A comparison of methane dynamics between wetlands constructed for wastewater treatment and a natural sedgeland in South Australia.

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Figures and Tables

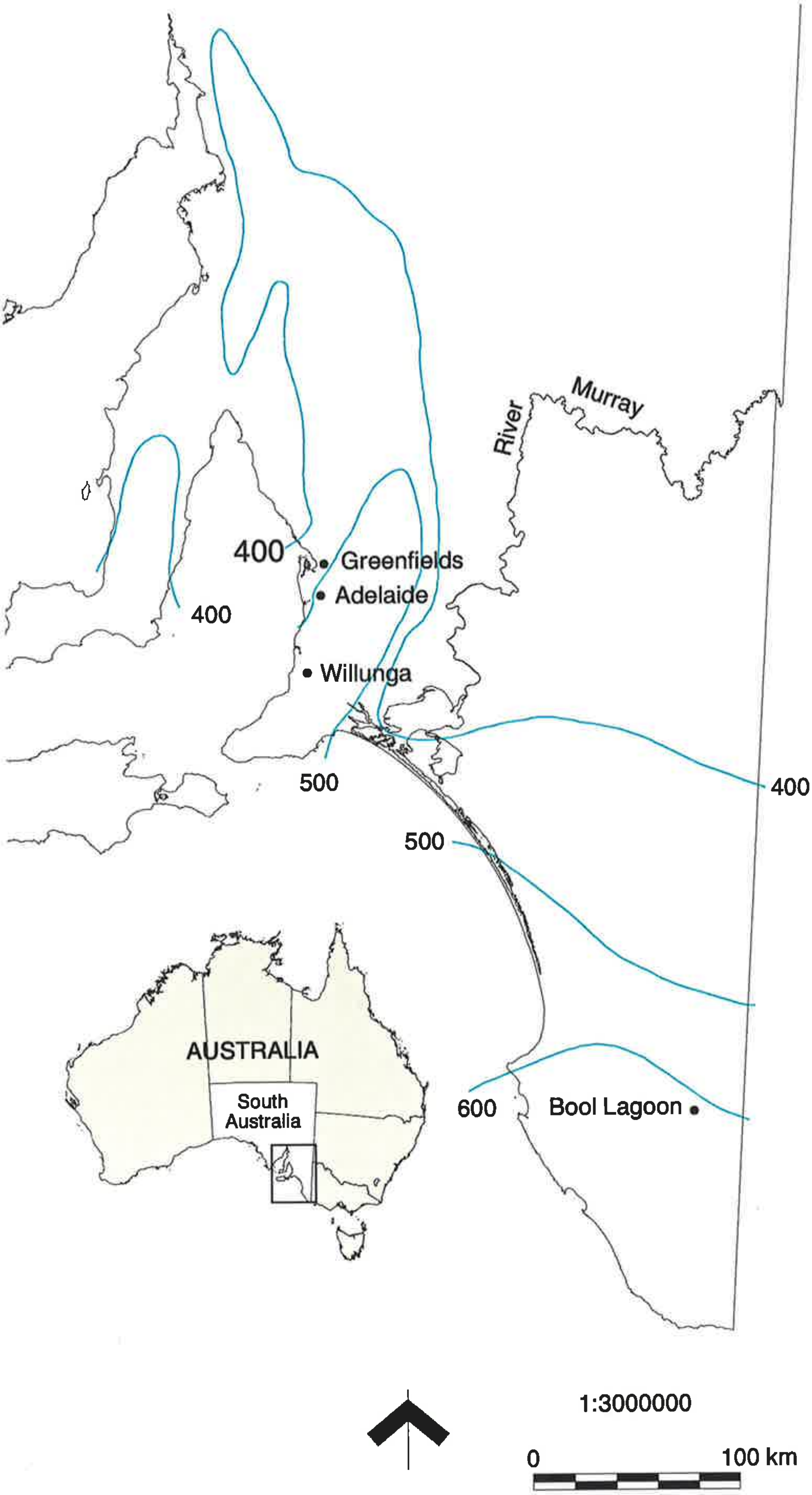
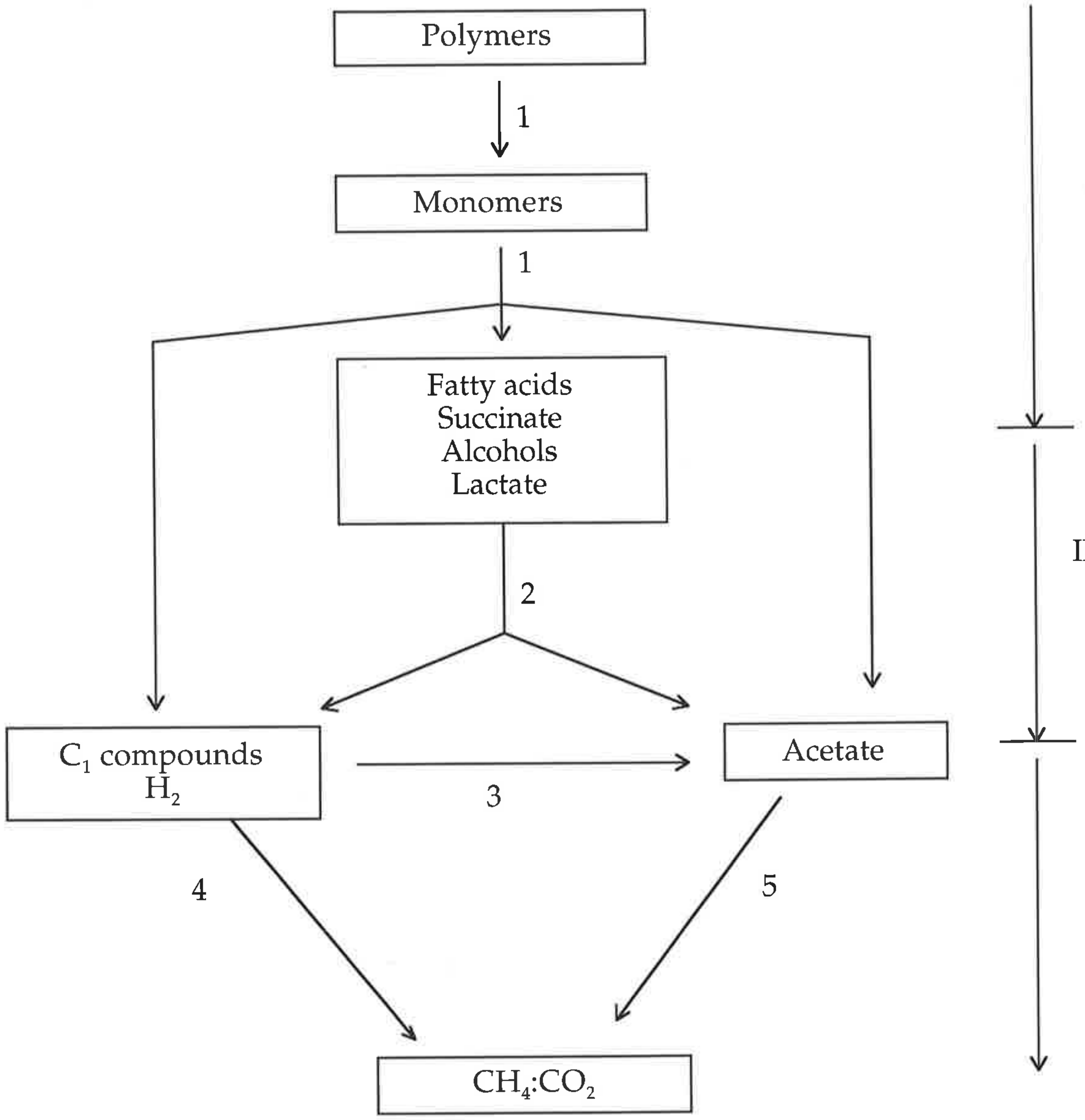


Figure 1.1 A map of South Australia showing the locations of Willunga Wetlands, Greenfields Wetlands and Bool Lagoon. The median (50th percentile) annual rainfall isopleths (mm) are also shown.

Table 1.1: Climatic averages for the Bureau of Meteorology station closest to Willunga Wetlands, Greenfields Wetlands and Bool Lagoon.

	Willunga Wetlands[a] (35°16'S;138°35'E)			Greenfields Wetlands[b] (34°52'S;138°35'E)			Bool Lagoon[c] (37°5'S;140°42'E)		
Month	**Mean Daily Max. Temp. (°C)**	**Mean Daily Min. Temp. (°C)**	**Mean Rainfall (mm)**	**Mean Daily Max. Temp. (°C)**	**Mean Daily Min. Temp. (°C)**	**Mean Rainfall (mm)**	**Mean Daily Max. Temp. (°C)**	**Mean Daily Min. Temp. (°C)**	**Mean Rainfall (mm)**
Jan	27.9	15.5	18	28.8	16.2	23	28.2	11.8	23
Feb	28	15.7	19	28.4	16.2	19	28.6	12.2	21
Mar	25.4	14.2	23	26.4	14.8	23	25.3	10.8	28
Apr	22.1	11.6	40	21.9	12.1	44	21.5	8.4	45
May	18.4	9.3	58	18.5	9.5	47	17.4	6.7	61
Jun	16	7.3	50	15.5	7	50	14.8	4.8	73
Jul	14.9	6.8	63	14.9	6.4	59	14.2	4.5	75
Aug	15.9	7.4	51	16.1	6.8	56	15.4	5.1	73
Sep	17.8	8.6	44	18.4	8.2	43	17.1	6.1	65
Oct	20.8	10.4	38	21.1	10.1	46	20.2	7.3	52
Nov	23.6	12.3	26	24.2	12.5	29	22.8	8.8	37
Dec	25.5	14.1	21	27.4	14.9	25	25.4	10.4	30
Yearly mean	21.4 *31 years of record*	11.1 *31 years of record*	451 *32 years of record*	21.8 *29 years of record*	11.2 *29 years of record*	464 *40 years of record*	20.9 *23 years of record*	8.1 *23 years of record*	583 *118 years of record*

Data taken from Bureau of Meteorology (1988).
[a]Adelaide Airport Station Number: 023034. Lat. 34°57'S Long. 138°32'E. Elevation 6.0m. Commenced 1955.
[b]Parafield Aero AMO Station Number: 023013. Lat. 34°48'S Long. 138°38'E. Elevation 14.0m. Commenced 1929.
[c]Naracoorte Post Office Station Number: 026023 Lat. 36°57'S Long. 149°45'E. Elevation 58.0m. Commenced 1868.

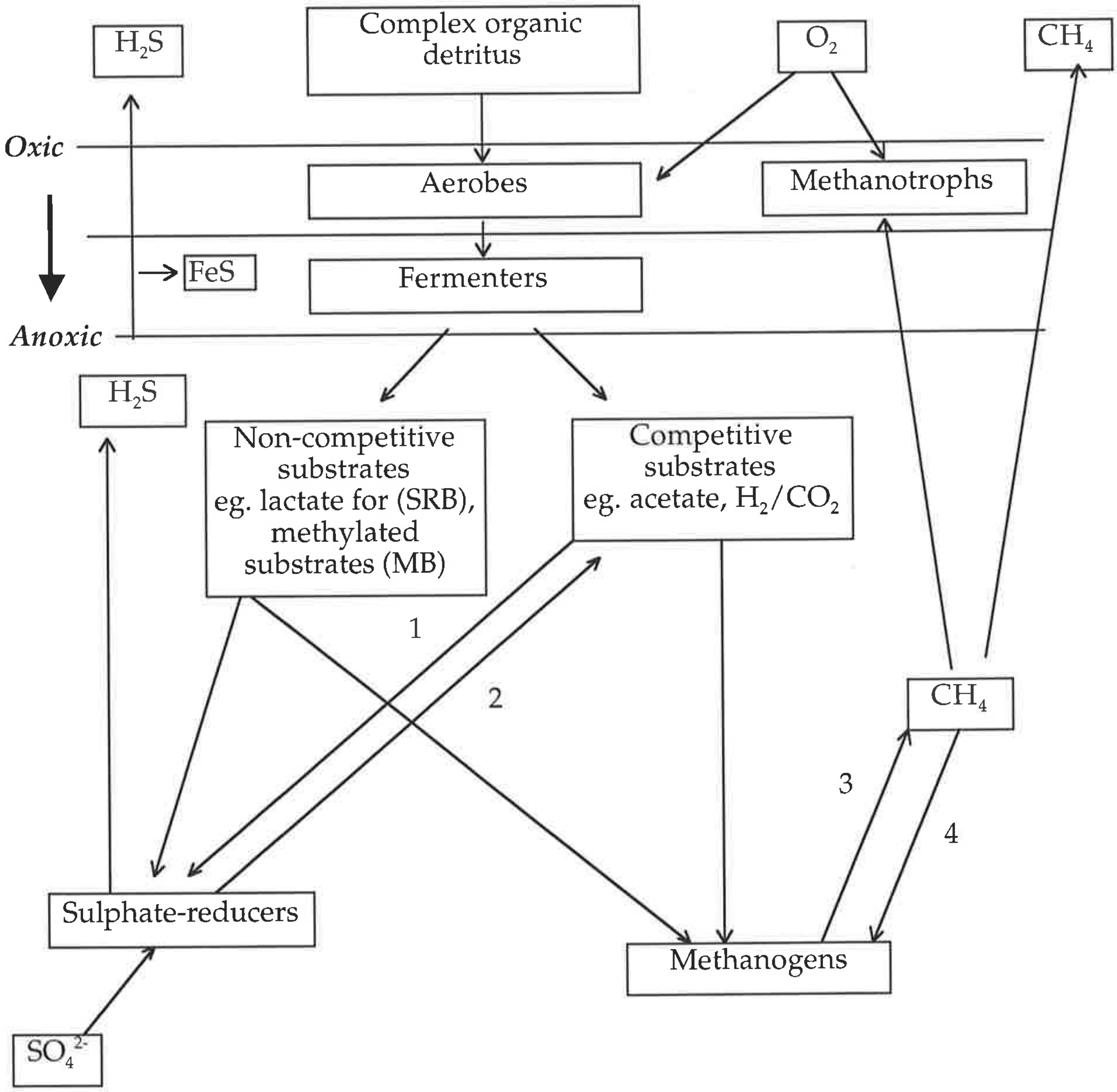


<u>5 Anaerobic Functional Bacterial Groups (Schink, 1997)</u>

1. Primary fermenting bacteria
2. Secondary-fermenting bacteria
3. Homoacetogens
4. H_2-oxidising methanogens
5. Aceticlasic methanogens

I, II, III represent the 3 functional groups identified by Wolfe and Higgins (1979)

Figure 2.1: Carbon and electron flow through the various anaerobic microbial functional groups in methanogenic degradation of complex organic matter. Adapted from Wolfe and Higgins (1979) and Schink (1997).



1. Complete oxidation by SRB removes acetate from the pool
2. Incomplete oxidation by SRB adds acetate to the pool
3. Methanogenesis
4. Reverse methanogenesis (anaerobic methanogenesis)

Figure 2.2 : A schematic model of the interactions between methanogens (MB) and sulphate-reducing bacteria (SRB) in the upper layers of a flooded sediment.

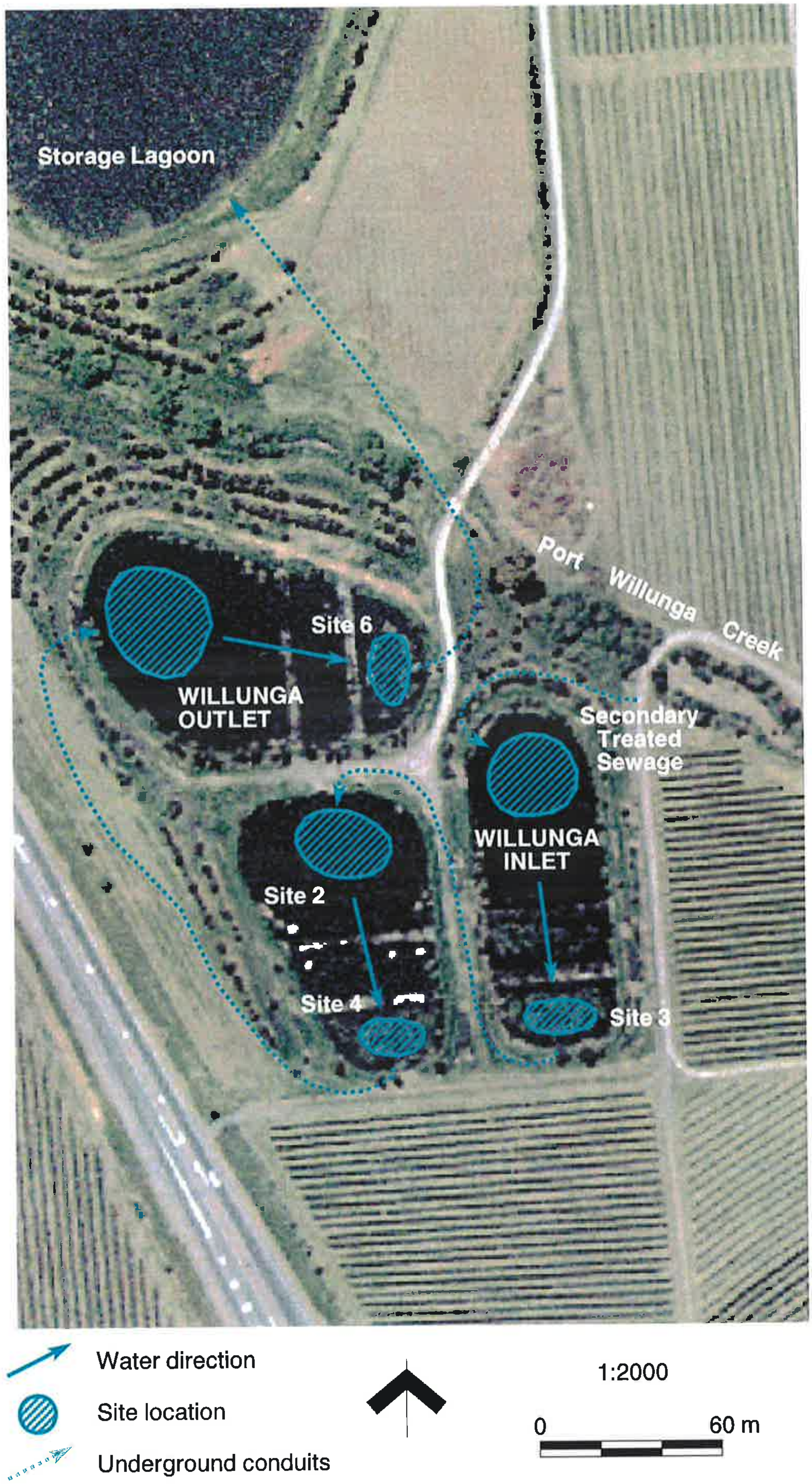


Figure 3.1 Site map of Willunga Wetlands showing the three treatment ponds, Aldinga Creek, the study sites and the storage lagoon. Note shallow (60cm) vegetated areas at Sites 3, 4 and 6.

