PORT PHILLIP BAY ENVIRONMENTAL STUDY

LITERATURE REVIEW
OF
METEOROLOGICAL ASPECTS OF
PHYSICAL AND CHEMICAL ATMOSPHERIC
INPUTS

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Literature review of meteorological aspects of physical and chemical atmospheric inputs

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1 Meteorological Aspects

The principles used in compiling this literature review were as follows:

1. Sources of published climatological data were identified so as to enable future researchers to access these data.

2. Analyses of the published climatological data were critically reviewed.

3. Established atmospheric processes were identified and summarised.

These principles were followed so as to assist the future participants in the Port Phillip Bay Study to determine the need to collect further meteorological and atmospheric data; to determine the requisite variables and their spatial and temporal distribution; and to determine the representativeness of any future data collection period.

1.1 Introduction

Port Phillip Bay, being situated in south-eastern Australia, has a climate that Gentilli (1972) classifies as cool and moist. Its general characteristics are that the number of rain days peaks in winter (as does the occurrence of fog), the temperature peaks in February - with daily mean February air temperatures less than 22•C - and that the short local water-courses do not run completely dry in summer, showing that climatologically the summer's drought is not extreme. Figure 1 depicts Port Phillip Bay and shows the locations of the stations from which long-term climatological data are available.

The meteorological aspects of Port Phillip Bay as a whole have not been well covered in existing literature. Literature searches on *Port Phillip Bay* were conducted on the Australian Bibliographic Network, on the Australian Bibliography of Agriculture, on Environmental Research in Progress, and on the GEAC Library System.

These yielded numerous references to the marine aspects of Port Phillip Bay, but only one reference related to meteorology (Bureau of **Meteorology,** 1966). Information as to the meteorology of the Bay has to be interpolated from literature dealing with the locations along the shores of the Bay where meteorological data have been gathered.

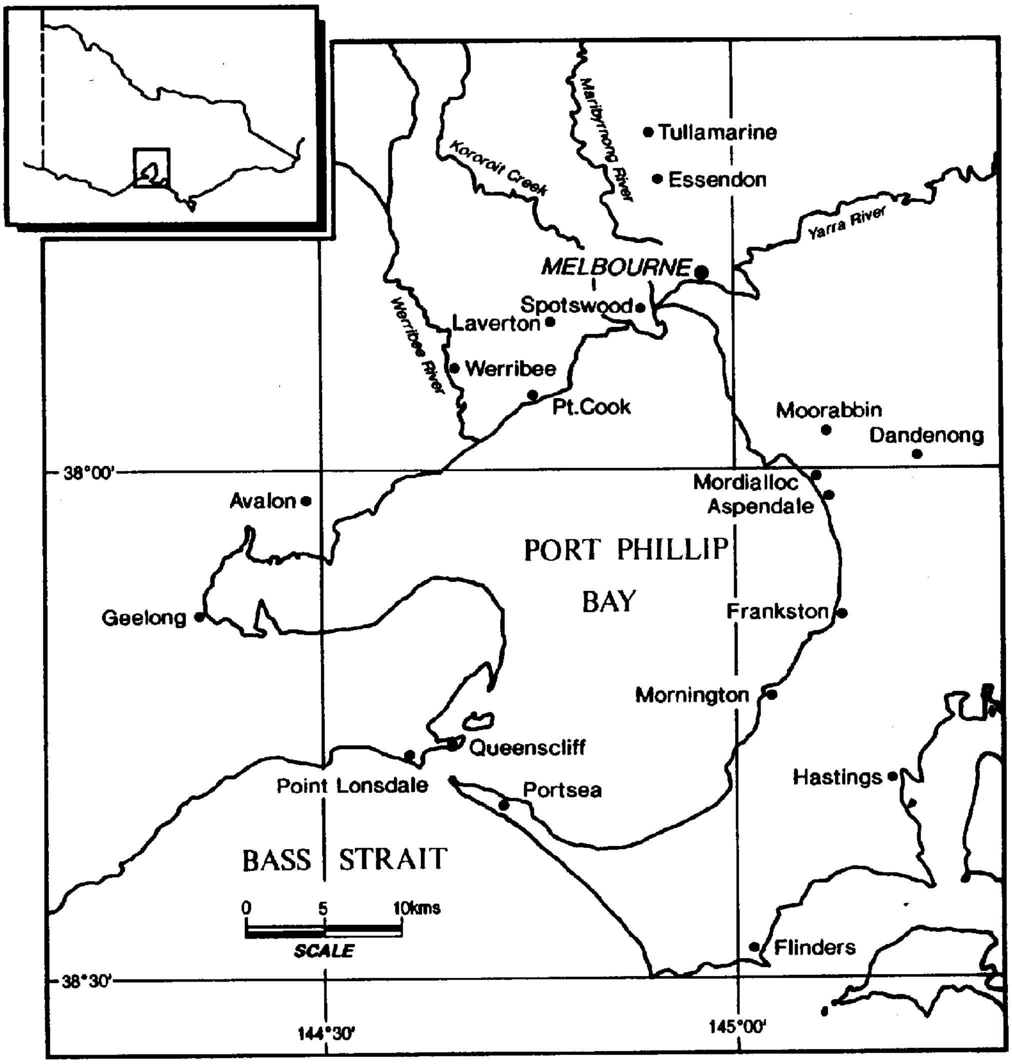

Fig. 1 - Map of Port Phillip Bay showing locations of data collection stations.

2 Wind speed and direction

Wind varies in magnitude and direction over the course of a day. It is appropriate for this literature review to consider it as being composed of two components, namely:

a synoptic component whose magnitude and direction are controlled by the synoptic meteorology, and

a mesoscale component whose magnitude and direction are influenced by the local details of Bass Strait, Port Phillip Bay and its surrounding topography.

2.1 Wind climatology

The longest records of wind speed and direction have been collected by anemographs situated at the airports surrounding Port Phillip Bay which are:

Avalon (38•2'S, 144•29'E), Laverton (37•52'S, 144•44'E), Point Cook (37•56'S, 144•45'E), Essendon (37•44'S, 144•54'E), and Moorabbin (37•59'S, 145•6'E).

Statistics of these wind data may be found on the World Weather Disc (Weather Disc Associates, 1990) but are limited to statistics (on a monthly and annual basis) of interest to aviation, which are:

i) Percentage frequency of wind speed greater than or equal to 17 knots. ii) Percentage frequency of wind speed greater than or equal to 28 knots. iii) Mean number of days when there is no precipitation and the surface wind speed exceeds 17 knots at 1000, 1600, 2200 and 0400 hours.

