0.0	0.0	
0200	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0300	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0400	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0500	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0700	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
0800	0.6	0.3	0.0	0.0	0.0	0.0	0.6	0.2	
0900	1.7	2.0	0.0	0.0	0.1	0.1	0.6	0.2	
1000	2.8	2.2	0.0	0.0	0.6	0.3	1.5	1.1	
1100	4.8	5.0	0.0	0.0	1.3	0.1	2.7	1.7	
1200	6.0	7.8	0.1	0.0	1.5	0.1	3.5	3.2	
1300	10.8	9.8	0.1	0.0	1.8	0.7	6.9	6.1	
1400	11.4	15.7	0.3	0.0	2.6	1.1	10.8	7.8	
1500	16.6	16.8	0.4	0.3	3.5	1.6	13.4	10.2	
1600	16.0	18.8	0.4	0.3	5.3	3.1	16.3	15.4	
1700	14.9	21.8	0.7	0.1	6.9	4.3	18.9	16.4	
1800	15.6	19.7	1.4	0.2	10.2	6.5	19.6	20.7	
1900	14.7	22.2	1.3	0.5	10.8	7.7	20.4	21.2	
2000	12.6	21.6	1.5	0.6	10.3	9.4	22.0	22.1	
2100	11.0	16.9	1.7	0.5	11.6	10.4	21.2	17.2	
2200	6.0	7.3	1.5	0.7	11.2	9.0	12.2	10.3	
2300	1.7	2.0	1.0	0.4	7.0	6.0	5.1	7.5	
Mean	6.2	6.5	0.4	0.1	3.6	2.6	7.4	6.8	

Table 6-2 Comparison table of percentage likelihood of visibility <800m for each hour of the day in June and July

By considering the 15% threshold it can be seen that Camden Airport has a probability of fog greater than 15% between the hours of 1500 to 1900UTC. RAAF Base Richmond has slightly longer hours of between 1600 to 2100 UTC. Canberra Airport breaches the threshold in June for two hours (2100 to 2200UTC), whilst Sydney KSA probability of fog does not exceed 2%.

From Table 6-1, it can be calculated that fog occurs approximately 30 times more often at Camden Airport than at Sydney KSA; and approximately 2 times more often at Camden Airport than at Canberra Airport. Alternatively, fog at RAAF Base Richmond is recorded on average an additional 10% of the time more than at Camden Airport.

Data in Table 6-2 are displayed graphically for the months of June and July in Figure 6.2 and Figure 6.3 respectively.



Figure 6.2 Line graph of percentage occurrence of visibility <800m for each hour of the day in June



Figure 6.3 Line graph of percentage occurrence of visibility <800m for each hour of the day in July

As Sydney Airport rarely sees fog, Canberra Airport is a more relevant airport to compare Camden Airport with to gain a relative perspective. Figure 6.2 and Figure 6.3 show that fog at Camden Airport more commonly forms earlier in the night than at Canberra Airport, with peak occurrence between 1700 UTC and 2100 UTC, whilst fog at Camberra Airport has a peak occurrence around 2200 UTC. Fog occurrence at Camden also tends to drop off earlier in the morning than at Canberra Airport.

6.3 Camden Fog Event Frequency

Further analysis was completed on the data to determine the frequency of fogs that lasted for periods equal to and greater than 1 and 4 hours. These longer periods with visibility continually below 1000m were termed fog 'events'. An average number of fog events per month over the four years of data was examined and has been supplied in Figure 6-4 below.



Figure 6.4 Monthly bar graph of number of days with fog events at Camden Airport

The number of events lasting an hour or more occurs on average more than 10 days a month during April to July. The average number of events that lasted more than 4 hours occurs two or more days a month during May to September.

7 Conclusion

This report has described the average climate of Badgerys Creek, with particular attention given to temperature, rainfall, wind and fog frequency. Comparisons between Badgerys Creek and Sydney Airport were given for heavy rainfall and potential fog events.

Badgerys Creek experiences slightly more frequent heavy rainfall events than Sydney Airport, however this was found to be within the range of normal rainfall variability. Camden airport, and most likely at Badgerys Creek, also experiences significantly more fog events than Sydney Airport. These fog events can occur during all months of the year, and can last for an extended period of time.

A detailed discussion of these parameters and their impact on potential airport operations is provided in the Western Sydney Airport Usability Report.

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