Figure 3.2: Willunga Wetlands, in the southern suburbs of Adelaide, a constructed wetland receiving secondary treated sewage effluent.

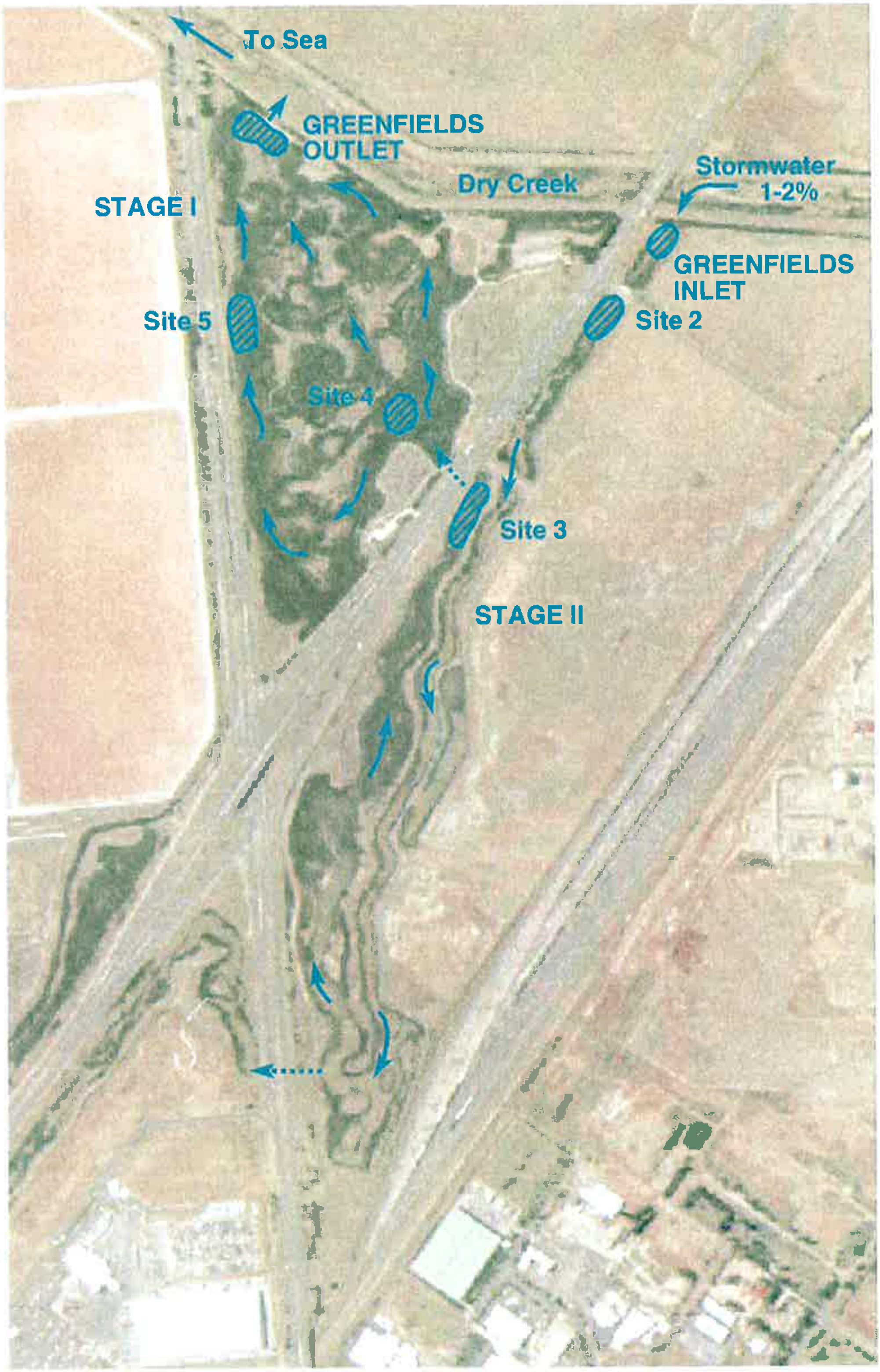


Figure 3.3 Site map of Greenfields Wetlands showing Dry Creek and the locations of study sites. Approximately 1-2% of the stormwater flow in Dry Creek enters the Greenfields Wetlands system.

Figure 3.4: Greenfields Wetlands, in the northern suburbs of Adelaide, a constructed wetland receiving stormwater inflow from Dry Creek. The upper photo shows the more heavily vegetated Stage I and the lower photo shows three static chambers set in the open water at the inlet.

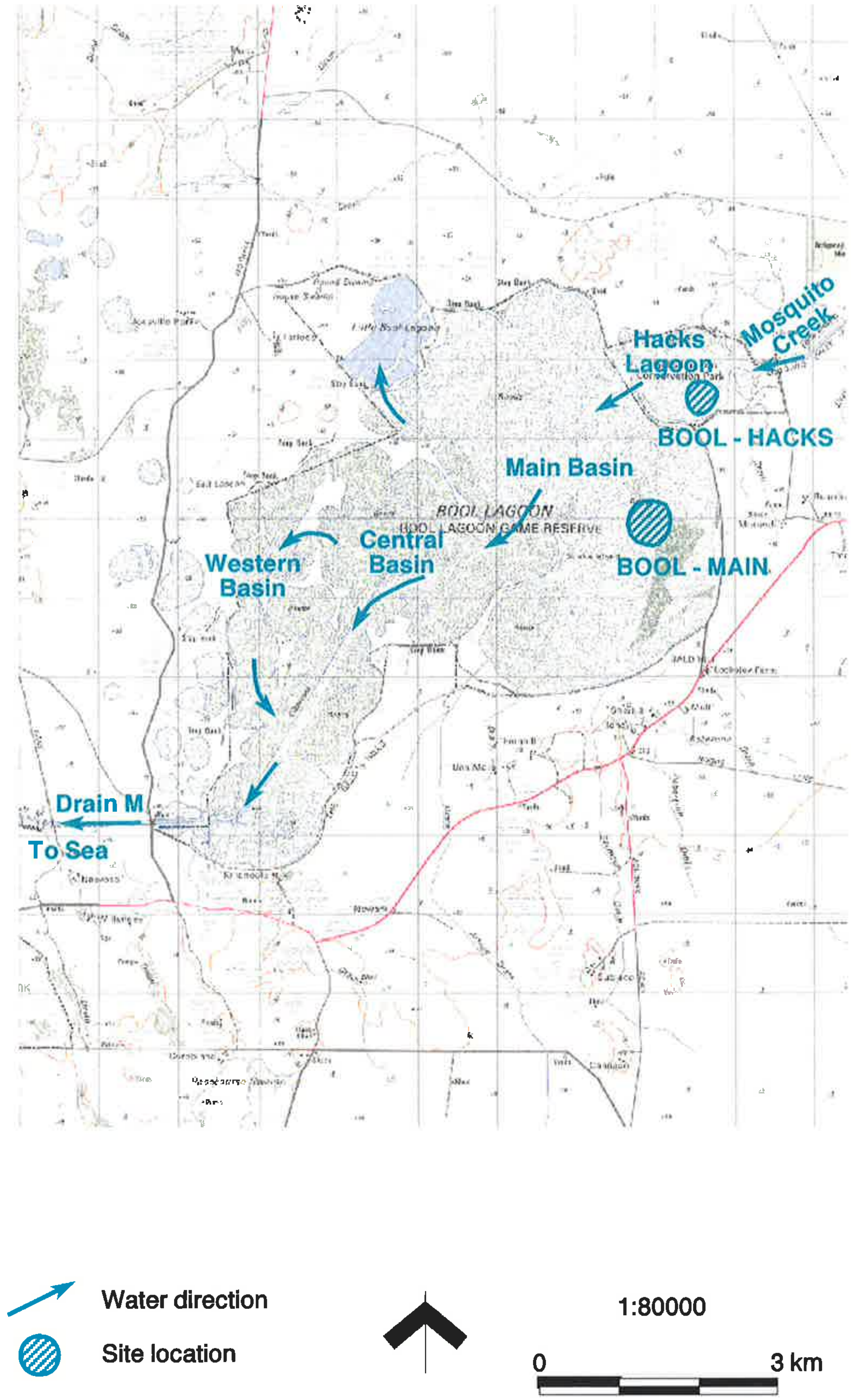


Figure 3.5 Site map of Bool Lagoon showing Mosquito Creek, the study sites and the major basins.

Figure 3.6: Bool Lagoon, south-east South Australia, a natural sedgeland receiving water from Mosquito Creek.

Figure 3.7: A detailed view of gas sample extraction from a static chamber using an evacuated tube and a hypodermic needle.

Table 4.1: Typical chemical composition of secondary treated sewage and stormwater run-off. Adapted from Kadlec and Knight (1996) and Tebutt (1998).

Secondary Treated Sewage ($mg\ L^{-1}$)			Urban stormwater run-off ($mg\ L^{-1}$)		
Constituent	**Typical**	**Range**	**Constituent**	**Typical**	**Range**
BOD	20	10 - 45	BOD	20	7 - 56
COD	75	35 - 75	COD	75	20 - 280
TSS	30	15 - 60	TSS	150	20 - 2900
TOC	35				
NH4-N	10	<1 - 20	NH3-N	0.582	-
NOx-N	6	<1 - 20			
Org-N	4	2 - 6			
TKN	14	10 - 20	TKN	1.4	0.6 - 4.2
Total N	20	10 - 30	Total N	2	0.7 - 20
Inorg P	4	2 - 8			
Org P	2	0 - 4	Ortho -P	0.12	-
Total P	6	4 - 8	Total P	0.36	0.02 - 4.3

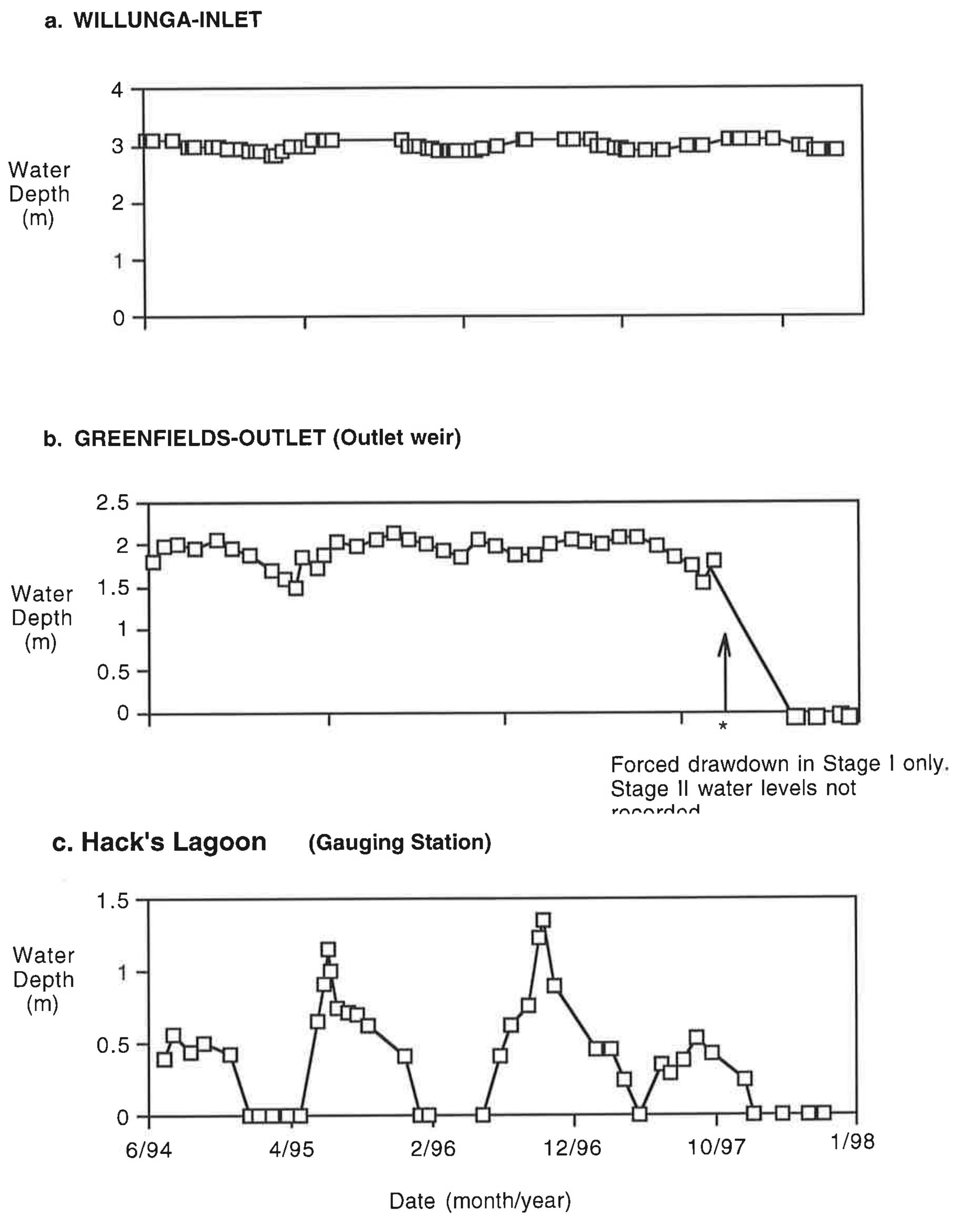


Figure 4.1: Hydrographs for the three study wetlands; Willunga Wetlands (a), Greenfields Wetlands (b) and Bool Lagoon (c), from June 1994 to December 1997. The data for WILLUNGA-INLET were taken at each site visit, the data for GREENFIELDS-OUTLET were provided by Salisbury City Council and the data for the gauging board in Hack's Lagoon (upstream of Bool Lagoon) were provided by the South East Drainage Board.

Table 4.2: Surface water (0.1m depth) organic carbon content at Willunga and Greenfields Wetlands. Data are presented as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings are denoted by the lower case letters in superscript.

Surface Water Organic Carbon Content (mg L^{-1})					
	Sites				
Season and Organic C Fraction	**WILLUNGA INLET**	**WILLUNGA OUTLET**	**GREENFIELDS INLET**	**GREENFIELDS OUTLET**	**P values**
November 1994					
DOC	29.8 ± 1.5^{a}	28.3 ± 0.6^{a}	4.9 ± 0.3^{b}	3.9 ± 0.2^{c}	
TOC	36 ± 3^{a}	32.7 ± 2^{a}	5.37 ± 0.4^{b}	4.68 ± 0.4^{b}	0.000
July 1996					
DOC	37.6 ± 1.2	34.6 ± 1			
TOC	39.4 ± 1.4	36.8 ± 0.7			
January 1998					
DOC	29.9 ± 3.1	29.4 ± 1.9			
TOC	35.3 ± 1.5	32.7 ± 0.7			
4 May 1995					
DOC			5.93 ± 0.06^{a}	4.4 ± 0.1^{c}	
TOC			6.73 ± 0.5^{a}	4.87 ± 0.3^{bc}	
22 May 1995					0.000
DOC			4.83 ± 0.3^{bc}	4.67 ± 0.2^{bc}	
TOC			5.16 ± 0.3^{b}	5.3 ± 0.3^{b}	

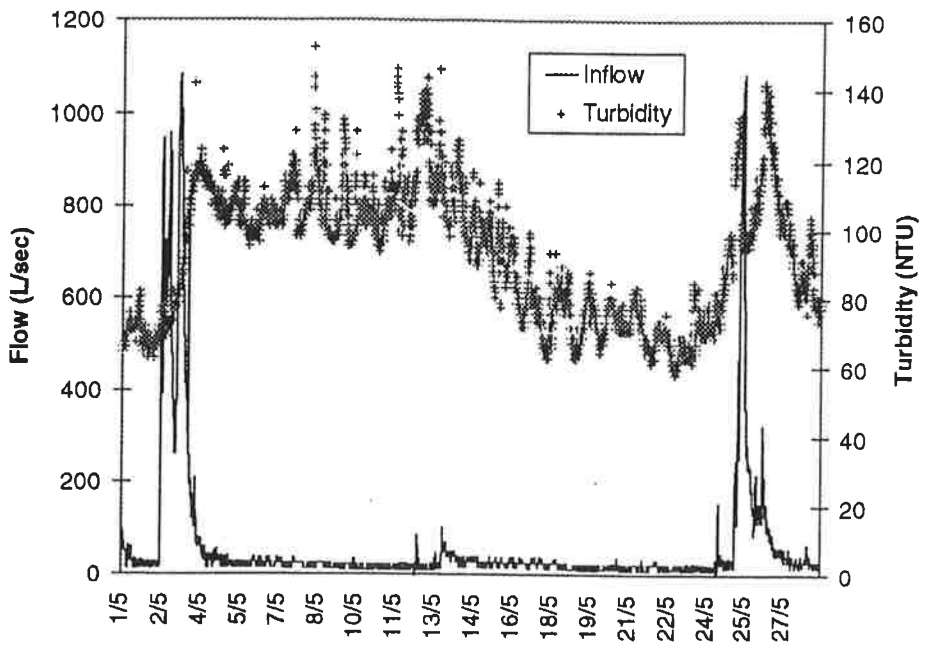


Figure 4.2: Inlet velocities and outflow turbidity at Greenfields Wetlands during May 1995. Taken from Jenkins (1996).

Table 4.3: Organic carbon content (%) of the surface sediments at Willunga Wetlands, Greenfields Wetlands and Bool Lagoon. Data are presented as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings for the 5cm data are denoted by the lower case letters in superscript.

Organic Carbon Content (%)						
	Sites					
Sediment depth and Date	**WILLUNGA INLET**	**WILLUNGA OUTLET**	**GREENFIELDS INLET**	**GREENFIELDS OUTLET**	**BOOL HACKS**	**BOOL MAIN**
5 cm depth						
Oct. 95	2.75 ± 0.39^{b}	0.86 ± 1.15^{cde}	1.32 ± 0.19^{bcd}	0.64 ± 0.19^{cde}		
Jan. 98	2.46 ± 0.85^{bc}	2.42 ± 1.06^{bc}				
Oct. 98			2.85 ± 0.28^{b}	2.42 ± 0.09^{bc}		
Jan. 96					8.62 ± 0.42^{a}	10.4 ± 0.73^{a}
1 cm depth						
Jan. 98	5.46 ± 0.81	3.5 ± 1.1				
Oct. 98			6.58 ± 0.76	4.66 ± 0.4		

Table 4.4: Significant Tukey-Kramer groupings identified when the 1cm and 5cm data presented in Table 4.3 were compared across the inlet and outlet of each wetland, separately.