The wind data from Essendon, Laverton and the Melbourne Regional Of fice have been analysed in more detail by the Bureau of Meteorology (1968) who give monthly tables of the number of occurrences linking wind speed (in nine classes plus calms) and wind direction (in eight classes, plus calms).

Abbs (1984) obtained data from anemometers operated by agencies in addition to the Bureau of Meteorology, and presented wind roses of the climatological data for 9am and 3pm as shown in Fig. 2. Brook (1974) presents a wind climatology based on anemometers situated at Victoria Dock.

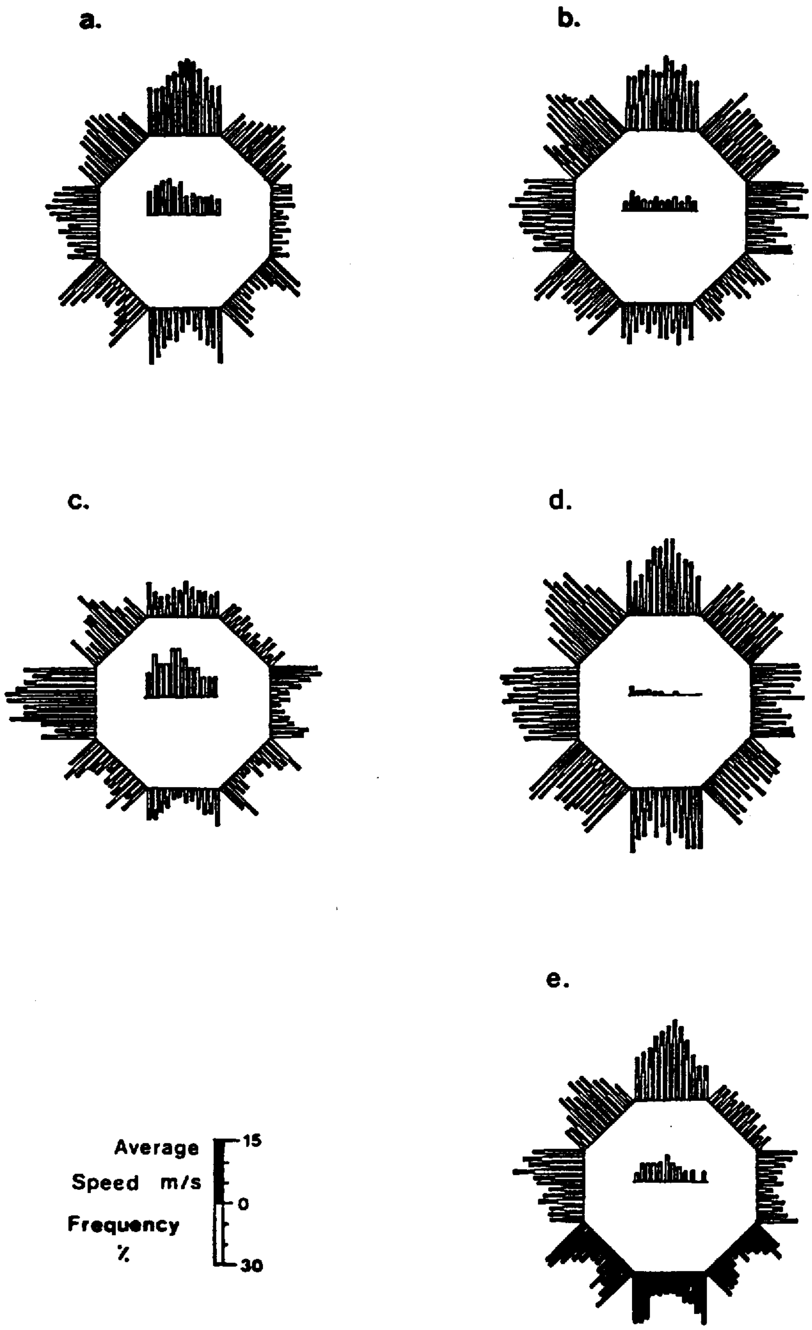

Fig. 2a Wind roses for 9am at (a) Melbourne, (b) Mt. Dandenong, (c) Geelong, (d) Pt. Lonsdale, and (e) Aspendale. The monthly average speed and frequency are shown for each octant for January to December. The monthly frequency of calms at each site is indicated in the centre of each wind rose. North is to the top of the figure. The monthly frequencies are shown in clockwise order. (Abbe, 1984)

