



## Sampling and analysis of lakes in the Corangamite CMA region (2)

Report to the Corangamite Catchment Management Authority  
CCMA Project WLE/42-009: Client Report 4

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Description: Rocks encrusted with salt crystals in hyper-saline Lake Weering.

Photographer: Annette Barton

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**Report Title**

Sampling and analysis of the lakes of the Corangamite CMA region

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## Executive Summary

This is the fourth milestone report for the Corangamite Catchment Management Authority (CCMA) project WLE/42-009 – *Understanding the processes causing salinity of the groundwater dependent ecosystems of the CCMA*.

A second batch of samples has been collected from those lakes sampled in the first sampling exercise. These have been analysed for major ions and stable isotopes. In general there has been an increase in the TDS concentrations of the lakes, most likely due to a concentration of ions through evaporation – as there was very little rainfall and inflow during the intervening period between the first and second sampling events.

In comparison with the other lakes, Lakes Weering and Martin show significant movement along the isotopic trend line between the first and second sampling events. The Lake Martin sample is most likely stream inflow and it is surmised that the rise in isotope concentrations is due to a reduction or cessation in flow; while in the case of Lake Weering the increase may be due to the lake becoming progressively decoupled from the groundwater table.

Three lakes have been selected for more in-depth study: Lake Weering, West Basin, and Lake Colac. These have a range of salinities and fall within the three types of lakes discussed in the third milestone report, viz, groundwater dominated/throughflow, surface water dominated/throughflow and groundwater dominated/long residence time.

Sampling and chemical analyses of lake waters will continue at increased frequency for the three study lakes. Modelling of the hydrologic systems will now commence with the aim of advancing tools which can predict lake response to changes in the surface and groundwater systems.

# 1. Introduction

This is the fourth milestone report for the Corangamite Catchment Management Authority (CCMA) project WLE/42-009 – *Understanding the processes causing salinity of the groundwater dependent ecosystems of the CCMA*.

This fourth project report details outcomes of the fourth quarter-year phase of the above research project. Work to date has included a second field trip to sample lake waters in the CCMA region and chemical analyses of the water samples for stable isotopes and major ions.

# 2. Sampling and Inspection of Lakes

Collection of a second batch of samples from the CCMA lakes was undertaken between 8-9 October. Samples were collected from those lakes sampled in the first sampling exercise, although in a few instances this could not be done because the lakes had dried out or were inaccessible due to soft mud. On this field trip access was sought and obtained to Lake Colongulac, hence this lake has been added to the sampling set. In addition samples were taken, where possible, from streams feeding into the lakes. Specific sampling localities are shown in Figure 1. In Table 1 the sampling sites are listed and relevant information recorded, including those sites in the set where it was not possible to obtain samples. In general, water levels had receded compared to the previous sampling exercise, however in Reedy Lake the water level had risen due to the diversion of water from the Barwon River.