Sediment Depth	**WILLUNGA INLET**	**WILLUNGA OUTLET**	**GREENFIELDS INLET**	**GREENFIELDS OUTLET**
1 cm depth	a	b	a	b
5 cm depth	b	b	c	d
	P<0.0001		**P<0.0001**	

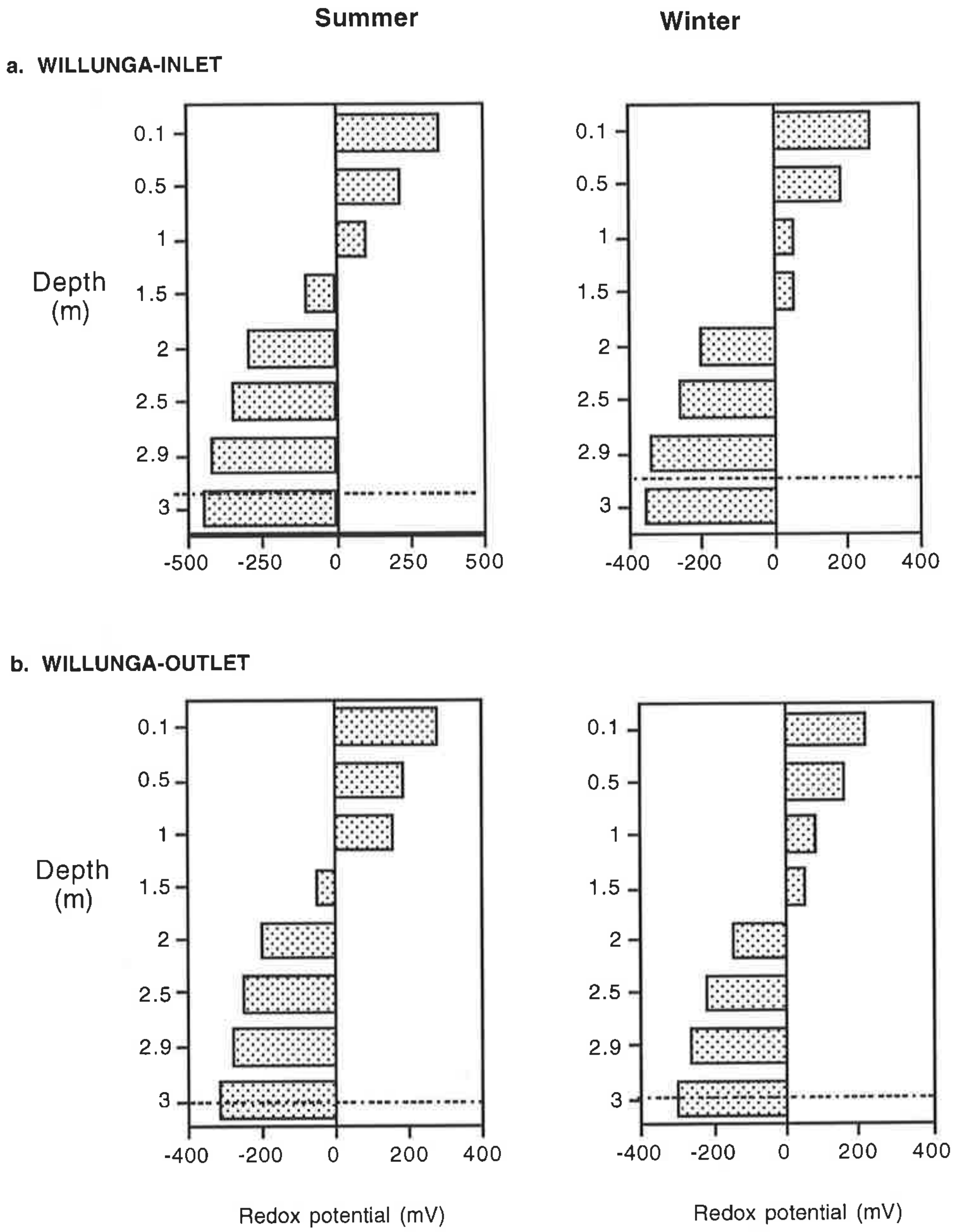


Figure 4.3: Depth profiles of redox potential in the water column of WILLUNGA-INLET and WILLUNGA-OUTLET in summer and winter. The dashed line indicates the position of the sediment-water interface.

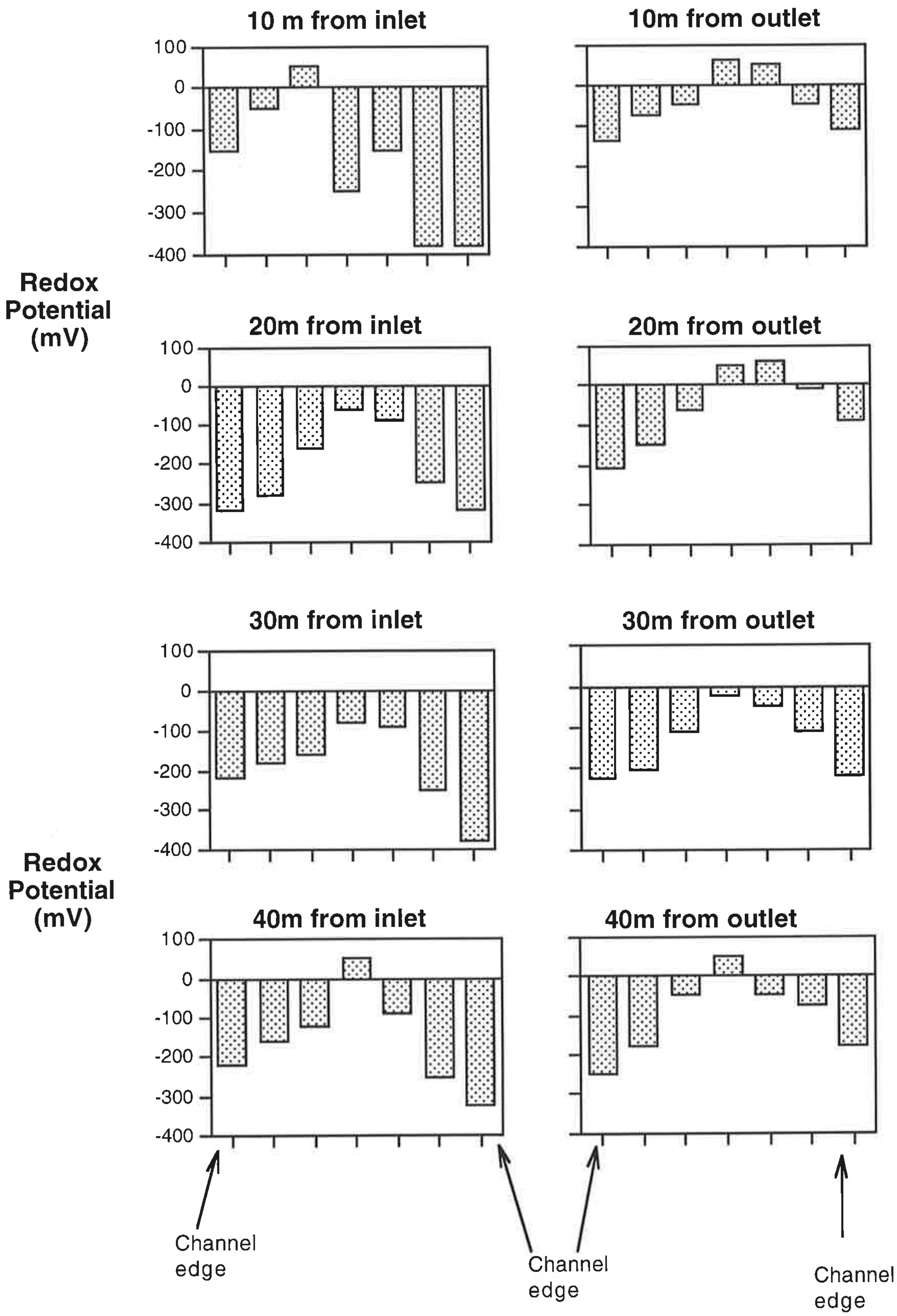


Figure 4.4: Sediment redox potential measured at 2-3m intervals across the channel (perpendicular to flow) at Greenfields Wetlands. Note the more reducing conditions at the edges of the channel (vegetated areas) and near the inlet.

Table 4.5: Depth profiles of temperature and dissolved oxygen at WILLUNGA-INLET and WILLUNGA-OUTLET in summer.

a. WILLUNGA-INLET in summer

Depth (m)	2 Jan 1996		18 Jan 1996		21 Jan 1996		30 Jan 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	31.8	22	32.2	21.9	30.8	22.4	28.8	21.8
0.5	27.5	11.9	28.5	12.9	28.2	14.2	28.6	10.3
0.75	25.6	3.81	27.1	4.20	26.8	8.16	26.3	3.46
1	22.5	1.82	23.6	2.16	22.9	1.36	21.8	<1
1.5	21.5	<1	22.2	<1	21.5	<1	21.0	<1
2	20.2	<1	21.3	<1	20.8	<1	20.4	<1
2.5	19.8	<1	19.8	<1	19.6	<1	19.4	<1
2.9	19.4	<1	19.4	<1	19.2	<1	19.0	<1

b. WILLUNGA-OUTLET in summer

Depth (m)	2 Jan 1996		18 Jan 1996		21 Jan 1996		30 Jan 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	30.6	20.2	32.4	22.6	29.5	19.7	28.4	18.2
0.5	27.2	12.3	28.8	12.9	26.9	10.9	27.8	10.3
0.75	25.8	7.12	27.3	8.22	25.3	7.95	26.1	7.66
1	23.0	4.87	24.1	5.87	22.8	4.73	22.0	5.89
1.5	21.5	2.05	22.8	2.31	21.2	2.00	21.4	2.11
2	20.6	<1	21.2	<1	20.4	<1	20.4	<1
2.5	19.7	<1	19.8	<1	19.4	<1	19.2	<1
2.9	19.4	<1	19.4	<1	19	<1	19	<1

Table 4.6:

Chlorophyll a concentrations down the water depth profile at WILLUNGA-INLET and WILLUNGA-OUTLET.

Data are presented as mean ± std. dev. (n=3).

	Chlorophyll a (µg L^{-1})	
	Sites	
Depth (m)	WILLUNGA INLET	WILLUNGA OUTLET
0.1	902.5 ± 176	664.6 ± 49.8
1	243.8 ± 12.7	138.6 ± 23.4
2	204.5 ± 39.8	97.4 ± 1.72

Table 4.7: Depth profiles of temperature and dissolved oxygen at WILLUNGA-INLET and WILLUNGA-OUTLET in winter.

a. WILLUNGA-INLET in winter

Depth (m)	8 July 1996		19 July 1996		23 July 1996		26 July 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	15.4	24.9	15.3	23.3	15.6	22.5	14.8	28.5
0.5	14.3	4.37	14.3	3.17	15.0	4.85	14.2	5.27
0.75	13.3	2.24	13.4	2.06	14.8	2.48	13.5	1.60
1	13.2	<1	13.1	<1	13.9	<1	13.0	<1
1.5	12.9	<1	12.8	<1	13.2	<1	12.8	<1
2	12.7	<1	12.6	<1	12.7	<1	12.6	<1
2.5	12.6	<1	12.5	<1	12.5	<1	12.4	<1
2.9	12.6	<1	12.5	<1	12.5	<1	12.2	<1

b. WILLUNGA-OUTLET in winter

Depth (m)	8 July 1996		19 July 1996		23 July 1996		26 July 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	15.2	11.8	15.1	12.5	15.4	12.48	14.6	10.9
0.5	14.1	5.67	14.2	5.08	14.8	5.34	14.0	5.04
0.75	13.1	3.89	13.5	3.95	14.2	4.02	13.3	3.78
1	12.9	1.28	13.0	1.45	13.8	1.89	13.0	1.61
1.5	12.7	<1	12.8	<1	13.3	<1	12.6	<1
2	12.6	<1	12.5	<1	12.8	<1	12.6	<1
2.5	12.6	<1	12.4	<1	12.6	<1	12.4	<1
2.9	12.5	<1	12.4	<1	12.5	<1	12.2	<1

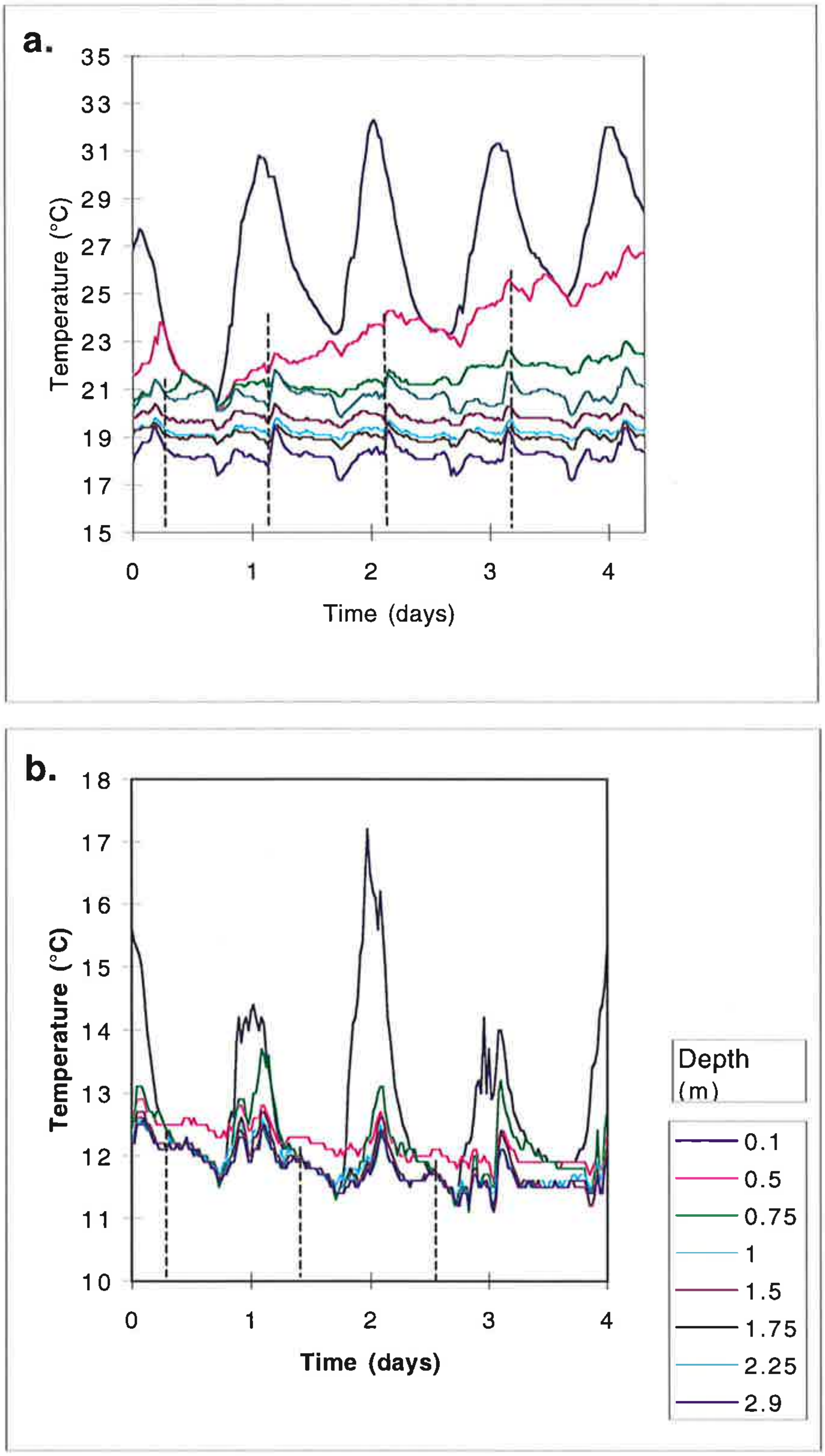


Figure 4.5: Diel changes in temperature at WILLUNGA-INLET in summer (a) and winter (b). Temperature readings began at 1600h on January 25 and July 25 and were logged every 30 min thereafter. Note diurnal stratification in both seasons although the mixing depths are different thus in summer the oxic surface layers did not mix with the anoxic benthic layers. The vertical dashed lines indicate the time of dawn on each day.

Table 4.8: Depth profiles of water temperature and dissolved oxygen at Greenfields Wetlands in summer. The depth to the water:floc interface is shown in parentheses at the bottom of the temperature columns.

a. GREENFIELDS-INLET in summer

Depth (m)	11 Jan 1996		15 Jan 1996		23 Jan 1996		28 Jan 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	26.3	8.57	23.5	13.0	21.5	7.33	22.4	9.49
0.2	25.8	7.17	22.3	8.33	21.0	6.34	21.8	7.52
0.3	25.2	5.25	21.9	6.34	20.7	6.10	21.2	6.25
0.4	24.8	4.14	21.7	4.93	20.4	4.12	20.8	4.12
Floc	24.3	<1	21.4	<1	20.1	<1	20.6	<1
	(0.52)		(0.57)		(0.55)		(0.56)	

b. GREENFIELDS-OUTLET in summer

Depth (m)	11 Jan 1996		15 Jan 1996		23 Jan 1996		28 Jan 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	27.5	11.7	24.5	10.7	21.8	8.66	22.8	10.1
0.2	26.8	8.76	22.9	8.43	21.4	7.13	22.0	8.23
0.3	25.8	6.98	22.6	6.71	20.8	6.54	21.6	6.83
0.4	25.4	4.97	21.7	5.09	20.6	5.28	21.2	5.93
Floc	24.6	<1	21.4	<1	20.4	<1	20.8	<1
	(0.85)		(0.65)		(0.67)		(0.68)	

Table 4.9: Depth profiles of water temperature and dissolved oxygen at Greenfields Wetlands in winter. The depth to the water:floc interface is shown in parentheses at the bottom of the temperature columns.

a. GREENFIELDS-INLET in winter								
Depth (m)	3 July 1996		16 July1996		20 July 1996		28 July 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	7.9	10.2	8.1	9.66	7.9	11.2	7.8	10.3
0.2	7.9	10.2	8.1	9.66	7.8	11.2	7.8	10.3
0.4	7.9	10.2	8.1	9.66	7.6	11.0	7.8	10.3
0.6	7.9	10.2	8.1	9.66	7.3	10.8	7.8	10.3
Floc	7.9	2.61	7.9	2.85	7.1	3.92	7.8	2.52
	(0.85)		(0.87)		(0.87)		(0.88)	

b. GREENFIELDS-OUTLET in winter								
Depth (m)	3 July 1996		16 July1996		20 July 1996		28 July 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	8.2	8.29	8.3	7.36	7.8	10.2	7.6	9.57
0.2	8.2	8.29	8.3	7.36	7.6	10.2	7.6	9.57
0.4	8.2	8.29	8.3	7.36	7.6	10.2	7.6	9.57
0.6	8.2	8.29	8.3	7.36	7.3	10.0	7.6	9.57
Floc	8.2	<1	8.1	<1	7.1	1.27	7.6	<1
	(0.85)		(0.87)		(0.87)		(0.88)	

Table 4.10: Depth profiles for water temperature and dissolved oxygen at Bool Lagoon in summer and winter.

a. BOOL-HACKS in Summer

Depth (m)	7 Jan 1996		8 Jan 1996		9 Jan 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	28.2	10.39	28.6	9.82	25.2	8.61
0.2	27.5	9.23	27.9	9.78	24.7	8.43
0.3	26.8	8.91	26.8	8.43	24.5	7.34
0.4	25.3	8.56	26.5	7.78	24.1	6.83
0.42	24.8	1.79	25.1	1.81	23.8	1.79

b. BOOL-HACKS in Winter

Depth (m)	10 July 1996		11 July 1996		12 July 1996	
	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})	Temperature (°C)	Dissolved oxygen (mg L^{-1})
0.1	11.6	8.76	10.8	7.79	10.4	7.63
0.2	11.6	8.76	10.8	7.79	10.4	7.63
0.3	11.6	8.76	10.8	7.79	10.4	7.63
0.4	11.6	8.76	10.8	7.79	10.4	7.63
0.5	11.6	8.76	10.8	7.79	10.4	7.63
0.6	11.6	8.76	10.8	7.79	10.4	7.63
0.7	11.6	8.76	10.8	7.79	10.4	7.63
0.74	11.2	2.34	10.6	1.88	10.2	1.75

Table 4.11: Diel water temperature profiles at Greenfields Wetlands and Bool Lagoon in January 1996.