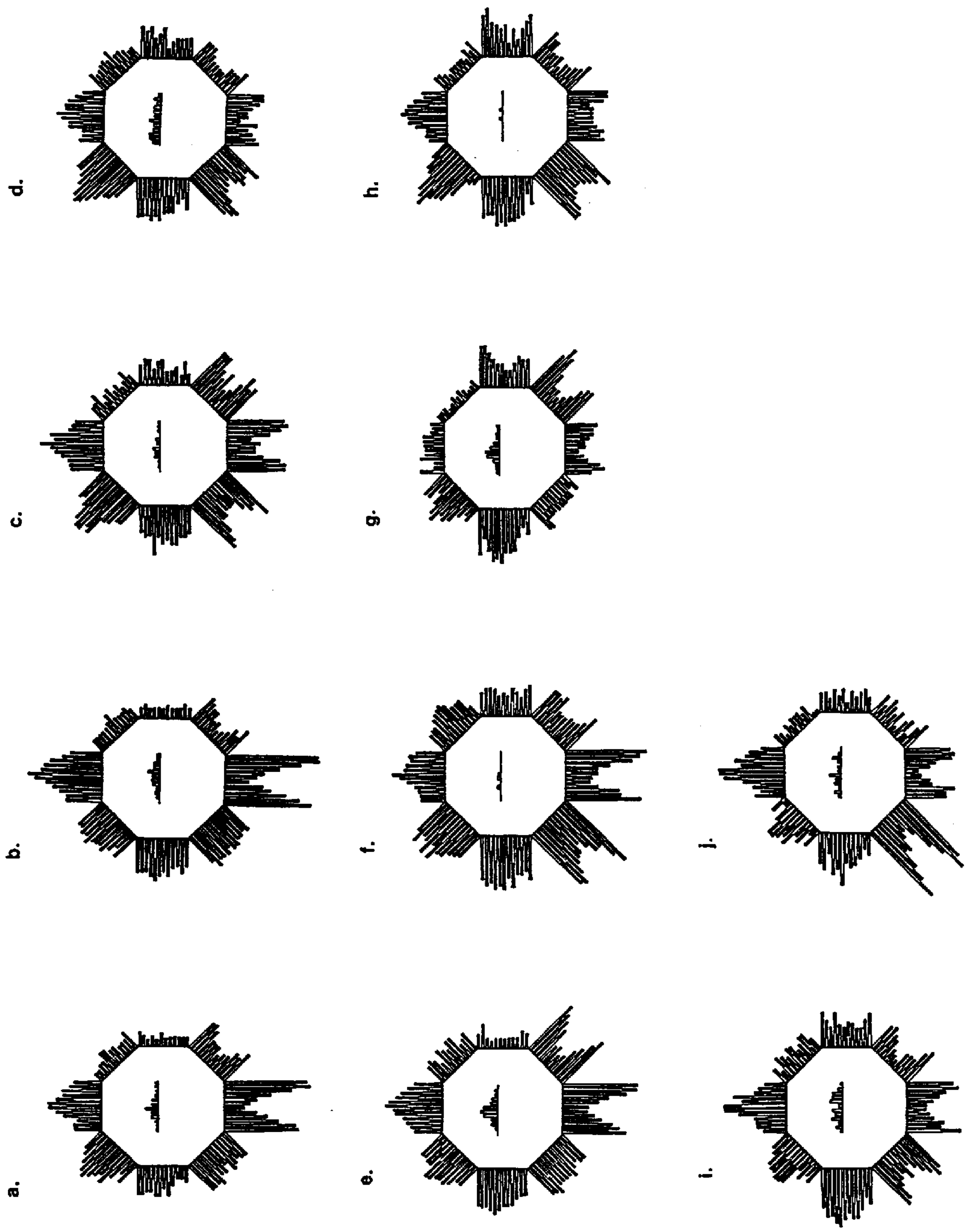

Fig.2b: Wind rosea for 1500 at (a) Melbourne, (b) Essendon, (c) Stony Pt., (d) Mt. Dandenong, (e) Laverton, (f) Pt. Lonsdale, (g) Geelong, (h) Cape Schanck, (i) Mornington, and (j) Aspendale.

2.2 Wind Speed statistics

The report by the Bureau of Meteorology (1966) consists of a theoretical study of the effects of wind duration and fetch on Port Phillip Bay so as to enable regional forecasters to equate Beaufort Force to sea state within the Bay - as given in Table 1.

Table 1

Bureau of Meteorology (1966) sea state categories for Port Phillip Bay

Wind properties			Waves in Port Phillip Bay	
Beaufort Force	Knots	Description	Height (m)	Description
1	1-3	Light air	O	Calm
2	4-6	Light Breeze	0 - 0.3	Smooth
3	7-10	Gentle Breeze	0.3 - 0.6	Slight
4	11-16	Moderate Breeze	0.6- 1.0	Choppy
5	17-21	Fresh Breeze	1.0- 1.6	Rather rough
6	22-27	Strong Breeze	1.6 - 2.0	Rough
7	28-33	Near Gale	2.0 - 2.6	Very Rough
8	34-40	Gale	2.6 - 3	High
9	41-47	Strong Gale	3.3 - 4	Very High

The Bureau undertook a similar, but more comprehensive and better documented study for winds and waves in Bass Strait (Falconer & Linforth, 1972). Extreme wind speeds, between 1951 and 1967, and their corresponding directions, were estimated from synoptic charts - and a Gumbel extreme value distribution was fitted to the results to produce the results given in Table 2.

Table 2
Return periods of extreme wind speeds at 39•S, 143•E
from Falconer & Linforth (1972)

Return Period (years)	Wind speed (Knots)	Wind speed (m s-1)	Wind speed (km h-1)
2	53	27	98
5	64	33	119
10	72	37	133
20	79	41	146
50	88	45	163

2.3 Synoptic Winds

The synoptic winds are the winds that arise from large-scale pressure gradients, such as those to be found on weather maps. Climatological wind roses are shown in Fig. 2a and 2b. On the exposed south coast of Port Phillip Bay moderate to fresh southerlies predominate in summer and are exacerbated by the sea breeze in the afternoons. In winter the winds are mainly north-west with a northerly tendency in the morning and a westerly tendency in the afternoon; the winter winds are mainly moderate to fresh but become strong to gale force at times with the passage of storms.

According to Bureau of Meteorology (1968: p. 78), there is little variation in mean monthly wind speed at Melbourne, but the autumn months have lighter winds than other months. The Victorian EPA (pers. comm.) indicates that the mean daily wind run at Melbourne when averaged over a month ranges from 245 km to 309 km indicating at least a 26% variation. In the mornings, northerlies prevail for most of the year except in summer when southerlies are the prevailing winds. In the afternoons southerlies predominate except in winter when the main winds are northerly. The winds at Melbourne are indicative of the synoptic pattern over the whole Bay, but there is a modification of the wind roses as one moves southward due to the sea breeze effects of Port Phillip Bay itself. There is also an east-west funnelling in the vicinity of Geelong which increases the frequency of easterlies and westerlies in Corio Bay. Easterly winds are also more frequent south of Frankston due, presumably, to the better exposure south of the Dandenong Ranges.

There are two synoptic situations that deserve special mention: cold fronts, and northerly winds.

2.3.1 Cold Fronts

Cold fronts are important to the meteorology of the Bay for a number of reasons. Over a relatively short period of time the wind direction changes, the wind speed increases and peaks, the humidity increases, the temperature falls, there is a decrease in solar radiation associated with increased cloud, and often there is enhanced rainfall.

Winter cold fronts

Cold fronts emanating from low pressure systems centred over the Southern Ocean occur frequently during the winter months. In general, they produce most precipitation near the coast and less inland. In Melbourne, the average rainfall total during June, July and August is 148 mm (Bureau of Meteorology, 1988) there being about 15 rain days a month. During the passage of a winter front the surface wind typically backs from the northwest to the southwest. Unlike the summertime cool change, where the temperature change across the front may exceed 10•C, the temperature change across the wintertime front is of the order of a few degrees. The heaviest rainfall is associated with the mesoscale ascent in the vicinity of the front. Studies by Kamiko (1964, 1965) and May et al. (1990) have documented the synoptic structure of mature winter cold fronts over relatively flat terrain.

Summertime cold fronts

The cold front in summer is a more noticeable phenomenon because it is characterized by an extreme temperature fall as strong, hot, and dry northerly winds are replaced with much cooler southerly winds from the Southern Ocean so that falls of 10 to 15 C• in a few tens of minutes frequently occur.