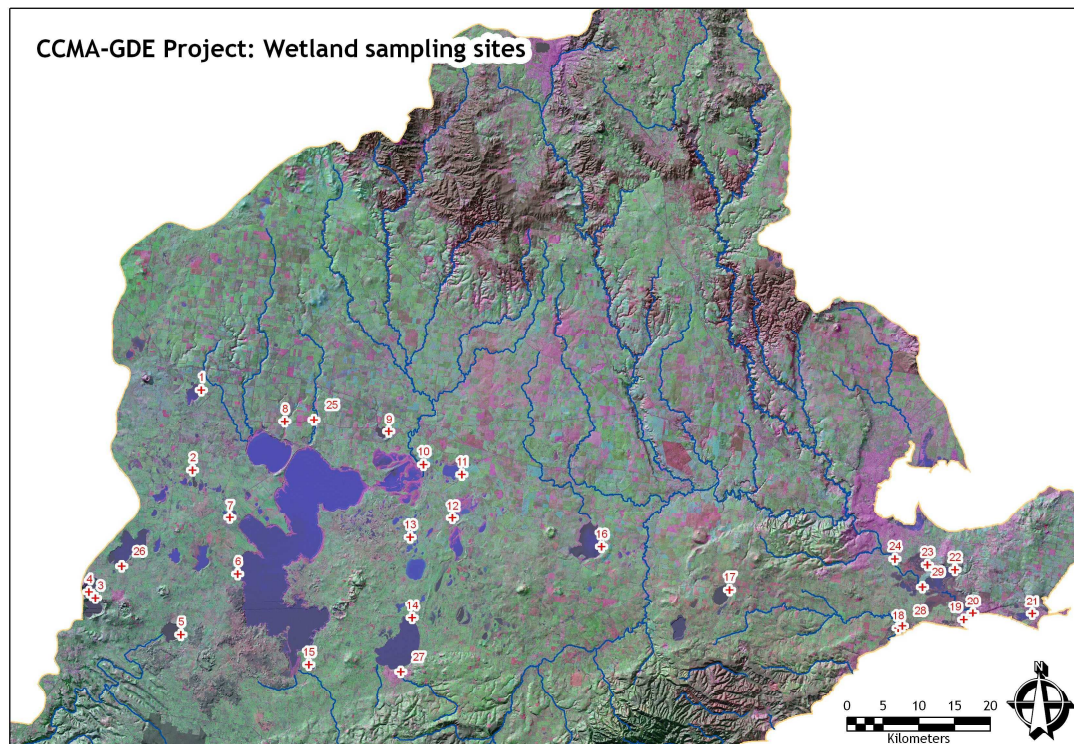


Figure 1. CCMA sampling sites.

**Table 1. Listing of CCMA Sampling Sites.**

No.	Lake Name/Reference	Comment
1	Lake Tooliorook	
2	Kooraweera Lakes	
3	Lake Bullen Merri	
4	Lake Gnotuk	At golf links.
5	Lake Purrumbete	
6	Lake Corangamite	
25	Gnarkeet Chain of Ponds River	Tributary to Lake Corangamite (northern end).
7	Lake Terangpom	
8	Lake Struan	
9	Lake Rosine	No sample due to mud.
10	Cundare Pool/Lake Martin Inlet	
11	Weering Lake	
12	Upper Lough Calvert	Almost dry. No sample.
13	Lake Cundare	Dry. No sample.
14	Lake Colac	
27	Barongaruk Creek	Tributary to Lake Colac. Uncertain if stagnant or flowing.
15	The Basins (West)	
16	Murdeduke Lake	
17	Modewarre Lake	
18	Breamlea Wetlands	Dry. No sample.
28	Breamlea Inlet	
19	Barwon Estuary/Mouth	Western side, at jetty. No sample taken.
20	Barwon Estuary/Mouth	Eastern side, at caravan park. Sample taken.
21	Victoria Lake	
22	Connewarre Lake	
29	Connewarre lake Inlet	
23	Reedy Lake	Considerably more water since last visit.
24	Barwon River	Inlet to Reedy Lake.
26	Lake Colongulac	

The sampling procedure was similar to that reported in the third client report (Barton *et al.*, 2006). A grab sample was obtained (most often using a bucket) and field parameters measured such as electrical conductivity (EC), pH, dissolved oxygen (DO) and temperature. Samples for isotope analysis were subsequently prepared at the University of Ballarat laboratories, along with filtered acidified (nitric acid) and non-acidified samples for each site. These were then freighted back to the CSIRO laboratory in Adelaide for analysis.

### 3. Chemical Analyses

#### 3.1. Field measurements

Field measurements for the 24 samples collected are given in Table 4. As on the first sample collection trip, no field measurements were taken for Sample 6 (Lake Corangamite) due to the shallowness of the water body and the difficulty of obtaining a reasonable volume of water. pH values were generally alkaline, ranging from 7.9 to 9.3 and EC values ranged over more than two orders of magnitude from about 0.85 mS/cm to hypersaline 115 mS/cm.