	Water Temperature (°C)					
	a. GREENFIELDS-INLET					
Depth (m)	**11 Jan 1996**		**23 Jan 1996**		**28 Jan 1996**	
	0600	**1400**	**0600**	**1400**	**0600**	**1400**
0.1	22	26.3	21.6	23.5	19.8	21.5
0.2	21.8	25.8	21.4	22.3	19.8	21
0.3	21.8	25.2	21.4	21.9	19.8	20.7
0.4	21.8	24.8	21.4	21.7	19.8	20.4
0.5	21.8	24.3	21.4	21.4	19.8	20.1
	b. BOOL-HACKS					
Depth (m)	**7 Jan 1996**		**8 Jan 1996**		**9 Jan 1996**	
	0600	**1400**	**0600**	**1400**	**0600**	**1400**
0.1	22.6	28.2	23	27.8	21.2	25.2
0.2	22.6	27.5	23	26.6	21.1	24.7
0.3	22.6	26.3	23	25.8	21.1	24.5
0.4	22.6	24.2	23	24	21.1	24.1
0.5	22.6	23.5	23	23.6	21.1	23.8

Table 4.12: Vertical profiles of dissolved methane at Willunga (a) and Greenfields (b) Wetlands in winter and summer. Data are presented as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings are denoted by the lower case letters in superscript.

a.	**Dissolved methane (µg L^{-1})**	
	Sites	
Depth (cm)	**WILLUNGA INLET**	**WILLUNGA OUTLET**
	Summer (21 Jan 1996)	
Inflow*	23.6 ± 1.4	
0	280 ± 12^{a}	35.8 ± 7^{a}
75	886 ± 71^{ab}	86.4 ± 21^{a}
150	1755 ± 456^{b}	395 ± 76^{b}
225	2348 ± 248^{b}	1148 ± 188^{c}
290	2825 ± 118^{c}	1487 ± 276^{c}
P-value	0.0000	0.0000
	Winter (23 July 1996)	
Inflow*	2.11 ± 0.8	
0	5.32 ± 2.3^{a}	3.3 ± 1.6^{a}
100	9.1 ± 5.1^{a}	5.6 ± 1.1^{a}
200	52.3 ± 37^{b}	32.1 ± 24^{b}
310	253 ± 53^{c}	122 ± 39^{c}
P-value	0.0000	0.0000

*data not included in statistical analyses.

b.	**Dissolved methane (µg L^{-1})**	
	Sites	
Depth (cm)	**GREENFIELDS INLET**	**GREENFIELDS OUTLET**
	Summer (23 Jan 1996)	
Inflow*	1.6 ± 0.5	
0	32.3 ± 7.9^{a}	11.3 ± 1.4^{a}
15	47.3 ± 8.3^{b}	11.9 ± 1.6^{a}
30	58.1 ± 9.2^{b}	12.7 ± 1.3^{a}
45	93.5 ± 15.2^{c}	17.8 ± 2.3^{b}
P-value	0.0000	0.0000
	Winter (26 July 1996)	
Inflow*	0.5 ± 0.3	
0	7.26 ± 1.1	2.43 ± 0.8^{a}
30	7.18 ± 1.5	3.46 ± 0.7^{ab}
60	6.76 ± 1.6	3.7 ± 1^{b}
80	7.36 ± 2.4	4.2 ± 0.8^{b}
P-value	0.9623	0.00018

Table 4.13:
Vertical profiles of dissolved methane at Bool Lagoon in summer and winter. Data are presented as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings are denoted by lower case letters in superscript.

Depth (cm)	Dissolved methane ($\mu g\ L^{-1}$)	
	Sites	
	BOOL HACKS	BOOL MAIN
	Summer (7 July 1996)	
0	28.7 ± 9.3^{a}	27.4 ± 8.7^{a}
20	48.3 ± 15.3^{b}	41.7 ± 9.9^{b}
30	67.2 ± 22.2^{c}	65.4 ± 17.3^{c}
42	95.9 ± 31.6^{c}	93.3 ± 26.7^{d}
P-value	0.0000	0.0000
	Winter (12 July 1996)	
0	4.82 ± 1.2	4.99 ± 1.4
30	4.77 ± 2.5	5.38 ± 1.8
60	5.12 ± 2.4	5.22 ± 2.3
74	5.32 ± 3.6	5.35 ± 1.5
P-value	0.9771	0.9813

Table 4.14: Dissolved oxygen to methane ratios at various water depths at each wetland site. These ratios were calculated from the data presented in Tables 4.5 to 4.13.

Depth (m)	WILLUNGA INLET		WILLUNGA OUTLET		GREENFIELDS INLET		GREENFIELDS OUTLET		BOOL HACKS	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
0.1	79	4661	563	3634	297	915	1417	3644	350	1672
0.2	-	-	-	-	155	869	1133	2559	219	1676
0.3	-	-	-	-	12	810	722	2393	103	1574
0.4	-	-	-	-		664		2147	19	1544
0.5	21	565	154	1237		5.3		N/A		372
0.6	-	-	-	-						
0.7	-	-	-	-						
0.8	-	-	30	277						
1	1.26	N/A	15.6	N/A						
1.5	N/A	N/A	N/A	N/A						
2	N/A	N/A	N/A	N/A						
2.5	N/A	N/A	N/A	N/A						
3	N/A	N/A	N/A	N/A						

Dissolved O_2:CH_4 Ratios — Sites

N/A - indicates data that is not available because the oxygen concentration was below the level of detection. The line beneath the Greenfields Wetlands and Bool Lagoon data indicates the sediment:water interface and the dashes (-) appear at water depths where no readings were taken.

Table 5.1: A summary of the treatments performed on sediment and water samples from Willunga Wetlands, Greenfields Wetlands and Bool Lagoon in summer 1996/1997 and winter 1997.

Samples	Sites				
	WILLUNGA INLET	**WILLUNGA OUTLET**	**GREENFIELDS INLET**	**GREENFIELDS OUTLET**	**BOOL HACKS**
Clay Sediment	L-cysteine $HgCl_2$	L-cysteine $HgCl_2$	L-cysteine $HgCl_2$	L-cysteine $HgCl_2$	L-cysteine $HgCl_2$
Flocculent Sediment	L-cysteine $HgCl_2$ BES	L-cysteine $HgCl_2$ BES	L-cysteine $HgCl_2$ BES	L-cysteine $HgCl_2$ BES	L-cysteine $HgCl_2$ BES
Surface Water	None	None	None	None	None

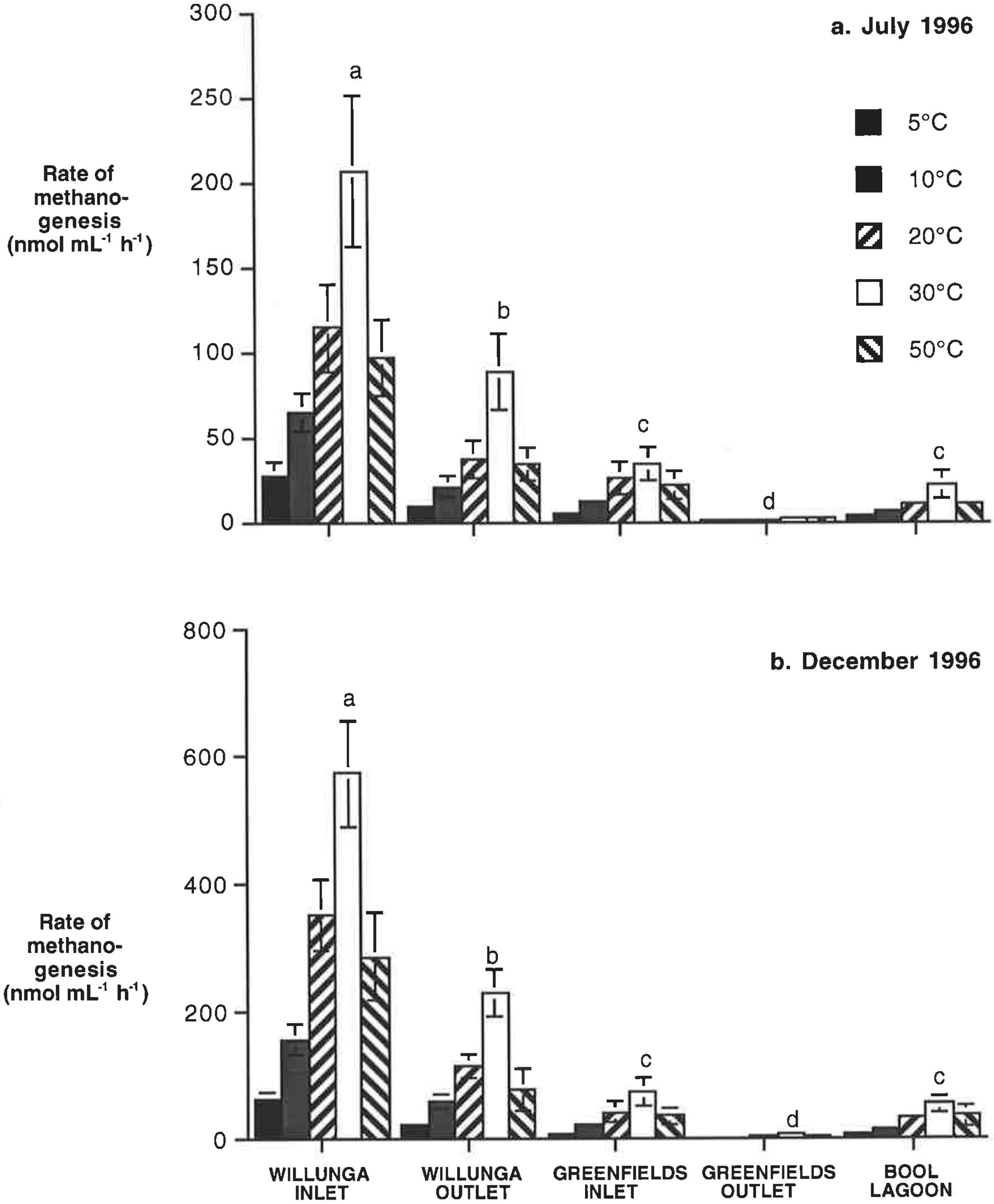


Figure 5.1: Effect of temperature on *in vitro* methanogenesis for each wetland site in July (a) and December (b) 1996. Means ± std. dev. are shown (n=3). Significant Tukey-Kramer groupings for the 30°C data are denoted by the lower case letters above each data set. Note the different y-axis scales in each season.

Table 5.2: *In vitro* methanogenesis under various carbon and salt treatments compared with unamended sediment samples (anaerobic controls) from each wetland site.

Treatment	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS	*RYAN'S BILLABONG**
	Methanogenesis (% compared with anaerobic control)					
	Site and season					
	Spring 1996 at 20 °C				Autumn 1997 at 25°C	Nov. 1993 at 20°C
Nitrate	88 ± 3	71 ± 11	25 ± 2	59 ± 14	12 ± 3	*8 ± 3*
Sulphate	102 ± 4	91 ± 9	76 ± 2	81 ± 6	112 ± 18	*158 ± 8*
Molybdate	158 ± 56	122 ± 23	220 ± 15	241 ± 31	126 ± 12	*120 ± 16*
Acetate	125 ± 13	186 ± 43	386 ± 46	371 ± 61	280 ± 51	*367 ± 20*
Cellobiose	129 ± 25	221 ± 36	391 ± 51	366 ± 72	206 ± 37	*395 ± 40* †
Fermenters	149 ± 32	199 ± 42	168 ± 31	149 ± 21	429 ± 78	
Fermenters + cellobiose	141 ± 28	286 ± 31	472 ± 63	431 ± 88	436 ± 81	
"Killed" fermenters	105 ± 2	108 ± 4	109 ± 3	101 ± 4	102 ± 7	
Rates of methanogenesis in anaerobic control ($nmol\ mL^{-1}\ h^{-1}$)	382 ± 36	121 ± 22	33.2 ± 6.1	5.3 ± 1.2	37.6 ± 4.8	*18 ± 0.1*

Data are shown as means ± standard deviation. The sample size was 3 for all treatments and 6 for the controls.
*data from Boon and Mitchell (1995) are expressed as means ± standard errors (n=4).
† polymeric substrate in Boon and Mitchell (1995) was starch not cellobiose

Table 5.3: Temperature, dissolved methane and dissolved oxygen profiles for Willunga Wetlands in summer and winter. Dissolved methane data are presented as mean ± std. dev. (n=3).

Water depth and Season	Temperature (°C)		Initial $[CH_4]$ (μg L^{-1})		Initial $[O_2]$ (mg L^{-1})	
	WILLUNGA WETLANDS					
	INLET	OUTLET	INLET	OUTLET	INLET	OUTLET
Shallow (10cm)						
summer	22.5 - 30.5	22.4 - 30.4	281 ± 13	36 ± 8.1	21.4	19.6
winter	12.8 -15.2	12.7 - 15.2	5.2 ± 2.2	3.1 ± 1.9	21.6	10.8
Deep (50cm)						
summer	21 - 27.2	20.8 - 27	554 ± 35	51.7 ± 8.2	11.6	12.2
winter	12.6 - 14.8	12.5 - 14.7	6.7 ± 2.2	4.3 ± 1.2	3.2	4.8
Floc						
summer	18.8 - 19.4	18.8 - 19.2	2784 ± 124	1377 ± 255	<1	<1
winter	11.8 - 12.4	11.7 - 12.5	214 ± 49	109 ± 42	<1	<1

Table 5.4: Temperature, dissolved methane and dissolved oxygen profiles for Greenfields Wetlands in summer and winter. Dissolved methane data are presented as mean ± std. dev. (n=3).

	Temperature (°C)		**Initial [CH_4] (µg L^{-1})**		**Initial [O_2] (mg L^{-1})**	
Water depth and Season	**GREENFIELDS WETLANDS**					
	INLET	**OUTLET**	**INLET**	**OUTLET**	**INLET**	**OUTLET**
Shallow (10cm)						
summer	22.2 - 26.4	22 - 26.5	28.6 ± 8.4	10.9 ± 1.8	8.4	7.6
winter	7.2 - 8.4	7.4 - 8.4	7.4 ± 1.4	2.5 ± 1.1	9.8	8.1
Deep (40-85cm)						
summer	21.8 - 24.4	21.6 - 24.5	62.3 ± 9.1	12.6 ± 1.2	5.16	4.8
winter	7.2 - 8.4	7.4 - 8.4	7.3 ± 1.3	2.4 ± 1.3	9.8	8.1
Floc						
summer	21.6 - 24.6	21.4 - 24.5	95.6 ± 16	21.2 ± 4.1	<1	<1
winter	7.2 - 8.4	7.4 - 8.4	7.6 ± 2.7	4.8 ± 1.	1.2	<1

Table 5.5:
Temperature, dissolved methane and dissolved oxygen profiles for Bool Lagoon in summer and winter. Dissolved methane data are presented as mean ± std. dev. (n=3).

Water depth and Season	Temperature (°C)	Initial [CH_4] (μg L^{-1})	Initial [O_2] (mg L^{-1})
		BOOL-HACKS	
Shallow (10 cm)			
summer	22.8 - 27.9	31.2 ± 8.8	8.92
winter	9.2 - 11.8	4.7 ± 1.8	7.6
Deep (50-85 cm)			
summer	22.6 - 24.2	69.5 ± 21	7.2
winter	9.2 - 11.8	4.8 ± 1.3	7.6
Floc			
summer	22.8 - 23.2	91.2 ± 26	1.2
winter	9.2 - 11.8	5.4 ± 1.5	1.6

Table 5.6: Rates of methanogenesis in the benthos, differentiated between floc and clay sediment samples, in summer and winter at each study site.

Season and Sediment type		Benthic methanogenesis (nmol mL^{-1} h^{-1})					
		Sites					
		WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS	P-values
Summer							
	Floc	605 ± 61[a]	230 ± 29[b]	83.3 ± 5.3[c]	5.67 ± 1.7[e]	50.6 ± 6.2[d]	0.0000
	Clay	95.2 ± 11[a]	29.8 ± 7.1[b]	6.96 ± 0.6[c]	1.47 ± 0.2[d]	8.85 ± 0.5[c]	0.0000
Winter							
	Floc	47.6 ± 11[a]	29.3 ± 3.6[a]	16.8 ± 2.5[b]	0.87 ± 0.1[d]	10.1 ± 2.9[c]	0.0000
	Clay	7.74 ± 2.4[a]	4.18 ± 0.6[ab]	3.44 ± 0.7[b]	0.13 ± 0.03[c]	2.91 ± 1.1[b]	0.0000

Data are shown as mean ± std. dev. (n=3). Superscript letters denote significant Tukey-Kramer groupings.

Table 5.7: Rates of methanotrophy in flocculent sediment samples from each study site, in the presence of bromoethanosulphonic acid (BES) and/or oxygen, in summer and winter.