Garratt (1988) has shown that there is a difference between early summer and late summer cold fronts. Those occurring in late spring and early summer have substantial middle level cloud associated with a pre-frontal trough. Late in summer it is more frequent for there to be an absence of strong convection and a coastal trough forms (generally in association with the sea-breeze) which does not bring much, if any, rain. Reeder & Smith (1992) provide a comprehensive review of the dynamics of summertime cold fronts.

2.3.2 Northerlies

Summer northerlies are responsible for extreme temperatures over Port Phillip Bay (Stern, 1982) and the whole of Victoria. Because the air trajectory associated with a synoptic high pressure system over the Tasman sea includes a large area of inland Australia, the air arriving in Victoria is hot and dry. The major bushfires of Black Friday (13 January 1939) and Ash Wednesday (16 February 1983) were associated with this synoptic pattern. The Ash Wednesday fires were exacerbated by a record low humidity and a late summer dry cold front moving through late in the day.

2.4 Mesoscale Winds

Mesoscale winds arise from local topographic effects. Though their effect will show up in climatological wind roses, they cannot all be inferred from weather maps: those caused by orography are the main example.

2.4.1 Sea Breezes

Sea breezes are the winds resulting from the temperature difference between the land and the sea. They are a frequent summer phenomenon around Port Phillip Bay. Abbs (1984) conducted a major observational and numerical modelling study of sea breezes over southern Australia, including Port Phillip Bay. She differentiated between the bay breeze - which is marked by a change in wind direction to onshore flow from Port Phillip Bay (or in the case of onshore flow, a freshening of the wind); and the ocean breeze which is a change in wind direction to flow from Bass Strait, in which case the wind direction is generally from the south or southeast. On a day of slack pressure gradient the bay and ocean breezes initially have a direction perpendicular to their coastline of origin, while on days of strong gradient wind they combine with these winds vec tori al l y .

Abbs (1984) showed that it was possible to use numerical models to realistically simulate the progress of the sea breeze winds over Port Phillip Bay for given conditions of synoptic wind, and sea and air temperatures.

Bay breeze
The bay breeze occurs on approximately 50% of summer days at wind measuring stations on the shores of the bay with an onset typically at noon, and a duration of approximately six hours. The time of bay breeze decay appears to be related to the distance from the Bass Strait coast so that the bay breeze decays first at Moorabbin, followed by Avalon, Laverton, Melbourne, Tullamarine and Essendon. This indicates that the pattern of decay is related to the ocean breeze. The average speed of the bay breeze at the shoreline is in the 4.5 to 5.0 m s~' range, and the average maximum speed is only slightly higher in the 5.2 to 5.6 m s~' range.

Ocean breeze
The summer-time occurrence of the ocean breeze varies with position along the Bay. It occurs on 36% of days during summer in Moorabbin, 21% at Avalon and only 16% at Laverton. The ocean breeze has a later onset than the sea breeze, typically at 1530 at Avalon, 1720 at Laverton and 1725 at Moorabbin. The duration is such that it decays by 2100 hours. The average speed of the ocean breeze ranges from 3.2 m s~' at Moorabbin to 5.0 m s ' at Avalon, with average maximum speeds at these locations of 3.9 m s' and 6.6 m s -1 respectively.

2.4.2 The Melbourne Eddy

When the surface wind in central Victoria comes from the east to north-east and the lower atmosphere is stably stratified then the Australian Alps block the air flow. The air flows around the Alps instead of over them. This flow pattern creates one or more closed circulations (or eddies) in the wake of the Alps.

It is known from laboratory simulations (Spillane, 1978) and surface wind trajectory analyses (Melbourne Airshed Study, 1985) that the eddy tends to have a diameter of either about 30km or about 60km and in many cases is responsible for transporting automotive emissions from the eastern suburbs, across Port Phillip Bay to the western suburbs of Melbourne, and at the same time transporting industrial emissions from the western suburbs to the eastern suburbs. If the eddy lingers then the emissions can be transported back to their source. At upper levels the eddy is maintained by subsidence inversions. The eddy is much deeper than drainage flows and dominates over them and the gradient flows. As morning heating intensifies the eddy weakens and decays. McGregor & Kimura (1989) and Johnson (1992) have produced successful numerical models of the eddy. Manins (1989) summarises both the numerical and laboratory modelling work.

3 Rainfall

There is a substantial gradient of rainfall across Port Phillip Bay, increasing in a southeastward direction (Bureau of Meteorology, 1968). Laverton has a mean annual rainfall of 566 mm (over 45 years of record, as quoted in Bureau of Meteorology, 1988) whereas Mornington to the southeast has a mean annual rainfall of 735 mm based on 101 years of record (Bureau of Meteorology, 1988). The catchments of the Maribyrnong and Werribee Rivers are in a marked rain shadow compared to the catchment of the Yarra River so that most freshwater input to Port Phillip Bay will be from the eastern side of the Bay. Bureau of Meteorology (1968) provides a detailed assessment of the rainfall climatology of the region using rainfall records up to 1968.

Fowleret al. (1991) noted that in Melbourne, the summer and winter totals for rainfall are similar (155 and 149 mm respectively), but the amount of 5.9 mrn rain per rainday in summer (with 26.1 raindays on average) is nearly twice that of winter when there is 3.1 mm rain per rainday (over 48.4 raindays on average). The oft-quoted remark that rainfall predominates in winter is incorrect with respect to mean rainfall, but refers to the number of raindays. In fact, examination of the rainfall percentiles for Melbourne (Bureau of Meteorology, 1968: Table 2) indicates that the 90-th percentile rainfall in summer (326 mm) is greater than the 90-th percentile rainfall in winter (233 mm).

3.1 Extreme rainfall events

Table 3
Extreme rainfall observations (mm) at Laverton, Spotswood and Mordialloc

Duration (min)	6	120	180	240	720
Laverton	11	105	138	154	185
Spotswood		68		76	102
Mordialloc		38		50	55

Despite Laverton being in a rain shadow, it is possible for it to receive extremely heavy rainfall. Bureau of Meteorology (1985) lists notable point rainfall events in Victoria; the storm of 7 April 1977 produced very large values at Laverton as given in Table 3. Each value in this table nominally represents a distinct rainfall event, but in the case of Laverton, all the extreme readings occurred during the single storm of 7 April 1977. For example, the maximum rain produced over a duration of 120 min. in the Laverton storm was 105 mm. The length of Laverton rainfall record at the time of the 1985 report is not given, but can be inferred from Bureau of Meteorology (1988) which lists 45 years of record for Laverton. Table 3 also reproduces values taken from Bureau of Meteorology (1968: Table 12) for the greatest amounts of rain at Spotswood between 1931 and 1960, and at Mordialloc between 1942 and 1957.