#### 3.2. Chemistry

Chemistry results for the samples collected are given in Table 2, and TDS values have been shown graphically in Figure 2. In general there has been an increase in TDS between the first and second sampling events, with the greatest increases occurring in Lake Corangamite (~ 23,500 mg/L) and Lake Weering (~43,400 mg/L) – the two most saline lakes. It is most probable that the increases are due to concentration of ions through evaporation as there was very little rainfall and inflow during the intervening period.

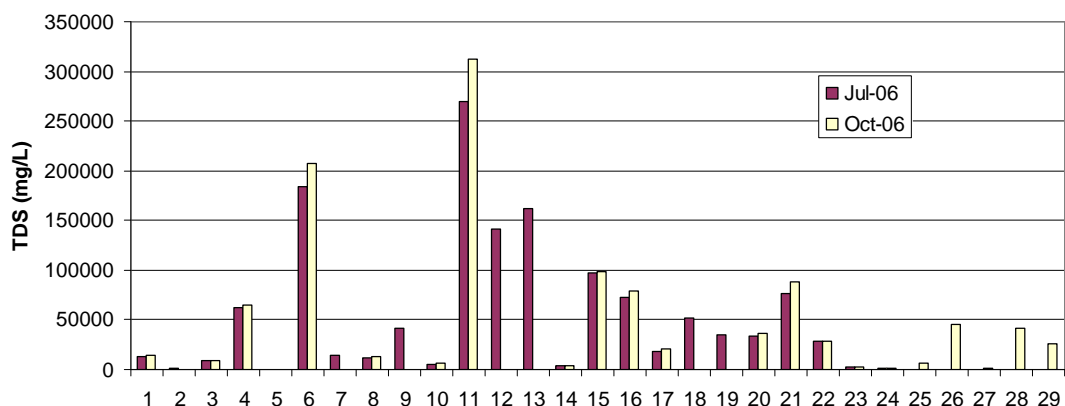
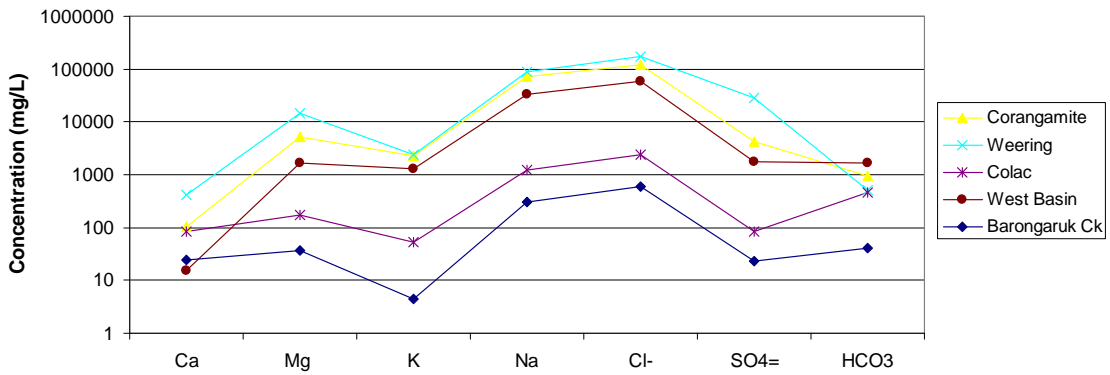


Figure 2. TDS values (July and October) at each sampling location.