Season and Treatment	Benthic methanotrophy (nmol mL^{-1} h^{-1})					
	Sites					
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS	P-values
Summer						
+BES, +O2	-	-	-489 ± 15^{ab}	-285 ± 34^{c}	-388 ± 63^{b}	0.0000
+BES	-562 ± 47^{a}	-191 ± 17^{d}	NS	NS	NS	
Winter						
+BES, +O2	-	-	-92.6 ± 18^{a}	-8.7 ± 1.9^{d}	-68 ± 19^{ab}	0.0000
+BES	-45.6 ± 11^{bc}	-27 ± 7.5^{c}	NS	NS	NS	

Data are shown as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings are denoted by the superscript letters.
A dash (-) indicates that the treatment was not performed and 'NS' indicates that no significant change occurred between the initial and final dissolved methane concentrations.

Table 5.8: Rates of methanotrophy in surface water samples (10cm depth) from each study site in summer and winter.

Season and Water depth	Surface water methanotrophy (nmol mL^{-1} h^{-1})					
	Sites					
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS	P-values
Summer						
Shallow (10cm)	-1.41 ± 0.24^{a}	-0.83 ± 0.12^{a}	-1.33 ± 0.14^{a}	-0.15 ± 0.05^{b}	-1.19 ± 0.24^{a}	0.0000
Deep (50cm)	-7.92 ± 0.67^{a}	-3.66 ± 0.18^{b}	-1.99 ± 0.21^{c}	-0.51 ± 0.08^{d}	-2.6 ± 0.21^{c}	0.0000
Winter						
Shallow (10cm)	NS	NS	NS	NS	NS	
Deep (50cm)	-0.15 ± 0.03^{a}	-0.11 ± 0.02^{a}	-0.11 ± 0.02^{a}	-0.05 ± 0.01^{b}	-0.15 ± 0.03^{a}	0.0000

Data are shown as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings are denoted by the superscript letters.

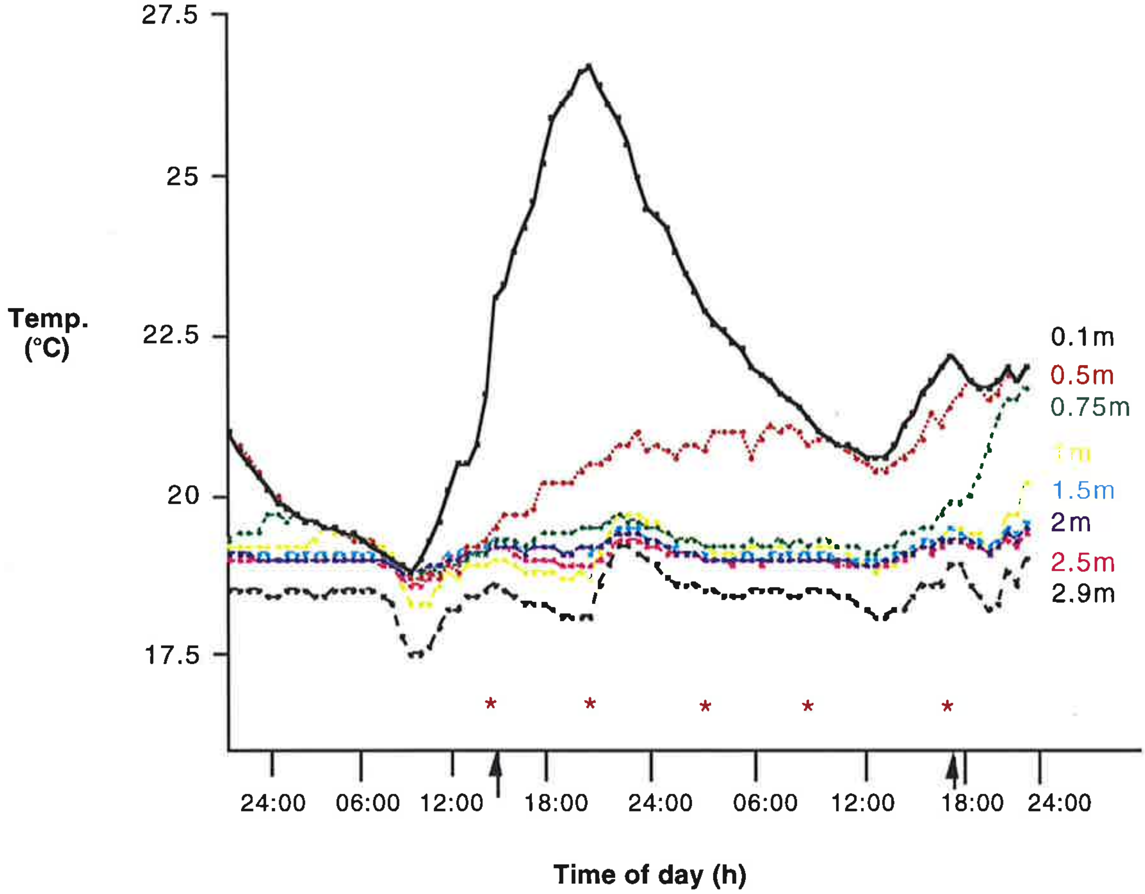


Figure 5.2: Water temperature at a range of depths in WILLUNGA-INLET measured at 30 minute intervals with a series of thermocouples and a datalogger on 1 March 1997. The asterixes indicate the start and finish times for the *in vitro* methanogenesis and methanotrophy experiments reported in Chapter 5.

Table 5.9: Dissolved oxygen profiles taken at WILLUNGA-INLET on 1 March 1997, during the *in situ* methanogenesis and methanotrophy trials.

Depth (m)	**Dissolved oxygen (mg L^{-1})** Time of Day (h)				
	1400	2100	0300	0800	1800
0.1	>15.0	>15.0	9.1	7.4	11.5
0.5	4.6	3.2	3.2	3.0	6.2
1	2.2	2.2	1.8	1	4.1
1.5	1.2	2.0	1	<0.5	1.2
2	0.8	1.6	0.8	<0.5	0.8
2.5	<0.5	1.2	<0.5	<0.5	0.8
2.9	<0.5	0.8	<0.5	<0.5	<0.5

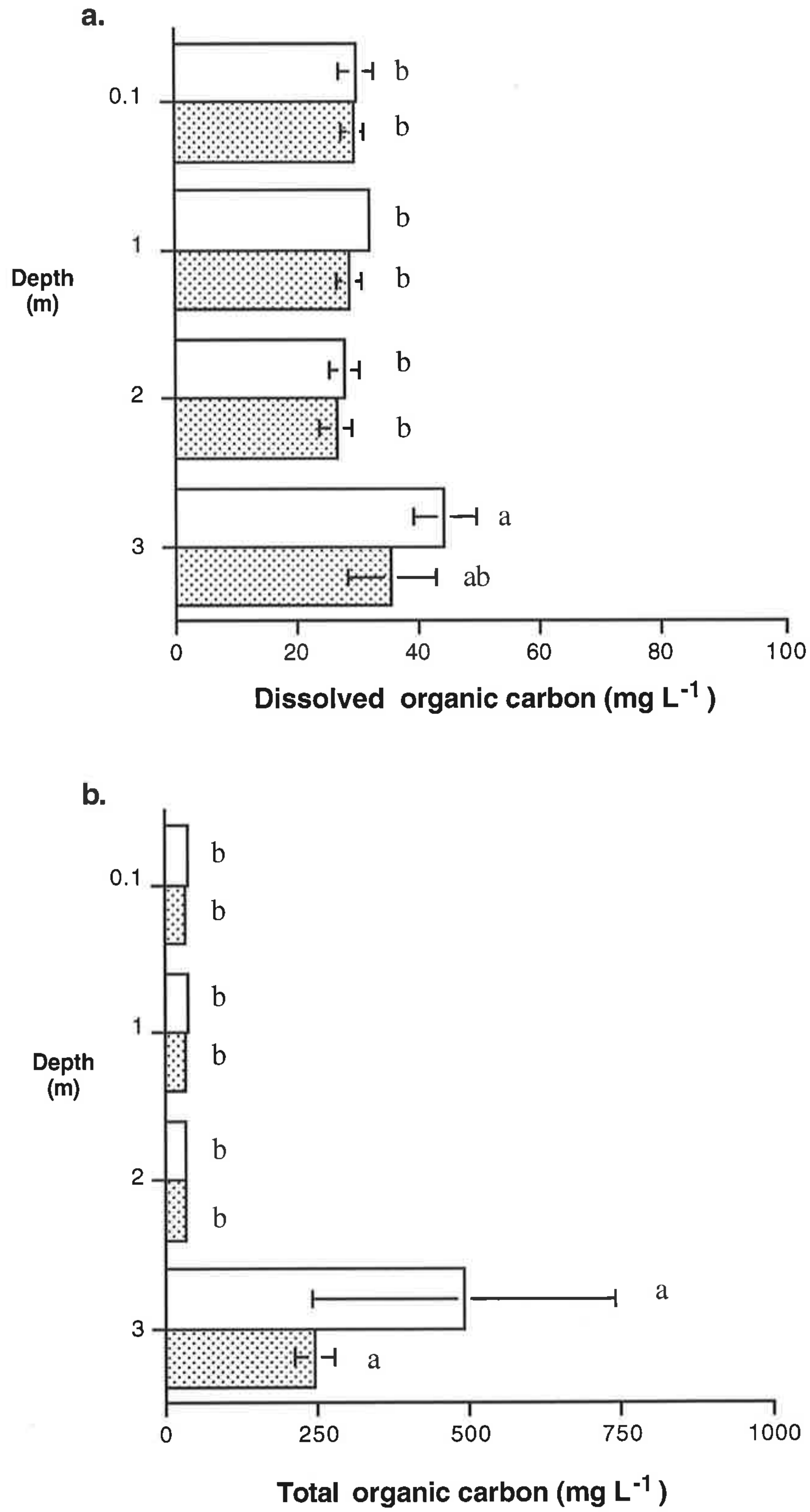


Figure 5.3: Depth profiles of DOC (a) and TOC (b) in WILLUNGA-INLET (▒) and WILLUNGA-OUTLET (□) in January 1999. Lower case letters denote significant Tukey-Kramer groupings (α=0.05) and error bars indicate one std. dev. about the mean (n=3).

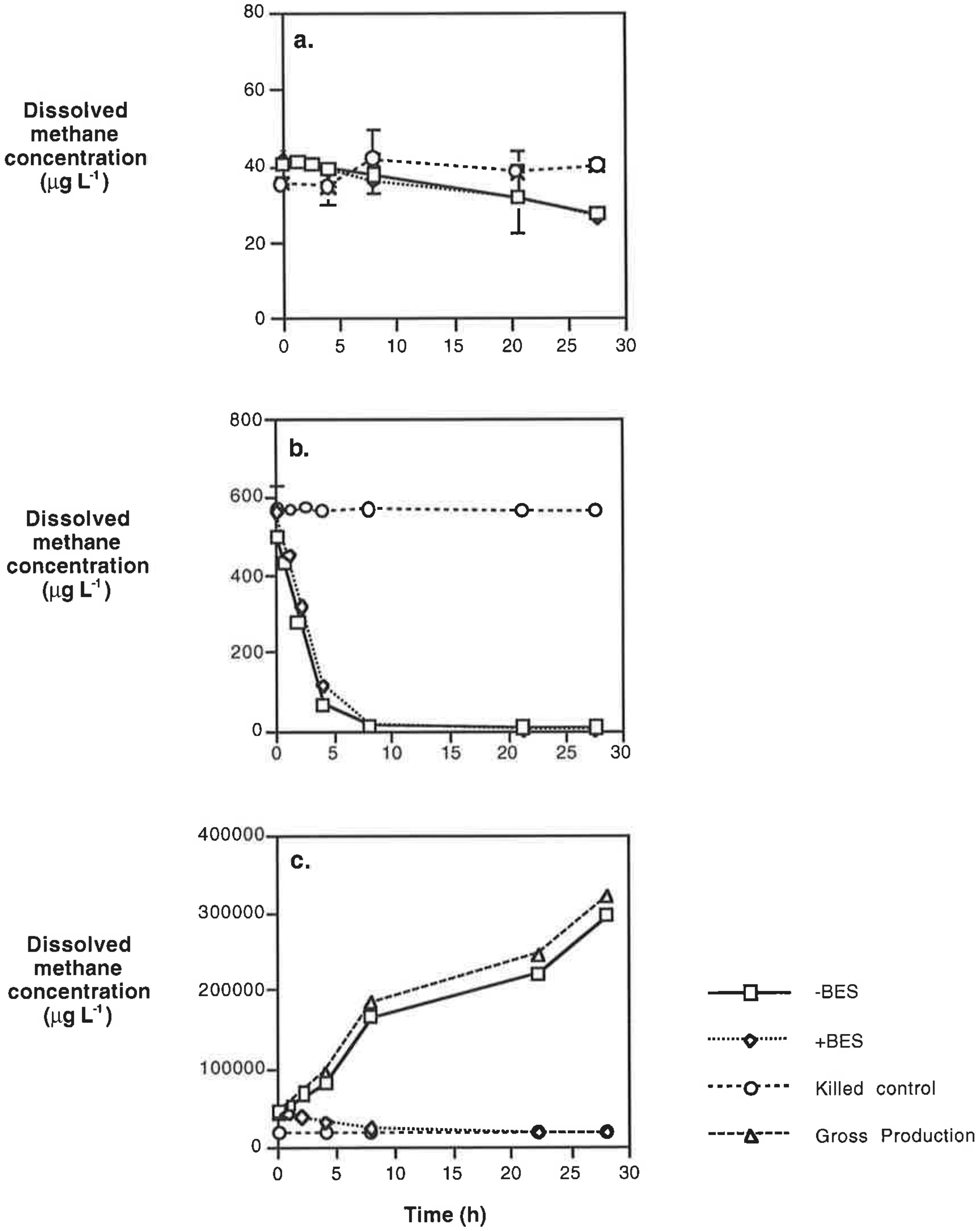


Figure 5.4: The effect of time and bromoethanosulphonic acid (BES) on the concentration of dissolved methane at 0.1m (a), 1.5m (b) and 3m (c) in the water column of WILLUNGA-INLET, as a measure of methanogenic or methanotrophic activity. Data are represented as mean values ± one standard deviation as error bars (n=3). Note the different y-axis scales for the three water depths.

Table 5.10: Gross and net rates of methanogenesis at WILLUNGA-INLET on 1 March 1997. The net rate shown for WILLUNGA-OUTLET was estimated from the relative rates of methanogensis reported in Chapter 5.

WILLUNGA-INLET				
Water Depth (m)	**Gross production**	**Oxidation**	**Net change**	**Net Rate**
		(nmol mL^{-1} h^{-1})		**(mmol m^{-2} h^{-1})**
0.1	0	-0.052	-0.052	-0.026
0.5	0	-0.35	-0.35	-0.175
1	0	-6.75	-6.75	-3.375
1.5	15	-13.7	1.69	0.845
2	35	-17.5	17.5	8.75
2.5	51	-24.3	26.25	13.125
3	1,003	-140	862.5	86.25
3.5	2	-0.08	1.56	0.078
Σ	**1,105**	**-203**	**902**	**106**
		WILLUNGA-OUTLET Net Rate		**36**

Table 6.1: The effect of cold storage (below 4°C) for ten days on methane concentrations in pre-evacuated vacutainers (n=10).

Storage time (days)	Target concentrations (ppm)		
	1.7	**100**	**3000**
0	1.87 ± 0.15	102.8 ± 5.2	3024 ± 50.2
0.5	1.84 ± 0.18	100.7 ± 4.8	2998 ± 47.8
4	1.80 ± 0.15	98.31 ± 4.5	3013 ± 62.2
10	1.85 ± 0.19	101.1 ± 4.08	3029 ± 50.9
P-values	0.77	0.21	0.57

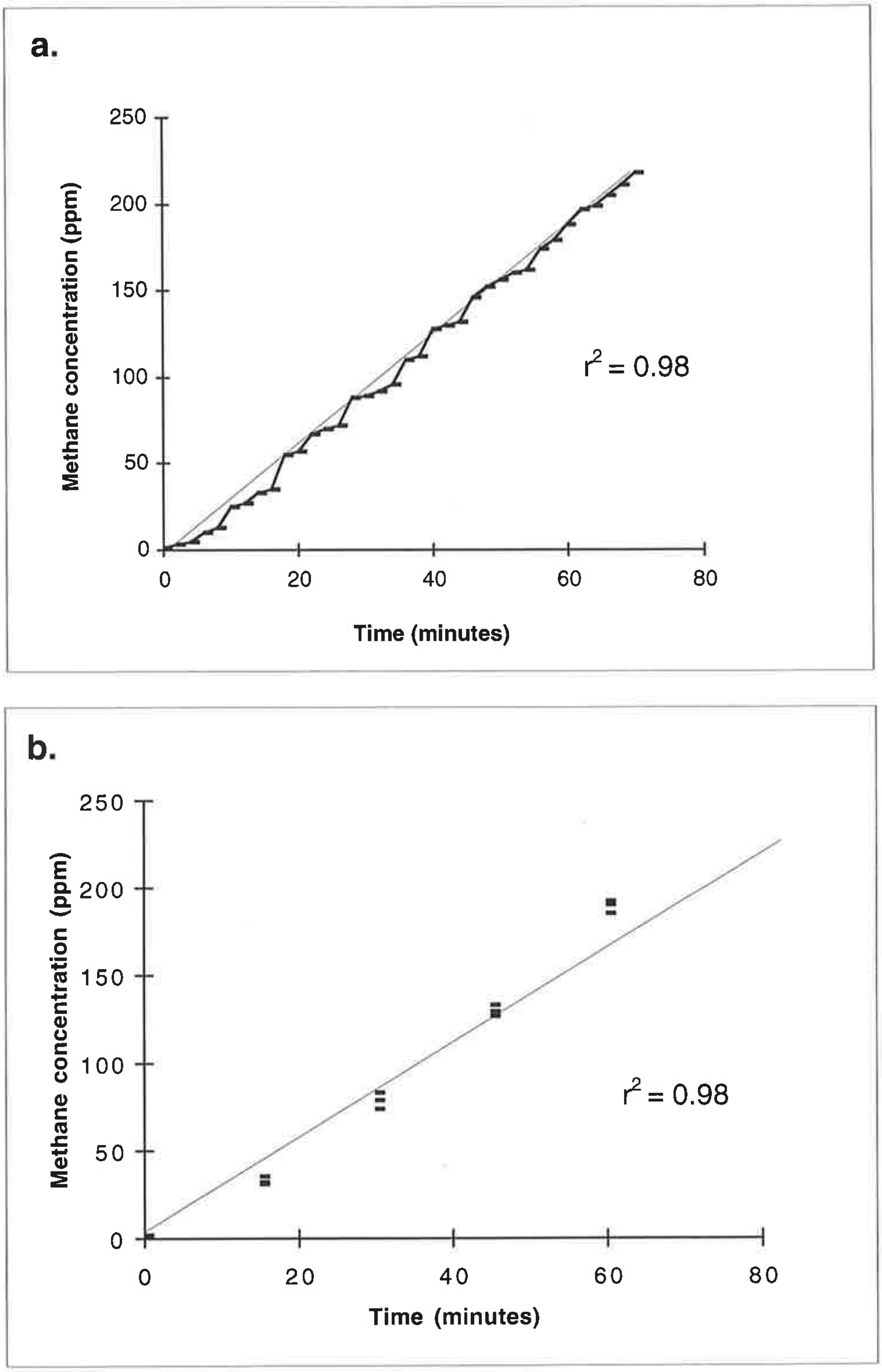


Figure 6.1: Example plots of methane accumulation inside static chambers deployed upon a methanogenic water surface.
Methane concentration was determined from samples taken at intervals of (a) 2 minutes and (b)15 minutes (n=3).
Note the 'rippling' effect when samples were taken at short intervals (a) indicating rapid and continuous ebullition.