3.2 ENSO effects

Major droughts in Australia are related to the sea-surface temperatures and air pressures over the Pacific ocean and tend to occur when air pressures in the Australian tropics and the eastern equatorial Pacific sea-surface temperature are both high (Nicholls, 1985).

This combination isknown as an El-Nino Southern Oscillation event (ENSO). During the last century the events of 1891, 1925-26and 1982-83 were very strong(Quinnet al., 1987). Howeverit would appear that only the event of 1982-83 was manifested as a drought over the Port Phillip Bay region (Reynolds et al., 1983). The fact that ENSO events only rarely manifest themselves over Port Phillip Bay is confirmed by the study of Whetton (1986) who statistically analysed Victorian rainfall data and found that only the Northern Victorian rainfall showed a correlation with ENSO events.

4 Evaporation

The Bureau of Meteorology (1968) report contains an analysis of the mean monthly and annual evaporation from Australian standard evaporation tanks for Melbourne and for Werribee from 87 and 47 years of data respectively. There are slight differences at the two locations; Melbourne recorded a mean annual evaporation of 1001 mm, while Werribee recorded 1138 mm. McIlroy & Angus (1964) give a detailed account of monthly and annual evaporation results from three years of data at Aspendale and compare water lysimeters, the Australian standard evaporation tank, and the Class A evaporation pan. The annual average evaporation readings were 1095 mm, 1241 mm and 1548 mm respectively.

McIlroy & Angus (1964) also compute the evaporation using the combination method, and obtain a mean annual average evaporation of 1402 mm. Because it is difficult to obtain good evaporation readings, in section 8.1 we shall advocate inferring evaporation using the combination equation. The remainder of this section is therefore devoted to a description of the combination method.

4.1 Combination method

The combination method of estimating evaporation was developed by Penman (1948) as an empirical relation. It assumes that the total evaporation is due to two terms; an energy component, *Qn,* which is determined solely from incoming and outgoing radiation, and an aerodynamic term which depends on the wind speed and the vapourpressure deficit. Monteith provided the method with a firm theoretical basis when he showed from first principles (see e.g. Monteith, 1973, 1981) that the latent heat flux from a saturated surface is

$$LE = \frac{\Delta Q_n + \psi[\rho_a c_p (e_s - e)/(\xi\psi)]}{\Delta + \psi} \quad \text{(Eq. 5.1)}$$

where L (J kg-') is the latent heat of vaporisation, E (kg m-2 s') is the evaporation, *Qn* (W m~2) is the nett radiation, Pa (kg m~3) and *cp* (J kg-' K-']) are the density and specific heat of air respectively, § (s m ') is the aerodynamic resistance, _ (hPa K-') is the gradient of the saturated vapour pressure *(eS)* with temperature and ¥ (hPa K-') is the psychrometric constant. The variable e represents the vapour pressure at screen height. Beer (1991) provides a computer program that produces tables of this quantity.

4.2 Aerodynamic term

The Penman equation in the form of Eq. 5.1 is a theoretical expression describing the instantaneous partitioning of energy and as such is valid over small periods of time. If it is used in this manner then the appropriate aerodynamic resistance is the theoretical value which, under conditions of neutral stability, is

$$\xi = \frac{6.25}{u}\left[\ln\left(\frac{z}{z_0}\right)\right]^2$$

(Eq.5.2)

where Garratt (1977) provides estimates of the roughness length z0 over open water. If data are acquired on a longer term (e.g. daily) basis then the empirically determined aerodynamic resistance, §, for a neutrally stable atmosphere, is (Thom & Oliver, 1977)

$$\xi = \frac{4.72}{(1+0.54u)}\left[\ln\left(\frac{z}{z_0}\right)\right]^2$$

(Eq.5.3)

where the reference height for anemometry is z = *2* m and where z0 = *1.37* mm for open water surfaces (Thom & Oliver, 1977: p.351). The wind speed, u, is in m s-1.

If one uses the combination method to estimate daily evaporation then mean daily values of the wind speed, nett radiation, and humidity variables are needed. Furthermore, many of the variables in Eq. 5.1 are temperature dependent, so that one needs a value for the daily mean temperature, so as to permit the user to calculate the appropriate density, specific heat, saturated vapour pressure and its gradient, and psychrometric constant. The mean value of the vapour pressure, e, needs to be determined and this can be done either from the mean values of dry bulb temperature and wet bulb temperature (as obtained from standard meteorological stations), or from temperature and dew point, or from temperature and relative humidity using tables such as those of Beer (1990). This procedure is illustrated in section 7 and Table 5.

Doorenbos & Pruitt (1984) recommend that in using the combination method to estimate daily evaporation, one should use the mean temperature, < T >, which in normal meteorological practice is defined as < T > = (Tmax + Tmin)/2. Alternatively, the 9am temperature reading provides an approximation to < T >. If daily relative humidity readings are available then one should use the average of the maximum and minimum daily relative humidities. If these are lacking then in non-arid parts of the world it is acceptable to use Tmin as an approximation to the dewpoint temperature.

5 Air Temperature

The air temperature is measured at a number of stations around the shores of Port Phillip Bay, but it is noteworthy that we have been unable to locate any study that deals - either directly or indirectly -with the air temperature over the waters of the Bay. Even though a number of organisations, including the CSIRO Division of Atmospheric Research, regularly monitor satellite observations and infer sea surface temperatures, there seems to have been little of this material actually published.

Statistical summaries of the temperature data for stations on the shores of Port Phillip Bay may be found in CDCD, the World Weather Disc, and Bureau of Meteorology (1968, 1988). Table 4 lists the monthly average 9am dry bulb temperatures (to the nearest integer) from CDCD. It is noticeable that compared to Melbourne, the mean temperature at the coast is cooler in summer and warmer in winter, by about one degree. Bureau of Meteorology (1968) provides contours of mean maximum temperatures, and mean minimum temperatures annually, and at selected months. In every case there is a temperature gradient such that the coastal locations have lower maximum temperatures, and higher minimum temperatures, than locations along the shoreline of the bay, with the section of Port Phillip Bay near Melbourne having the highest maximum, and lowest minimum readings.

Table 4

Monthly average 9am dry bulb temperatures

	J	F	M	A	M	J	J	A	S	O	N	D
Melbourne RO	19	19	17	14	11	09	08	09	12	14	16	17
Portsea Quarantine	18	18	17	15	12	10	09	10	11	13	14	16

Brook (1974: p.52) plots contours of the annual march of the diurnal variation of the hourly average of the mean temperature, and of the mean lapse rate.

5.1 Extreme temperatures

Maximum

The maximum air temperatures over Port Phillip Bay are associated with summer northerlies (Stern, 1982), and the maximum temperature recorded in Melbourne was 45.6•C at 12.30pm on 13 January 1939. By contrast the highest recorded at Mornington up to 1968 was 41.1•C. Between 1855 and 1964 there were 3 occurrences in Melbourne when the daily maximum temperature exceeded 40.5•C for three days in a row, and 11 occasions when it exceeded this value for two days in a row. A table of Melbourne hot spells may be found in Bureau of Meteorology (1968).

Minimum

The lowest temperature recorded in Melbourne (Bureau of Meteorology, 1968) is -2.7•C, whereas the lowest recorded at Mornington is - 1.1 •C. These temperatures occurred during July. A table of Melbourne cold spells may be found in Bureau of Meteorology (1968).

5.2 Melbourne Heat Island

Melbourne, in common with many cities, exhibits an urban heat island effect in which there is a warming due to anthropogenic energy usage, and modifications of the albedo. There has been no systematic study of this published though Tapp (1977) and Bond (1974) confirm that thereis an ncrease of about 4 to 6•C in temperature within Melbourne on windless nights.

The heat island is discernable in the mean daily minimum temperature which is always lower at Laverton, by about lC•, than at the Melbourne Regional Office (Bureau of Meteorology, 1988).

6 Relative Humidity

The relative humidity of a sample of moist air is the ratio of the amount of water vapour in the sample to the maximum amount of water vapour which could be in the same volume of air at the same temperature. The relative humidity during the course of a cloudless day varies from a large value at night (which equals 100% if the minimum temperature falls below the dew point), to a minimum value when the temperature reaches its maximum value. Thus the mean 3pm readings of relative humidity are close to the mean of the daily minimum. Bureau of Meteorology (1988) gives the mean monthly and annual relative humidities at 9am and 3pm for stations around Port Phillip Bay. These figures are reproduced in Table 5, and have been used in conjunction with the 9am and 3pm mean temperatures to infer the 9am and 3pm mean vapour pressures as given in the final two columns. The slight increase in vapour pressure as a result of evaporation during the course of the day can be seen, as can a general tendency for lower vapour pressures in moving inland from the sea.

Table 5
Average annual humidity variables around Port Phillip Bay for relative humidity *(<RH>),* dry
bulb temperature (<T>), wet-bulb temperature (<Tw>) and vapour pressure *(e).*

Station	9am	9am	9am	3pm	3pm	3pm	9am	3pm
	<RH>	*<T>*	*<Tw>*	*<RH>*	*<T>*	*<Tw>*	*e*	*e*
	%	•C	•C	%	•C	•C	hPa	hPa
Pt. Lonsdale	78	13.9	11.9	68	16.5	13.4	12.32	12.71
Queescliff	78	13.7	11.7	73	16.4	13.8	12.21	13.57
Werribee	71	14.4	11.6				11.63	
Laverton	71	13.9	11.2	54	18.2	13.2	11.23	11.27
Melbourne	69	14.1	11.2	52	18.6	13.2	11.10	11.12
Mornington	73	14.3	11.8	60	18.0	13.7	11.89	12.37
Portsea	77	14.1	12.0	69	17.0	13.8	12.37	13.36

Table 5 also gives the mean wet bulb temperatures recorded around the bay.

7 Photosynthetically Available Radiation

Photosynthetically Available Radiation (PAR) comprises the wavelength band between 0.38 and 0.71 micrometres. The tables of Beer (1990) indicate that 41% of the total irradiance will be in this spectral range for ideal black body radiation at 6000K. However, much of the ultra-violet radiation and far infra-red is absorbed by the atmosphere. List (1951: p.438) gives tables that estimate the amount of solar radiation at sea level allowing for absorption by water vapour and ozone, and scattering by air, dust and water vapour. Within the 0.40 to 0.70 micrometre band, the irradiance ranges from 45% (for a solar zenith angle of zero) to 38% (for a solar zenith angle of 78•) of the total irradiance at sea level.

There is no literature that deals specifically with PAR over Port Phillip Bay and the characteristic s of PAR would need to be inferred from the characteristics of total global radiation, which consists of the total radiation from the sun (direct radiation) plus the radiation from the sky (diffuse) received by a horizontal surface. Bureau of Meteorology (1968) presents monthly averages of global radiation measured at Melbourne (in calories per square centimetre per day) for the period 1953 to 1961, inclusive. These values range from a low corresponding to 75 W m~2 in June, to a high of 286 W m~2 in January. Nunez (1990) has used three years of satellite data between 1985 and 1988 to produce maps of the spatial distribution of monthly values of mean global radiation (in Megajoules per square metre per day), its standard deviation, the number of inferred sunny days, and the number of inferred cloudy days for the region surrounding each Australian capital city.

The results of Nunez (1990) show that the spatial variation of monthly mean global radiation overPort PhillipBayisrelatively uniform (end the standarddeviations over theBay are relatively low), except during December when the south-eastern side of the bay has 10% more global radiation than the north-western side. The Werribee-Laverton region has a mean global radiation of 266 W m~2 (23 MJ m~2 d-2) - with a standard deviation of about 80 W m~2, increasing to about 284 W m~2 (24.5 MJ m~2 d-2) - with a standard deviation of about 70 W m~2 in the southern parts of the bay. These data almost certainly represent variability due to cloud across the Bay.

8 Fluxes

This section discusses the data requirements needed to estimate the fluxes of water, heat, light and momentum to Port Phillip Bay. In particular, can climatological data be used for this purpose? The answer appears to be that large errors and discrepancies arise. Hart (1983) obtained disappointing results which he attributed to the large amount of missing data. In addition, the occurrence of extreme events, especially high winds, will dominate fluxes. Accurate data collection will be needed to be able to quantify their return period. It therefore appears that during the Port Phillip Bay Study it will be necessary to establish meteorological stations (or to supplement existing meteorological stations) so as to calculate fluxes on the basis of observed (rather than on the basis of climatological) data.

Fig. 3 depicts the locations and controlling authorities for most of the automatic weather station network around Port Phillip Bay during 1992. It is expected that most of these stations will continue in operation during the term of the Port Phillip Bay Environmental Study. Most data are logged on a half-hourly interval, and the variables measured by these stations, and their exact coordinates, are listed in Appendix 1. Measurements over water are now routinely made in the South Channel and at Fawkner Beacon. The centre of the Bay is deficient in meteorological data collection and it would be useful to install at least one extra station to cover this region.