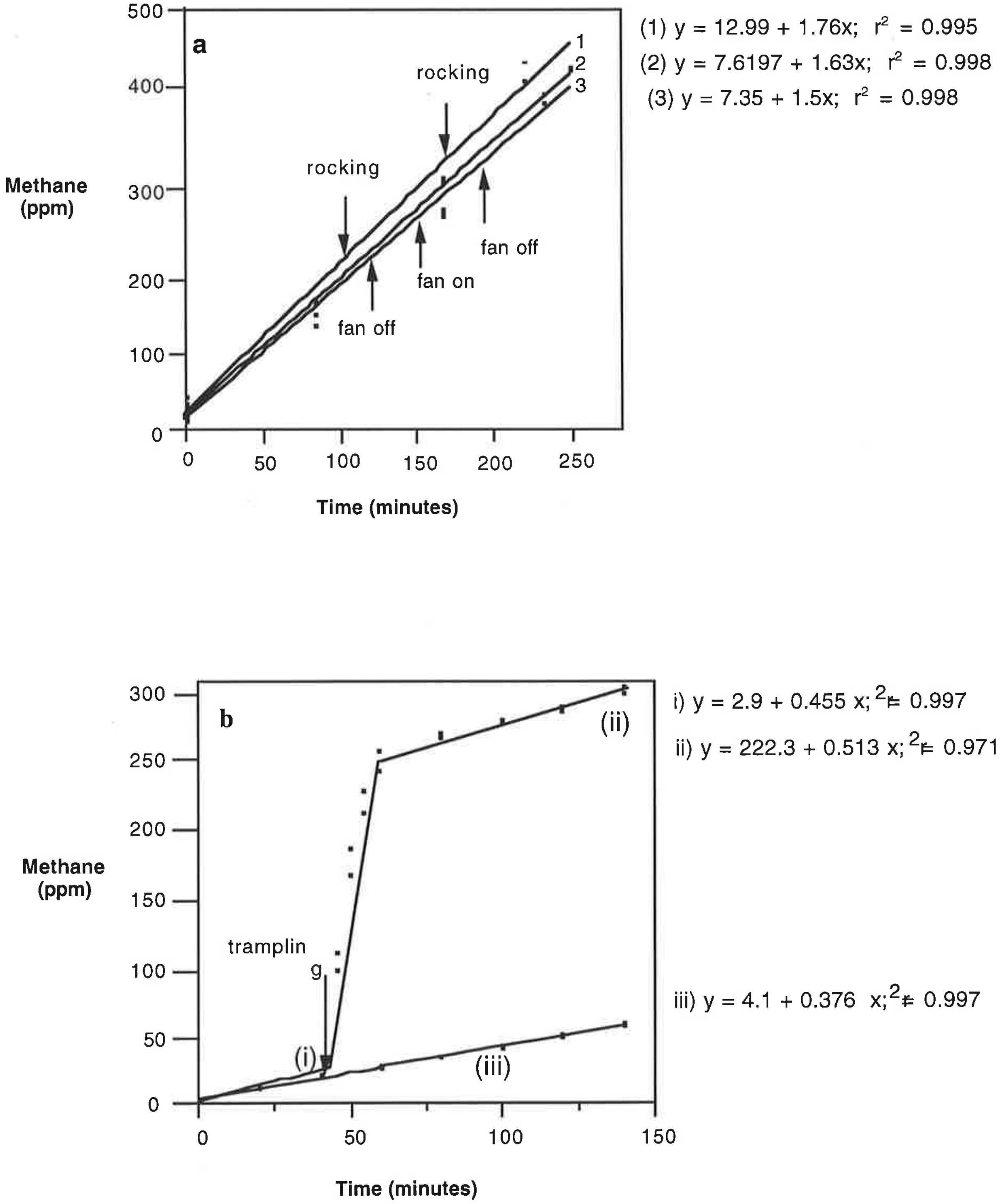


Figure 6.2: Effects of physically disturbing the static chambers on estimates of methane emission. The effects of rocking the chamber and turning the internal fan on and off are presented in plot (a) and the effect of trampling the sediment surrounding the chamber for three minutes is presented in plot (b).

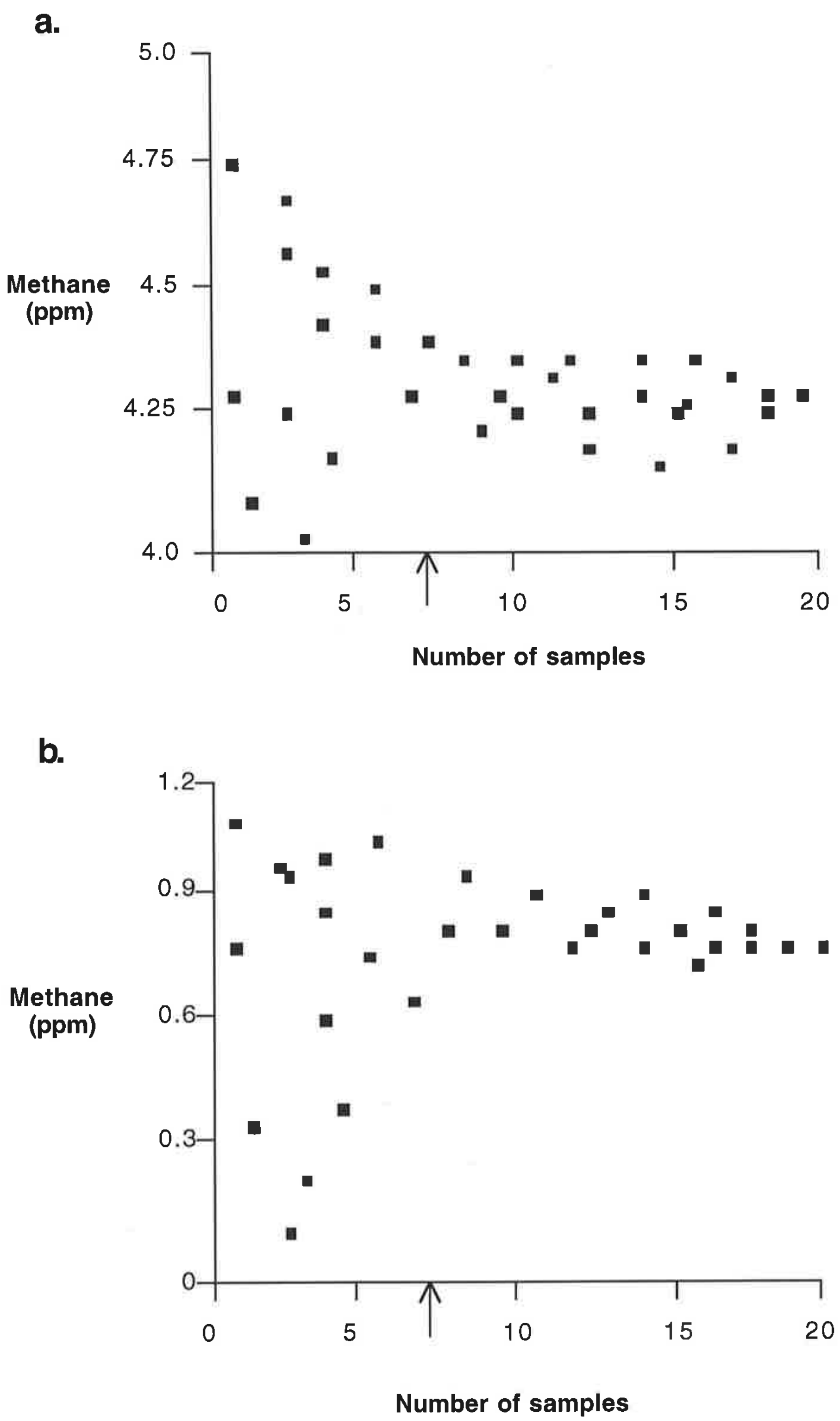


Figure 6.3: The effect of increasing sample size on estimates of mean (a) and standard deviation (b) values associated with methane emissions (n=1-18). The arrows indicate the minimum number of samples required to accurately describe the mean and standard deviation.

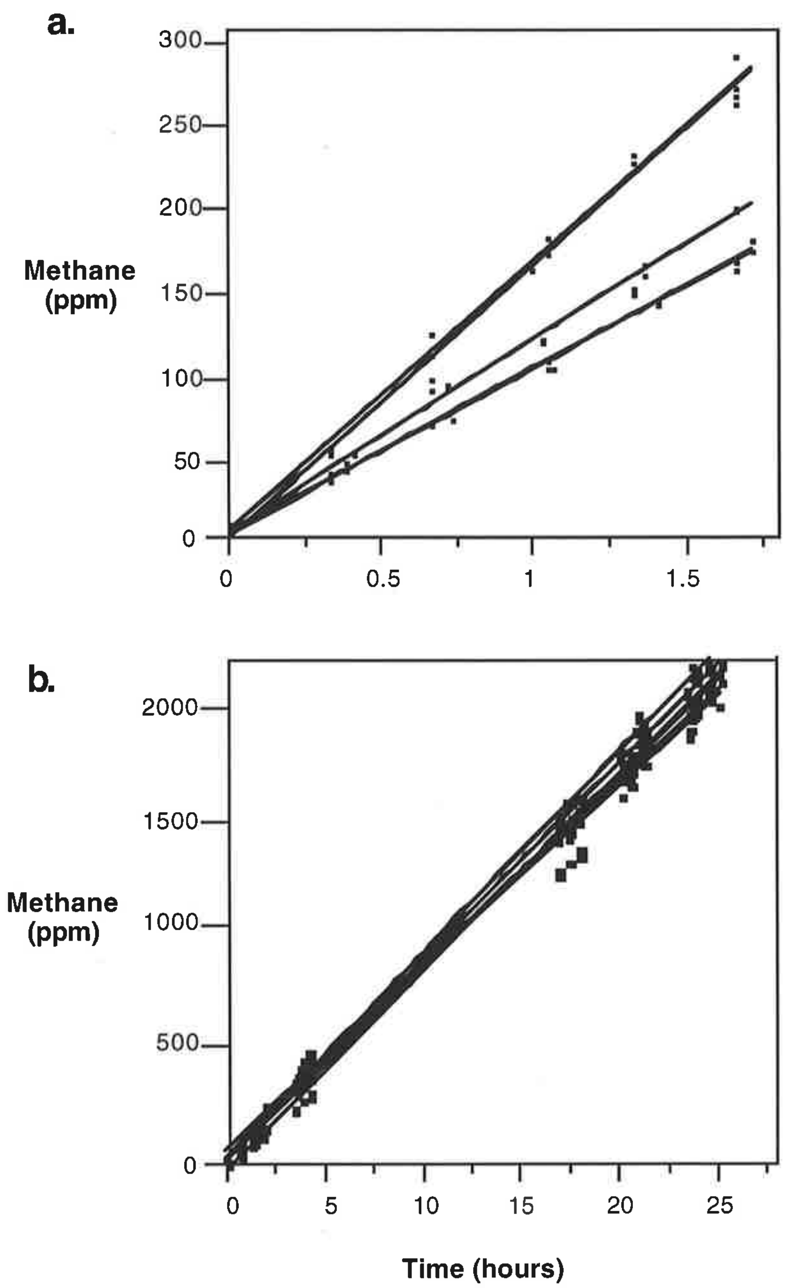


Figure 6.4: The effect of increasing deployment time on decreasing variation in methane emission estimates from six chambers. The chambers were deployed for less than two hours in plot (a) and 24 hours in plot (b).

Table 6.2:
The effect of increasing deployment time from less than two hours to 24 hours on decreasing variation in methane emission estimates (ppm/h) as described by the range of values, means, standard deviations and coefficients of variance of each data set.

	Chamber exposure time	
	100 minutes (ppm/h)	**24 hours** (ppm/h)
Range	50-97	65-72
Mean	70	69
Std. Dev.	20.8	2.96
Coeff. of variance	30%	4.30%

Table 6.3:
Day-to-day variations in methane emissions at Willunga Wetlands and Greenfields Wetlands in spring 1996.
Data are presented as mean values ± one standard deviation (n=3).

	Methane emissions (mmoles m^{-2} h^{-1})			
Day	**Sites**			
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET
1	3.26 ± 0.33	2.18 ± 0.30	1.23 ± 0.19	0.16 ± 0.05
2	3.06 ± 0.83	1.94 ± 0.23	1.33 ± 0.18	0.14 ± 0.06
3	3.25 ± 0.58	2.05 ± 0.39	1.22 ± 0.16	0.12 ± 0.03
Mean	3.25 ± 0.55	2.06 ± 0.29	1.26 ± 0.16	0.14 ± 0.05
P value	0.9046	0.635	0.7298	0.4274

Table 6.4: Methane emissions from the five wetland sites over nine consecutive seasons, summer 1994/1995 to autumn 1997. Mean values ± std. dev. are presented (n=18-48).

	Methane emissions (mmoles m^{-2} h^{-1})				
Season	**Site**				
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS
Summer 94/95	8.52 ± 5.7	2.66 ± 2.63	3.29 ± 0.48	0.53 ± 0.11	2.13 ± 1.61
Winter 95	2.26 ± 0.5	0.87 ± 0.08	5.99 ± 1.40	0.06 ± 0.01	0.16 ± 0.04
Spring 95	4.25 ± 0.79	2.34 ± 0.36	1.15 ± 1.04	0.11 ± 0.03	-
Summer 95/96	8.91 ± 2.6	2.63 ± 0.73	3.28 ± 1.4	0.44 ± 0.04	1.26 ± 0.13
Autumn 96	1.83 ± 0.61	0.75 ± 0.33	1.68 ± 0.25	0.18 ± 0.08	0.58 ± 0.08
Winter 96	2.44 ± 0.61	0.94 ± 0.12	6.07 ± 1.3	0.06 ± 0.01	-
Spring 96	3.31 ± 0.84	1.83 ± 0.67	1.31 ± 0.89	0.12 ± 0.07	-
Summer 96/97	7.78 ± 0.67	3.13 ± 0.43	3.87 ± 1.25	0.49 ± 0.09	-
Autumn 97	2.61 ± 0.76	0.63 ± 0.09	1.92 ± 0.36	0.21 ± 0.09	0.18 ± 0.1

Table 6.5:
Intrasite spatial variation in emissions from Willunga Wetlands and Greenfields Wetlands in Spring 1994 when chambers were deployed adjacent to one another or 4m apart.
Data presented as mean ± std. dev. (n=19-27).

	Methane emissions (mmol m^{-2} h^{-1})			
Position	**Sites**			
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET
Adjacent	4.38 ± 0.82	2.42 ± 0.28	3.43 ± 0.92	0.11 ± 0.03
4 m apart	4.12 ± 0.78	2.24 ± 0.42	4.88 ± 0.57	0.11 ± 0.06
P value	0.482	0.252	0.017	0.87

Table 6.6:
Percentage decrease in emissions from the inlet to the outlet of Willunga and Greenfields Wetlands between summer 1994/95 and autumn 1997.
Data taken from Table 6.4.

	Outlet/Inlet (%)	
Season	**Site**	
	Willunga Wetlands	Greenfields Wetlands
Summer 94/95	31	16
Winter 95	39	1
Spring 95	55	2
Summer 95/96	30	13
Autumn 96	41	11
Winter 96	38	1
Spring 96	55	3
Summer 96/97	40	12
Autumn 97	24	11

Table 6.7: The effect of location along the flow path on methane dynamics and sediment carbon content at Willunga Wetlands in spring 1996. Data are presented as mean ± std. dev. (n=3).

Location	Water Depth (m)	Methane Emission ($mmol\ m^{-2}\ h^{-1}$)	Methane Production* ($nmol\ mL^{-1}\ h^{-1}$)	Methane Oxidation** ($nmol\ mL^{-1}\ h^{-1}$)	Sediment Carbon Content (% w/w)	Sediment Methane Concentration (% v/v)
WILLUNGA-INLET	3.1	7.78 ± 0.67	461 ± 54	-1.34 ± 0.22	1.42 ± 0.21	78 ± 25
Pond 2 (site 2)	3	5.31 ± 0.49	332 ± 26	-1.13 ± 0.14	1.35 ± 0.38	68 ± 26
WILLUNGA-OUTLET	2.95	3.13 ± 0.43	204 ± 19	-0.87 ± 0.09	0.64 ± 0.13	59 ±19
Pond 1 (site 3)	0.65	1.51 ± 0.15	71 ± 22	-0.88 ± 0.16	0.87 ± 0.09	35 ± 12
Pond 2 (site 4)	0.63	1.45 ± 0.26	61 ± 15	-0.73 ± 0.23	1.05 ± 0.5	28 ± 9
Pond 3 (site 6)	0.61	1.21 ± 0.19	57 ± 21	-0.64 ± 0.13	0.66 ± 0.08	24 ± 7

*Methane production rates were monitored in flocculent sediment samples
**Methane oxidation rates were monitored in water samples from 10cm depth.
See Figure 3.1 for site locations.

Table 6.8: The effect of location along the flow path on methane dynamics and sediment carbon content at Greenfields Wetlands in spring 1996. Data are presented as mean ± std. dev. (n=3).

Location	Parameter					
	Water Depth	Methane Emission	Methane Production*	Methane Oxidation**	Sediment Methane Concentration	Sediment Carbon Content
	(m)	(mmol m^{-2} h^{-1})	(nmol mL^{-1} h^{-1})		(% v/v)	(% w/w)
GREENFIELDS-INLET	0.65	3.92 ± 0.19	72 ± 27	-1.25 ± 0.25	69 ± 22	1.32 ± 1.2
Site 2	0.64	2.69 ± 0.6	55 ± 18	-1.06 ± 0.21	55 ± 24	1.18 ± 0.13
Site 3	0.65	2.06 ± 0.29	44 ± 15	-0.91 ± 0.19	50 ± 30	1.42 ± 0.12
Site 4	0.62	0.82 ± 0.19	9 ± 7	-0.55 ± 0.11	12 ± 7	0.94 ± 0.67
Site 5	0.61	0.7 ± 0.18	5 ± 2	-0.22 ± 0.09	7 ± 2	0.87 ± 0.42
GREENFIELDS-OUTLET	0.61	0.49 ± 0.09	2 ± 1	-0.13 ± 0.06	6 ± 2	0.96 ± 0.34

*Methane production rates were monitored in flocculent sediment samples

**Methane oxidation rates were monitored in water samples from 10cm depth.

See Figure 3.2 for site locations.