8.1 Water

The flux of water to the bay needs to be determined by summing the rainfall and runoff, and subtracting the evaporation and groundwaterpercolation. There is a northwest-southeast rainfall gradient, and a southwest-northeast temperature gradient across the bay so that a spatial network is required. Raingauges can be used to measure rainfall directly, but it is difficult to obtain good evaporation readings. There is much to be said for inferring evaporation from the combination equation in which case measurements of nett radiation, humidity, wind speed, and air and water temperature are needed.

One expects large year to year variations in the flux of water, with most of the inputs occurring during episodic events. The data collection system needs to be able to accurately measure such extreme events.

8.2 Heat

If the combination method is used to infer evaporation, and the nett radiation is known, then the sensible heat flux can be obtained by subtraction by using the energy balance equation

$$Qn = H + LE + G \qquad \textit{(Eq.9. 1)}$$

where H is the sensible heat flux. The term G is the energy flux into the water. This will depend on the dynamics of the Bay and the turbidity of the water, but can be calculated from the rate of heat storage which is, in turn, estimated from the variation in the vertical profile of water temperature (Arya, 1988: p. 199).

8.3 Momentum

The flux of momentum from wind to water is determined by the wind stress. This can be calculated from the wind speed (and direction) provided that the drag coefficient is known. Garratt (1977) has reviewed drag coefficient formulations over water.

8.4 Light

Radiation measurements are needed if the combination equation is used to estimate evaporation. They can also be used to determine the amount of light penetrating the water, provided that the optical properties of the water are known.

These optical properties will, in turn, be affected by meteorological conditions. Strong winds and large runoff will lead to sediments in the water column, greater wave activity, more absorption and less penetration of the solar radiation.

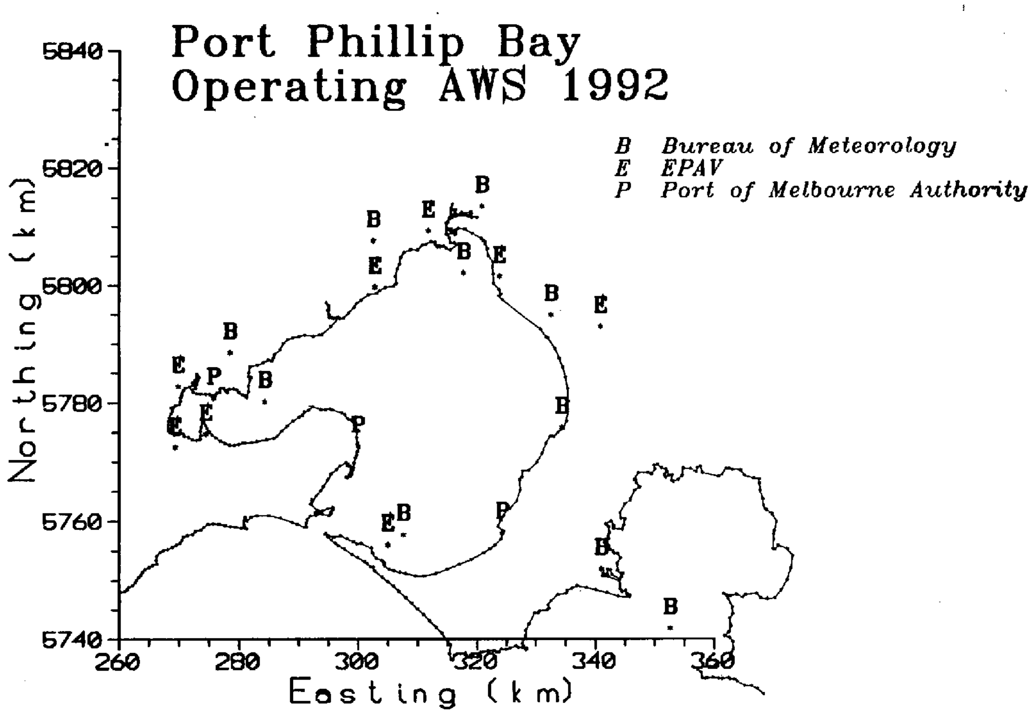

Fig. 3 Locations (in National Map Grid coordinates) and controlling authorities for the automatic weather station network around Port Phillip Bay during 1992.

9 Summary

A summary of the main points of the above critical review of the physical aspects of atmospheric inputs to Port Phillip Bay.

i. Information as to the meteorology of Port Phillip Bay has to be interpolated from literature dealing with locations along the shores of the Bay.

ii. Climatological data on Port Phillip Bay is available so that it will be possible to assess the representativeness of any future data collection period during the term of the Port Phillip Bay Environmental Study.

iii. The data from existing meteorological stations will need to be used during the Port Phillip Bay Environmental Study, and augmented by meteorological stations measuring sufficient variables to determine fluxes. iv. The centre of the Bay is deficient in meteorological data collection.

v. A method for estimating evaporative fluxes based on the combination method is detailed for consideration. Use of this method requires data on air and water temperature, wind speed, atmospheric moisture, and nett radiation.

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11 References

Abbs, D.J., *Observations and numerical modelling of southern Australian sea breezes,* Ph.D. thesis, Meteorology Dept., University of Melbourne, 1984.

Arya, S.P., *Introduction to micrometeorology,* Academic Press, San Diego, 1988.

Beer, Tom, *Applied Environmetrics Meteorological Tables,* Applied Environmetrics, Balwyn (Melbourne), 1990.

Beer, Tom, *Applied Environmetrics Hydrological Tables,* Applied Environmetrics, Balwyn (Melbourne), 1991.

Bond, P.G., *Horizontal temperature patterns in and around the city of Melbourne with respect to their importance in the concentration of pollution,* B.A. (Hons) thesis, Geography Dept., Monash University, 1974.

Brook, R.R., A study of wind structure in an urban environment, *Meteorological Study No. 27,* Australian Government Publishing Service, Canberra, 1974.

Bureau of Meteorology, Victorian Regional Office Staff, Wind and waves in Port Phillip Bay, Victoria, *Meteorological Note No. 2,* 1966.

Bureau of Meteorology, *Climatic Survey: Region 10 - Port Phillip, Victoria,* Melbourne, 1968.

Bureau of Meteorology, *The estimation of probable maximum precipitation in Australia for short durations and small areas,* Bulletin 51, Australian Government Publishing Service, Canberra, 1985.

Bureau of Meteorology, *Climatic averages - Australia,* Australian Government Publishing Service, Canberra, 1988.