Table 6.9:
Correlation values (r^2) for a series of regressions between rates of emission and sediment organic carbon content, sediment methane concentration, benthic methane production and planktonic methane oxidation at 6 sites in Willunga and Greenfields Wetlands in spring 1996 (n=18).

	Correlation with emissions (r^2 values)	
Parameter	Willunga Wetlands	Greenfields Wetlands
Sediment organic carbon content (% w/w)	0.61911045	0.630069854
Sediment methane concentration (% v/v)	0.889283524	0.945205429
Benthic methane production (nmol mL^{-1} h^{-1})	0.991888501	0.976429395
Planktonic methane oxidation (nmol mL^{-1} h^{-1})	0.908968754	0.901400747

Table 6.10:
Effect of water depth on methane emissions from Willunga Wetlands. Data are presented as mean values ± one standard deviation (n=3).

		Methane emissions (mmol m^{-2} h^{-1})	
Season	**Water Depth (m)**	**Site**	
		Pond 1	Pond 3
Spring 1995	0.6	0.35 ± 0.03	0.83 ± 0.09
	1.2	2.19 ± 0.20	2.37 ± 0.46
	3	4.42 ± 0.29	4.09 ± 0.40
		P<0.0001	**P<0.0001**
Summer 1995/96	0.6	0.73 ± 0.07	0.43 ± 0.03
	1.2	4.26 ± 0.50	2.59 ± 0.55
	3	8.73 ± 1.22	5.58 ± 1.5
		P<0.0001	**P=0.0017**
Spring 1996	0.6	1.52 ± 0.16	1.18 ± 0.22
	1.2	4.39 ± 0.56	2.51 ± 0.43
	3	7.30 ± 0.60	3.18 ± 0.45
		P<0.0001	**P=0.0018**

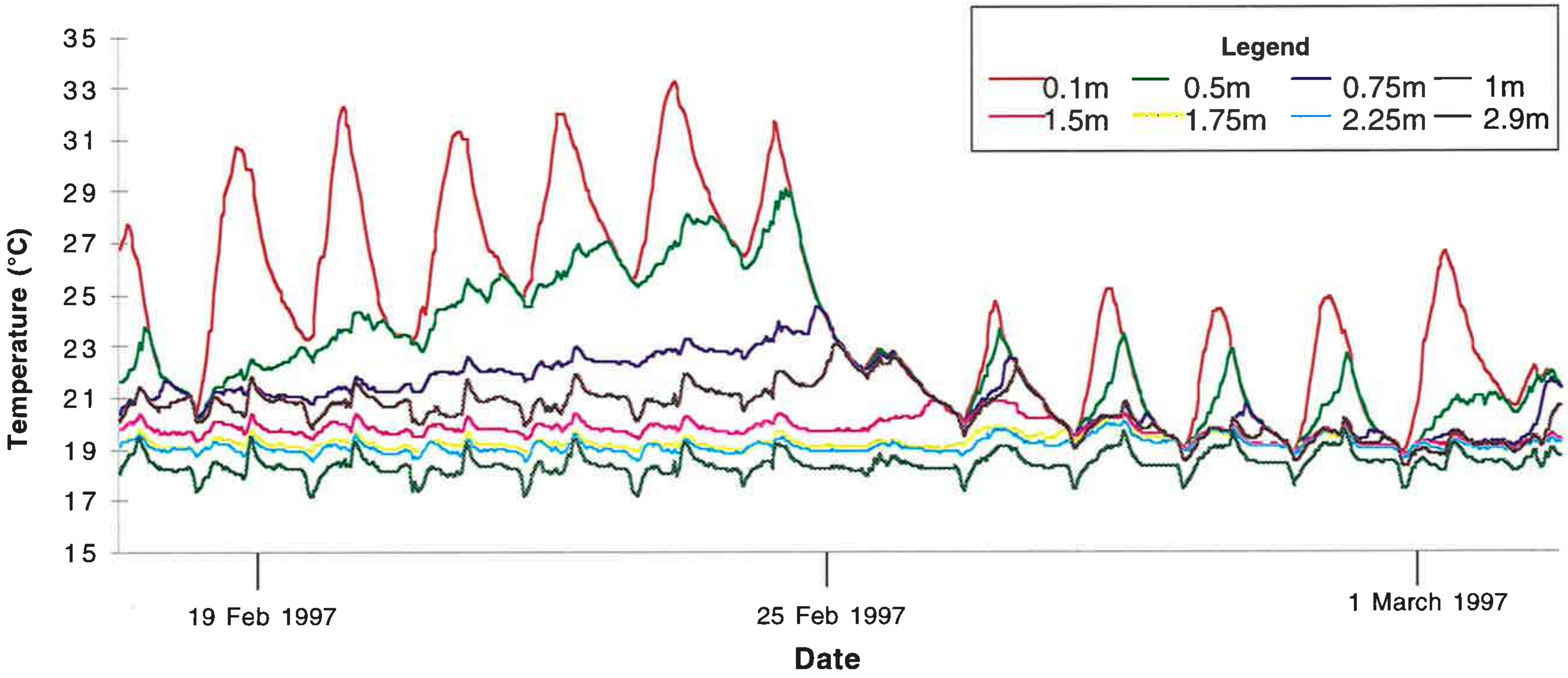


Figure 6.5: Temperature profiles for the water column of WILLUNGA-INLET between 19 February and 1 March 1997. One thermocouple was deployed at each depth and logged at 30 minute intervals.

Table 6.11:
A comparison of dissolved oxygen and methane concentrations with methane emissions before and after the first major mixing of the water column at the break of autumn in 1997 (25.2.97). Dissolved methane and emission data are presented as mean ± std. dev. (n=3).

	WILLUNGA-INLET			
	20.2.97		**2.3.97**	
Water Depth (m)	Dissolved Oxygen ($mg\ L^{-1}$)	Dissolved Methane ($\mu g\ L^{-1}$)	Dissolved Oxygen ($mg\ L^{-1}$)	Dissolved Methane ($\mu g\ L^{-1}$)
0.1	15	37.4 ± 5.1	15	11.6 ± 1.5
0.5	12.5	44.8 ± 9.2	12.8	26.2 ± 6.7
1	6.3	533 ± 51	6.6	93.6 ± 15.1
1.5	1.4	1804 ± 93	1.8	667 ± 112
2	0.8	2652 ± 106	1.4	1459 ± 338
2.5	0.3	7740 ± 181	1.2	2825 ± 206
3	<0.2	44354 ± 1036	0.6	3216 ± 764
Emission ($mmol\ m^{-2}\ h^{-1}$)	4.07 ± 1.1		1.95 ± 0.71	

Table 6.12:
Total atmospheric emmision and ebullition rates from GREENFIELDS-INLET in winter 1996 and summer 1996/97. These data are presented as mean ± std. dev. (n=12-24). The relative proportion of ebullition to total emission and the range of stormwater inflow rates measured each season are also shown.

Emissions (mmol m^{-2} h^{-1})			
	Season		**P value**
	Winter 96	Summer 96/97	
Ebullition	5.64 ± 1.2	3.45 ± 1.07	<0.0001
Total	6.07 ± 1.3	3.80 ± 1.4	0.0004
Ebullition/Total	93%	91%	
Flow Rate (ms^{-1})	4.5 - 7.3	0 - 1.3	

Table 6.13:
Seasonal variation in sediment gas methane content at GREENFIELDS-INLET in winter 1996 and summer 1996/97. Data are presented as mean ± std. dev. (n=10).

Methane concentration (%v/v)	
May 1996	48.7 ± 8.7
August 1996	42.1 ± 18
January 1997	54.9 ± 9.3
P value	0.0986

Table 6.14:
The effect of vegetation on methane emissions from Bool Lagoon in summer and winter. Data are presented as mean ± std. dev. (n=3).

Season	Methane emissions ($mmol\ m^{-2}\ h^{-1}$)		
	Vegetation Type		
	Unvegetated	*Phragmites australis*	*Triglochin procerum*
Summer 94/95	1.31 ± 0.50	2.77 ± 0.66	2.75 ± 0.92
Winter 95	0.16 ± 0.04	0.2 ± 0.11	nd
Summer 95/96	1.26 ± 0.13	nd	2.81 ± 0.71

nd=no data taken

Table 6.15:
The effect of water depth and vegetation on methane emissions from Bool Lagoon in autumn 1997. Data are presented as mean ± std. dev. (n=3). Significant Tukey-Kramer groupings are denoted by the lower case letters in superscript.

Water Depth	Methane emissions ($mmol\ m^{-2}\ h^{-1}$)	
	Vegetation Type	
	Unvegetated	*Triglochin procerum*
Exposed	-0.83 ± 0.013^{b}	0.21 ± 0.11^{b}
Shallow (15 cm)	0.0074 ± 0.03^{b}	0.42 ± 0.11^{b}
Deep (35 cm)	1.07 ± 0.15^{a}	1.37 ± 0.31^{a}
	P value <0.0001	

Table 6.16:
Interpolation factors and wetland area estimates used to model annual methane emissions on a whole wetland basis for Willunga Wetlands (a), Greenfields Wetlands (b) and Bool Lagoon (c). The interpolation factors are shown as a percentage of methane emissions at the inlet or outlet of the respective wetland.

a. Willunga Wetlands

Depth (m)	**Area (ha)**	**Interpolation Factors**		
		Pond 1	Pond 2	Pond 3
0.6	0.4	8% WI	5% WI	15% WO
1.2	0.1	49% WI	35% WI	52% WO
3	0.5	WI	68% WI	WO

b. Greenfields Wetlands

Site Name	**Interpolation Factors**	**Area Winter/Spring (ha)**	**Area Summer/Autumn (ha)**
GFI	GFI	6.7	6.7
2	68% GFI	6.7	6.7
3	53% GFI	6.7	6.7
4	167% GFO	6.7	4.5
5	142% GFO	6.7	4.5
GFO	GFO	6.7	4.5

c. Bool Lagoon

Season	**Area (ha)**	
	Wet Winter	Dry Winter
Summer	1250	10
Autumn	1565	10
Winter	2500	250
Spring	1875	125

WI = WILLUNGA-INLET, WO = WILLUNGA-OUTLET,
GFI = GREENFIELDS-INLET, GFO = GREENFIELDS-OUTLET

Table 6.17: Estimates of methane emissions from each of the five wetland sites over nine consecutive seasons from summer 1994/95 to autumn 1997. Data are presented as mean ± std. dev. (n=28-115).

	Methane emissions (kg ha^{-1} $season^{-1}$)				
Season	Site				
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS
Summer 94/95	2952 ± 1964	922 ± 903	1135 ± 166	183 ± 37	736 ± 545
Winter 95	786 ± 171	300 ± 27	2071 ± 484	21 ± 3.6	56 ± 14
Spring 95	1463 ± 263	805 ± 127	397 ± 362	38 ± 11	-
Summer 95/96	3081 ± 875	911 ± 251	1127 ± 481	152 ± 14	435 ± 45
Autumn 96	633 ± 201	259 ± 115	581 ± 87	63 ± 28	201 ± 28
Winter 96	849 ± 203	324 ± 41	2098 ± 48	21 ± 3.5	-
Spring 96	1147 ± 294	633 ± 227	453 ± 302	41 ± 24	-
Summer 96/97	2689 ± 33	1083 ± 147	1337 ± 429	169 ± 29	-
Autumn 97	902 ± 267	219 ± 31	664 ± 123	73 ± 32	62 ± 33

Table 6.18: Estimates of seasonal methane emissions from each of the five wetland sites. Data are presented as mean ± std. dev. (n=28-115).

	Methane emissions (kg ha^{-1})				
Season	**Site**				
	WILLUNGA INLET	WILLUNGA OUTLET	GREENFIELDS INLET	GREENFIELDS OUTLET	BOOL HACKS
Summer	2907 ± 961	972 ± 438	1199 ± 361	168 ± 23	586 ± 261
Autumn	768 ± 236	239 ± 75	624 ± 103	55 ± 28	132 ± 41
Winter	822 ± 181	311 ± 36	2085 ± 273	21 ± 3.5	56 ± 14
Spring	1307 ± 272	721 ± 173	432 ± 338	39 ± 16	132 ± 41

Table 6.19: Estimates of annual methane emissions from Willunga Wetlands, Greenfields Wetlands and Bool Lagoon.

	Methane emissions (kg y^{-1})			
Season	**Wetland**			
	Willunga Wetlands	Greenfields Wetlands	Bool Lagoon Wet winter	Bool Lagoon Dry winter
Summer	3470	18900	732500	5900
Autumn	900	9570	206600	1300
Winter	1000	31460	140000	14000
Spring	1740	7470	247500	16500
Annual	**7,110**	**67,400**	**1,326,600**	**37,700**

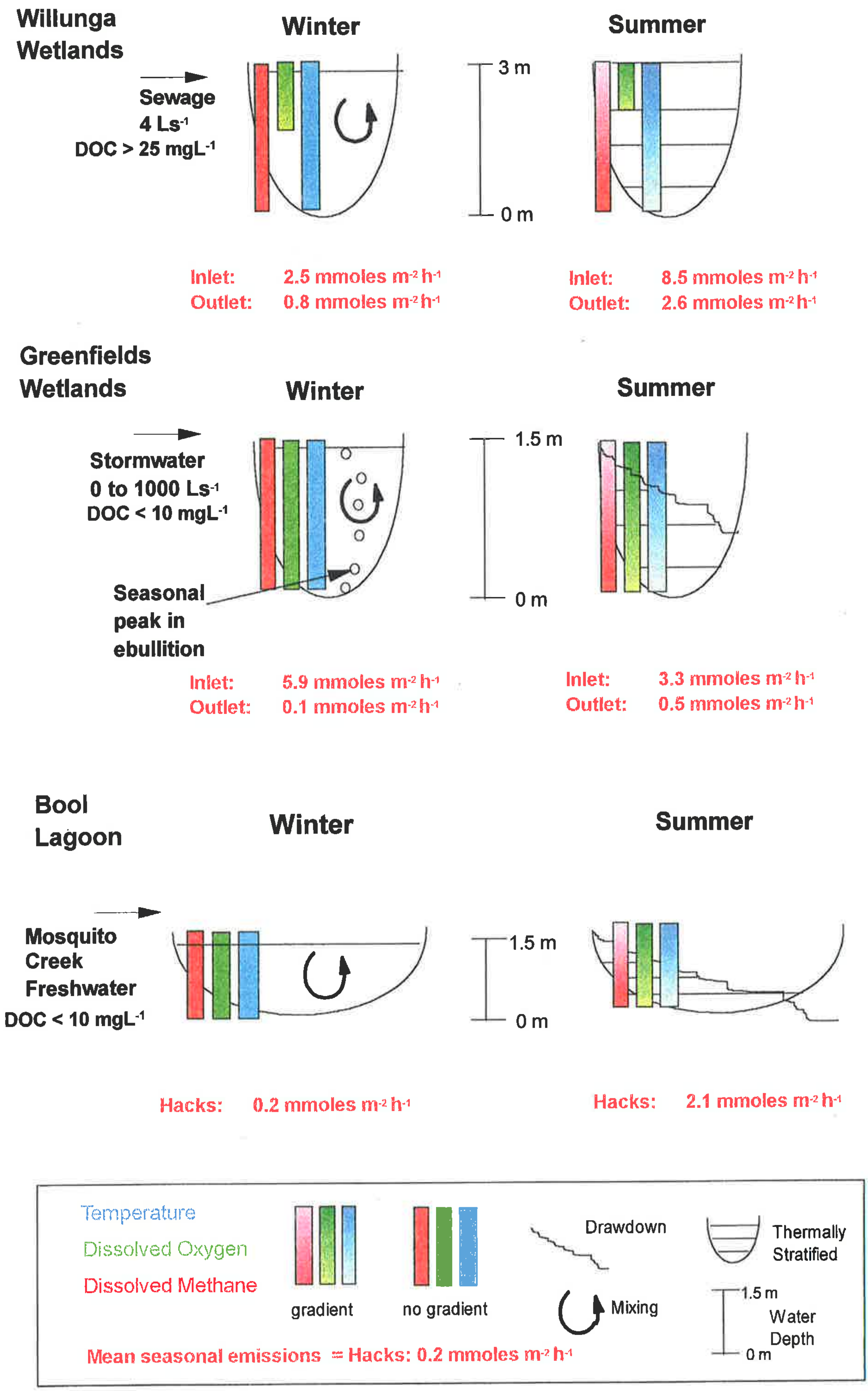


Figure 7.1: Schematic models of methane dynamics in the three wetlands in winter and summer.

Appendices

Appendix 1.1: ANOVA tables for Chapter 4

The effect of DATE on TOC content at WILLUNGA-INLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	28.542222	14.2711	3.1918
Error	6	26.826667	4.4711	Prob>F
C total	8	55.368889	6.9211	0.1137

The effect of DATE on DOC content at WILLUNGA-INLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	121.80096	60.9005	14.1293
Error	6	25.8614	4.302	Prob>F
C total	8	147.66236	18.4578	0.0054

The effect of DATE on TOC content at WILLUNGA-OUTLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	33.620000	16.8100	8.147
Error	6	12.380000	2.0633	Prob>F
C total	8	46.000000	5.7500	0.0195

The effect of DATE on DOC content at WILLUNGA-OUTLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	68.649041	34.3245	20.8084
Error	6	9.897301	1.6496	Prob>F
C total	8	78.546342	9.8183	0.002

The effect of DATE on TOC content at GREENFIELDS-INLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	4.3349556	2.16748	13.2838
Error	6	0.9790000	0.16317	Prob>F
C total	8	5.313955	0.6642	0.0063

The effect of DATE on DOC content at GREENFIELDS-INLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	2.2538667	1.12693	21.4699
Error	6	0.3149333	0.05249	Prob>F
C total	8	2.5688	0.3211	0.0018

The effect of DATE on TOC content at GREENFIELDS-OUTLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	0.6124222	0.306211	2.9074
Error	6	0.6319333	0.105322	Prob>F
C total	8	1.2443556	0.155544	0.131

The effect of DATE on DOC content at GREENFIELDS-OUTLET
One-way ANOVA performed in JMP v3.2

Source	DF	Sum of Squares	Mean Squares	F ratio
Model	2	0.9088889	0.454444	18.5909
Error	6	0.1466667	0.024444	Prob>F
C total	8	1.055556	0.131944	0.0027

Appendix 1.2: ANOVA tables for Chapter 5

The effect of Wetland site and Season on rates of in vitro methane production at 30°C. Two-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	F	P
Site	4	10.989045	221.9091	0.0000
Season	1	1.214475	98.0988	0.0000
Site*Season	4	0.009825	0.1984	0.9363

The effect of Site on in vitro control rates of methanogenesis One-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	5.3475905	1.3369	292.4974	0.0000
Error	10	0.0457063	0.00457		
C Total	14	5.3932968			

The effect of Wetland site and Season on methanogenesis in flocculent sediment Two-way ANOVA on log10(x+1) transformed data performed on JMP v3.2.

Source of variation	DF	SS	F	P
Site	4	9.8730813	492.0289	0.0000
Season	1	4.5145854	899.9446	0.0000
Site*Season	4	0.2869918	14.3023	0.0000

The effect of Wetland site and Season on methanogenesis in clay sediment samples Two-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	F	P
Site	4	4.9885013	233.1533	0.0000
Season	1	2.4000535	448.6962	0.0000
Site*Season	4	0.6694681	31.2897	0.0000

The effect of Site on rates of methane production in the flocculent sediment in summer One-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	6.6068359	1.65171	388.8211	0.0000
Error	10	0.0424799	0.00425		
C Total	14	6.6493158			

The effect of Site on rates of methane production in the clay sediment in summer
One-way ANOVA on $log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	4.3882129	1.09705	385.5800	0.0000
Error	10	0.0284520	0.00285		
C Total	14	4.4166649			

The effect of Site on rates of methane production in the flocculent sediment in winter
One-way ANOVA on $log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	3.5532372	0.88309	153.5529	0.0000
Error	10	0.0578504	0.005785		
C Total	14	3.6110876			

The effect of Site on rates of methane production in the clay sediment in winter
One-way ANOVA on $log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	1.2697565	0.317439	40.4242	0.0000
Error	10	0.0785270	0.007853		
C Total	14	1.3482835			

The effect of Site and Season on rates of methane consumption in the floc sediment
Two-way ANOVA on $log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	F	P
Site	4	1.6338450	64.3301	0.0000
Season	1	7.1599849	1127.653	0.0000
Site*Season	4	0.5893672	23.2054	0.0000

The effect of Site on rates of methane consumption in the flocculent sediment in summer
One-way ANOVA on $log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	0.42473081	0.106183	50.2789	0.0000
Error	10	0.02111873	0.002112		
C Total	14	0.44584955			

The effect of Site on rates of methane consumption in the flocculent sediment in winter
One-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	1.7984814	0.449620	42.4689	0.0000
Error	10	0.1058704	0.010587		
C Total	14	1.9043518			

The effect of Site on methane consumption in the surface water layers in summer
One-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	2.1045325	0.526133	53.6211	0.0000
Error	10	0.0981205	0.009812		
C Total	14	2.2026530			

The effect of Site and Season on methane consumption in the surface water layers
Two-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	F	P
Site	4	2.363490	129.0263	0.0000
Season	1	13.677518	2986.7	0.0000
Site*Season	4	0.450808	24.6102	0.0000

The effect of Site on rates of methane consumption in at 50cm depth in summer
One-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	2.3085814	0.577145	265.8116	0.0000
Error	10	0.0217126	0.002171		
C Total	14	2.3302939			

The effect of Site on rates of methane consumption in at 50cm depth in winter
One-way ANOVA on $\log_{10}(x+1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	4	0.50571660	0.126429	18.0931	0.0000
Error	10	0.06987692	0.006988		
C Total	14	0.57559352			

The effect of Water depth on DOC in WILLUNGA-INLET and WILLUNGA-OUTLET (Jan99)
One-way ANOVA on $\log_{10}(x + 1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	7	0.10033404	0.014333	7.2967	0.0005
Error	16	0.03142978	0.001964		
C total	23	0.13176382			

The effect of Water depth on TOC WILLUNGA-INLET and WILLUNGA-OUTLET (Jan99)
One-way ANOVA on $\log_{10}(x + 1)$ transformed data performed on JMP v3.2.

Source of variation	DF	SS	MS	F	P
Model	7	5.8162906	0.830899	51.7724	0.0000
Error	16	0.2567853	0.016049		
C total	23	6.0730758			

Appendix 1.3: ANOVA Tables for Chapter 6.

The effect of Storage Time on methane concentrations in vacutainers (1.7 ppm methane).
One-way ANOVA performed in Microsoft Excel 5

Source of variation	DF	SS	MS	F	P-value	F-crit
Between groups	3	0.03183461	0.01061154	0.37061674	0.77465513	2.866265447
Within groups	36	1.0307556	0.0286321			
Total	39	1.06259021				

The effect of Storage Time on methane concentrations in vacutainers (100 ppm methane).
One-way ANOVA performed in Microsoft Excel 5

Source of variation	DF	SS	MS	F	P-value	F-crit
Between groups	3	103.874902	34.6249674	1.60608951	0.20496899	2.866265447
Within groups	36	776.107946	21.5585541			
Total	39	879.982848				

The effect of Storage Time on methane concentrations in vacutainers (3000 ppm).
One-way ANOVA performed in Microsoft Excel 5

Source of variation	DF	SS	MS	F	P-value	F-crit
Between groups	3	5677.21681	1892.4056	0.67206141	0.57478431	2.866265447
Within groups	36	101369.607	2815.82243			
Total	39	107046.824				

Day-to-day variation in methane emissions from WILLUNGA-INLET in spring 1996.
One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	0.0736336	0.036817	0.102	0.9046
Error	6	2.1666373	0.361106		
C Total	8	2.2402709	0.280034		

Day-to-day variation in methane emissions from WILLUNGA-OUTLET in spring 1996.
One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	0.09675756	0.048379	0.4903	0.635
Error	6	0.592086	0.098681		
C Total	8	0.68884356	0.086105		

Day-to-day variation in methane emissions from GREENFIELDS-INLET in spring 1996. One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	0.02144241	0.010721	0.3321	0.7298
Error	6	0.19368925	0.032282		
C Total	8	0.21513166	0.026891		

Day-to-day variation in methane emissions from GREENFIELDS-OUTLET in spring 1996. One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	0.2608756	0.130438	0.9622	0.4274
Error	6	0.9489627	0.135566		
C Total	8	1.2098383	0.134426		

Effect of increasing water depth on emissions from WILLUNGA-INLET in spring 1995. One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	24.970599	12.4853	302.8987	<0.0001
Error	6	0.247316	0.0412		
C Total	8	25.217915	3.1522		

Effect of increasing water depth on emissions from WILLUNGA-INLET in summer 1995/96. One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	96.32181	48.1609	82.5343	<0.0001
Error	6	3.501157	0.5835		
C Total	8	99.822967	12.4779		

Effect of increasing water depth on emissions from WILLUNGA-INLET in spring1996. One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	50.127163	25.0636	106.4642	<0.0001
Error	6	1.412508	0.2354		
C Total	8	51.539671	6.4425		

Effect of increasing water depth on emissions from WILLUNGA-OUTLET in spring1995.
One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	16.028599	8.0143	63.6685	<0.0001
Error	6	0.755252	0.12588		
C Total	8	16.783851	2.09798		

Effect of increasing water depth on emissions from WILLUNGA-OUTLET in summer1995/96.
One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	40.200133	20.1001	22.2786	0.0017
Error	6	5.413285	0.9022		
C Total	8	45.613418	5.7017		

Effect of increasing water depth on emissions from WILLUNGA-OUTLET in spring1996.
One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	6.2305587	3.11528	21.5881	0.0018
Error	6	0.8658338	0.14431		
C Total	8	7.0963925	0.88705		

The effect of Season on rates of methane emissions at GREENFIELDS-INLET.
One-way ANOVA performed in Microsoft Excel 5

Source of variation	DF	SS	MS	F	P-value	F-crit
Between groups	1	30.9106812	30.9106812	17.1845532	0.00042298	4.300943601
Within groups	22	39.5724565	1.79874802			
Total	23	70.4831377				

The effect of Season on rates of methane ebullition at GREENFIELDS-INLET.
One-way ANOVA performed in Microsoft Excel 5

Source of variation	DF	SS	MS	F	P-value	F-crit
Between groups	1	57.666562	30.9106812	17.1845532	0.00042298	4.300943601
Within groups	46	1.2445314	1.79874802			
Total	47	70.4831377				

Effect of vegetation on emissions from BOOL-HACKS in summer 1994/95.
One-way ANOVA performed in JMP Version 3.2.

Source of variation	DF	SS	MS	F Ratio	P-value
Model	2	4.2368734	2.11844	4.1615	0.0735
Error	6	3.0543091	0.50905		
C Total	8	7.2911825	0.9114		

Effect of vegetation on emissions from BOOL-HACKS in summer 1995/96.
One-way ANOVA performed in JMP Version 3.2.

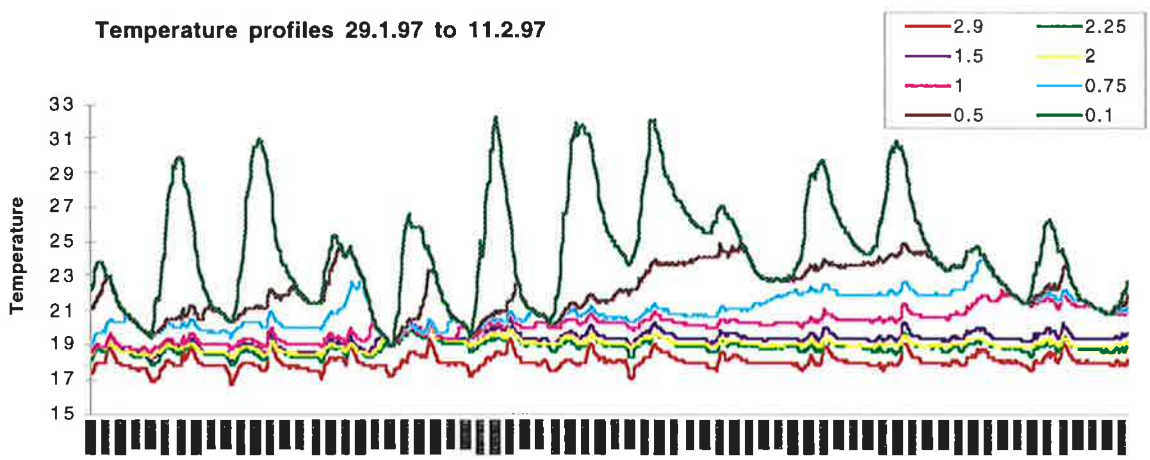
Source of variation	DF	SS	MS	F Ratio	P-value
Model	1	2.8745682	2.87457	22.6242	0.0089
Error	4	0.5082287	0.12706		
C Total	5	3.3827968	0.67656		

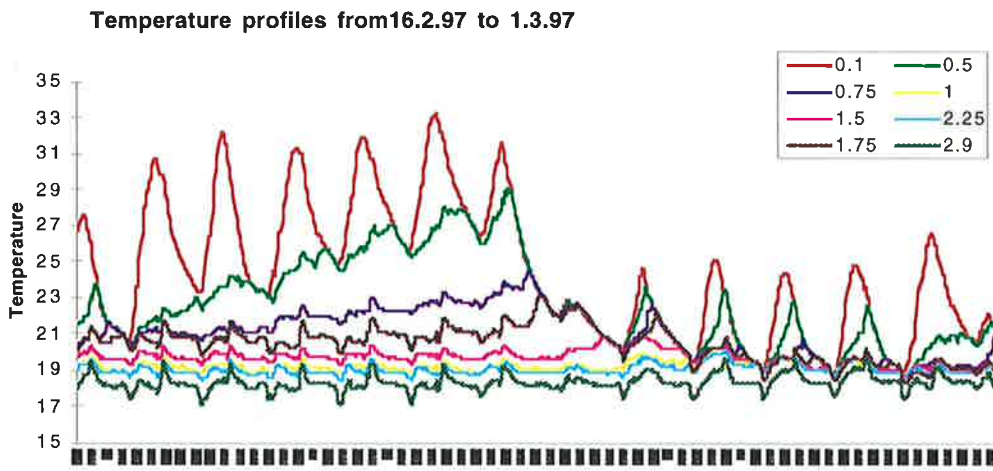
Effect of increasing water depth/vegetation on emissions from BOOL-HACKS (autumn 97).
One-way ANOVA performed in JMP Version 3.2.

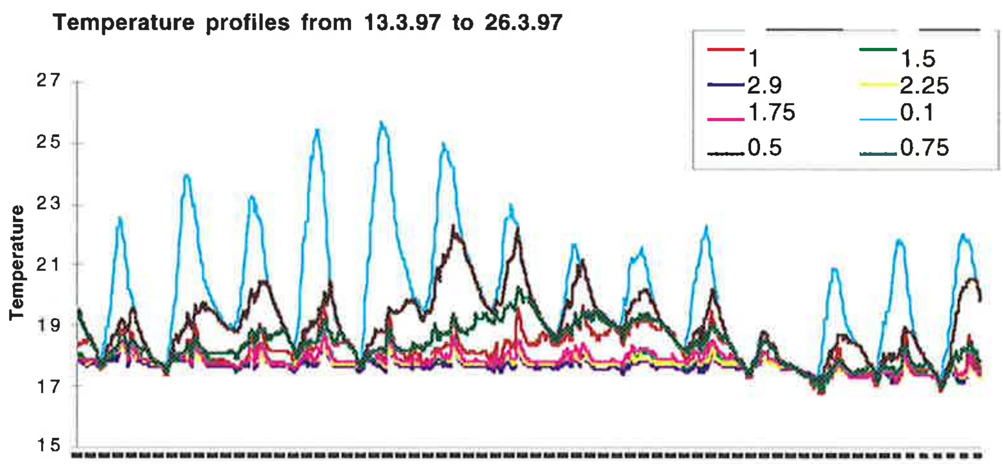
Source of variation	DF	SS	MS	F Ratio	P-value
Model	5	5.2607865	1.05216	44.3634	<0.0001
Error	12	0.2846013	0.02372		
C Total	17	5.5453878	0.3262		

Appendix 2: Water temperature profiles for WILLUNGA-INLET

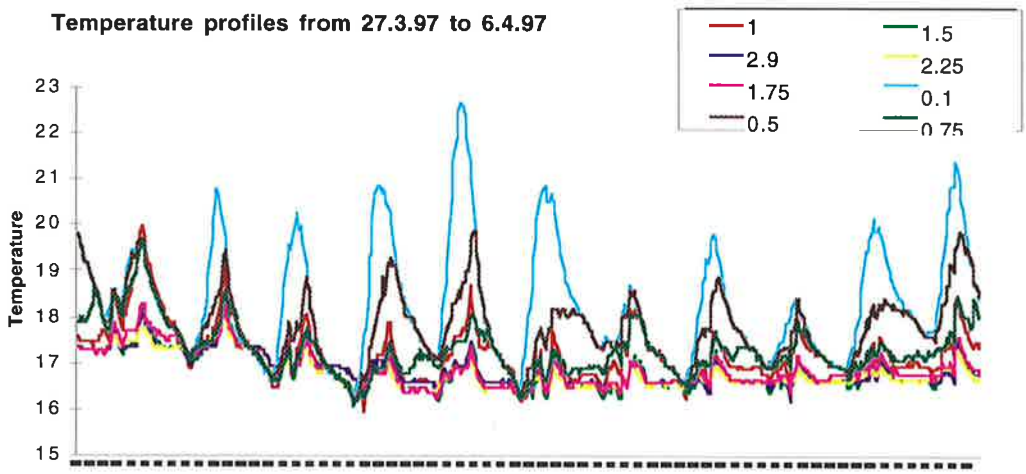
These data were taken at 30 min intervals using a chain of thermocouples.

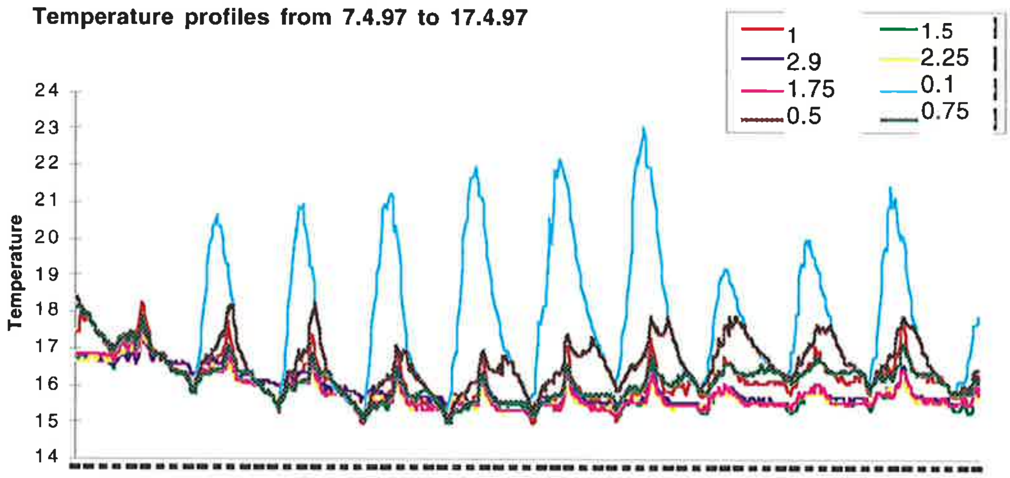


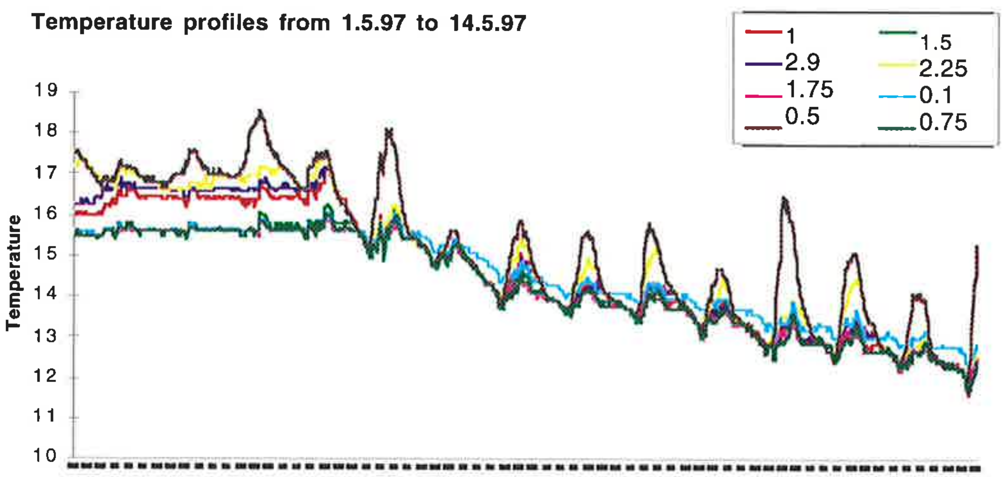




Time (minutes)







Time (minutes)