Doorenbos, J. & W. O. Pruitt, Guidelines for predicting crop water requirements, *FAO Irrigation & Drainage Paper 24,* Food & Agriculture Organization, Rome (2nd printing), 1984.

Falconer, R.L. & D.J. Linforth, *Winds and waves in Bass Strait,* Bureau of Meteorology (Meteorological Summary), Melbourne, 1972.

Fowler, A., K. Hennessy, P. Whetton & A.B. Pittock, *Extreme rainfall events associated with global warming: urban drainage implications,* paper presented at the workshop on climate change impacts and adaptation, Macquarie University, 1991.

Garratt, J.R., Review of drag coefficients over oceans and continents, *Mon. WeatherRev.,* 105, 915-929, 1977.

Garratt, J.R., Summertime cold fronts in southeast Australia: behaviour and low-level structure of the main frontal types, *Mon. Weather Rev.,* 116, 636-649, 1988.

Gentilli, J., *Australian Climate Patterns,* (Chapter 11: The cool moist climates in Victoria), Nelson, Melbourne, 1972.

Hart, T.L., Aspects of the atmospheric energy budget over southeast Australia, *Meteorological Study No.* 33, Australian Government Publishing Service, 1983.

Johnson, M.H., Roles of dynamic and thermodynamic processes in determining the near-surface wind over Melbourne, *Proc. 11th Int. Conf. Clean Air Soc. Aust. New Zealand,* pp. 588 - 597, Brisbane, July, 1992.

Kamiko, T., Detailed structure of two subtropical frontal zones, *Aust. Met. Mag., 12,* 54-75, 1964

Kamiko, T., A developing subtropical depression and its frontal structure, *Aust. Met. Mag., 13,* 1 -14, 1965

List, R.J., *Smithsonian Meteorological Tables,* 6th revised edtn., Smithsonian Institution, Washington, 1951.

Manins, P.C., A meteorological curiousity of Melbourne, Australia, J. *Korean Met. Soc., 25,* 289-295, 1989.

May, P.T., Wilson, K.J. & Ryan, B.F., VHF Radar studies of cold fronts traversing southern Australia, *Beitrage Atrnos. Physik,* 63, 257-269, 1990.

McGregor, J.L. & F. Kimura, Numerical simulation of mesoscale eddies over Melbourne, *Monthly Weather Rev.,* 117, 50-66, 1989.

Melbourne Airshed Study, *The impact of emissions from Newport D power station on air quality,* Environmental Protection Authority of Victoria, Melbourne, 1985.

McIlroy, I.C. & D.E. Angus, Grass, water and soil evaporation at Aspendale, *Agricultural Meteorology, 1,* 201-224, 1964.

Monteith, J.L., *Principles of Environmental Physics,* Edward Arnold, London, 1973.

Monteith, J.L., Evaporation and surface temperature, Q. *J. Roy. Met. Soc.,* 107, 1-27, 1981.

Nicholls, N., Towards the prediction of major Australian droughts, *Aust. Met. Mag.,* 33,161166, 1985.

Nunez, M., Satellite estimation of regional solar energy statistics for Australian capital cities, *Meteorological Study, No.* 39, Australian Government Publishing Service, Canberra, 1990

Penman, H.L. Natural evaporation from open water, bare soil and grass, *Proc. Roy Soc., A193,* 120-145, 1948.

Quinn, W.H., Neal, V.T. & S.E.A. de Mayolo, E1 Nino occurrences over the past four and a half centuries, *J. Geophys. Res., 92,* 14449 - 14461, 1987.

Reynolds, R.G., Watson, W.D. & D.J. Collins, *Water resources aspects of drought in Australia,* Australian Government Publishing Service, Canberra, 1983.

Reeder, M.J. & R.K. Smith, Australian spring and summer cold fronts, *Aust. Met. Mag.,* (in press).

Space-Time Research, *CDCD, (A* compilation of Australian climate data on a CD-ROM), Melbourne, 1991.

Spillane, K.T., Atmospheric characteristics on high oxidant days in Melbourne, *Clean Air, 12,* 50-56, 1978.

Stern, H., Melbourne's highest air temperature, *Meteorology Australia, 1,* 14-15, 1982

Tapp, R.G., *Studies in urban meteorology,* M.Sc. thesis, Meteorology Dept., University of Melbourne, 1977.

Thom, A.S. & H.R. Oliver, On Penman's equation for estimating regional evaporation, Q. J. *Roy. Met. Soc.,* 103, 345-357, 1977.

Weather Disc Associates, *World Weather Disc* (A compilation of data on a CD-ROM), Seattle, WA, 1989.

Whetton, P.H., *A synoptic climatological analsis of Victorian rainfall variability,* Ph.D. thesis, Meteorology Dept., University of Melbourne, 1986.

12 Appendix 1

Coordinates, controlling authorities, location name, measured **variables and comments for the automatic** weather stations depicted in Fig. 3.

			Wind	Temperature	Rain	Evaporation	Radiation	Comments
302.5	5807.6	B LAVERTON	x	x	x	x	x	Synoptic station
332.6	5794.9	B MOORABBIN	x	x	x			AWS 10sec data
278.5	5788.5	B AVAhON	x	x				Synoptic station Cont. wind chart closes overnight
320.8	5913.5	B VRO	x	x	x	x		Synoptic station some data logged
341.0	5751.9	B CERBERUS	x	x				Metars
302.8	5799.7	E PT COOK	x	x				Historical Radn.
311.8	5809.3	E PAIShEY	x	x	92		92	Micromet upgrade 92
323.8	5801.5	E BRIGHTON	x	x			x	
340.9	5792.9	E DANDENONG	x	x			x	
274.5	5774.7	E PT NENRY	x	x	x			
269.9	5782.7	E SHELL	x	x				Under threat
269.4	5772.4	E GEELONG SOUTH	x	x				
317.7	5802.1	B FAWKNER BEACON	x					
334.4	5775.8	B FRANKSTON	x	x				Metars
284.3	5780.2	B PT WILSON	x					Metars
352.6	5741.8	B RHYLL	x	x				Metars
275.8	5780.8	P CORIO BAY	x					
324.3	5758.0	P SAFETY BEACH	x					
300.0	5772.6	P ST LEONARDS	x					
307.6	5757.7	B STH CHANEL	x					May be upgraded
305	5750	E STN CHANE L	x					Unknown other, posn

B: Bureau of Meteorology
E: Environment Protection
P: Port of Melbourne Authority

Authority of Victoria

Metars: Bureau half hourly 10min averages with specials when gusts exceeed 28kts

Many different systems using different averaging times. PMA for example are 10min aveaged wind speed but instantaneous direction at the 10min.