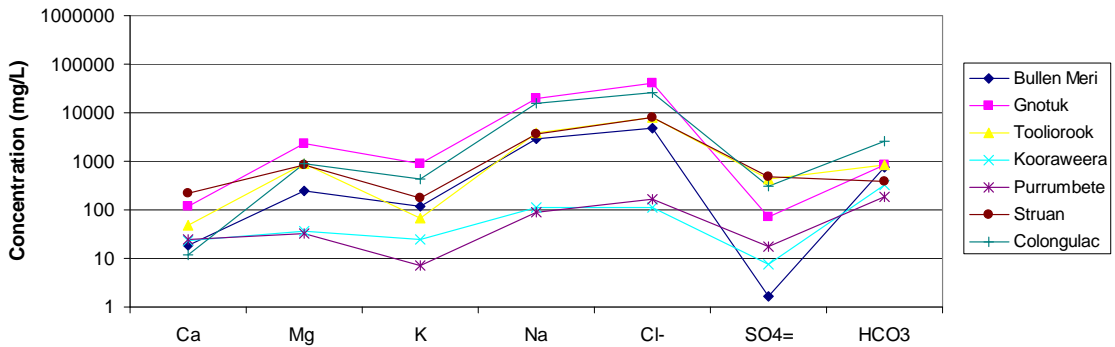
**Table 2. Laboratory analysis results for CCMA Lakes**

Wetland Number	Rank	Wetland	TDS*	Tot Alk	Cl <sup>-</sup>	Br <sup>-</sup>	NO <sub>3</sub> <sup>-</sup>	SO <sub>4</sub> <sup>-</sup>	HCO <sub>3</sub> <sup>-</sup>	Ca <sup>++</sup>	K <sup>+</sup>	Mg <sup>++</sup>	Na <sup>+</sup>
			mg/l	meq/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
994938	99	Lake Tooliorook	14344	13.6	8130	24	3	438	827	48	67	884	3950
988822	34	Kooraweera Lakes	637	5.3	111	0.36	12.43	7.7	323	23	25	36	112
840643	74	Lake Bullen Merri	8918	12.3	4930	12	1	1.7	752	19	117	249	2850
839675	73	Lake Gnotuk	64272	13.7	40100	113	8	73	834	121	904	2320	19920
950604	123	Lake Purrumbete	521	3.1	162	0.38	0.14	18	187	24	7	32	91
120710	8	Lake Corangamite	207612	15.4	123200	391	4	4330	937	105	2230	5310	71500
121897	86	Lake Struan	13470	6.4	7820	25	1	481	391	216	175	827	3560
280809	16	Cundare Pool/Lake Martin	6436	2.9	3610	10	<1	414	177	132	47	396	1660
351812	90	Lake Weering	312918	8.2	176000	722	23	28000	503	415	2400	14700	90900
268572	67	Lake Colac	4490	7.6	2370	6.1	1	82	463	84	53	177	1260
139554	39	West Basin	98299	28.1	58200	163	13	1780	1714	15	1280	1710	33600
540707	10	Lake Murdeduke	78564	30.9	46700	145	6	1820	1886	36	422	2800	24900
470630	93	Lake Modewarre	20279	20.8	11500	24	<2	105	1266	27	92	720	6570
782634		Barwon R. Mouth (at Caravan Pk)	35725	2.1	20000	64	3	2670	130	424	481	1220	10800
893610	120	Lake Victoria	88044	4.5	49300	140	16	6850	274	1120	1330	2870	26300
770658	2	Connewarre Lake	28325	2.6	15800	48	2	2140	159	348	394	984	8500
739680	12	Reedy Lake	2198	3.6	947	2.3	<0.3	286	218	99	25	93	530
		Barwon River (above Reedy Lake)	1039	2.3	481	1.0	0.4	62	143	36	9	50	259
		Gnarkeet Chain of Ponds River	6530	7.3	3610	10	<1	313	446	195	18	418	1530
898723	23	Lake Colongulac	45693	43.5	26000	78	5.86	304	2654	12	428	896	15400
		Barongaruk Creek	1026	0.7	590	1.3	1.23	24	42	25	4	38	304
		Breamlea Inlet	42019	3.3	23500	70	6.17	3150	201	512	537	1420	12700
		Connewarre Lake inlet	25895	2.5	14400	44	4.12	1950	152	319	334	900	7840

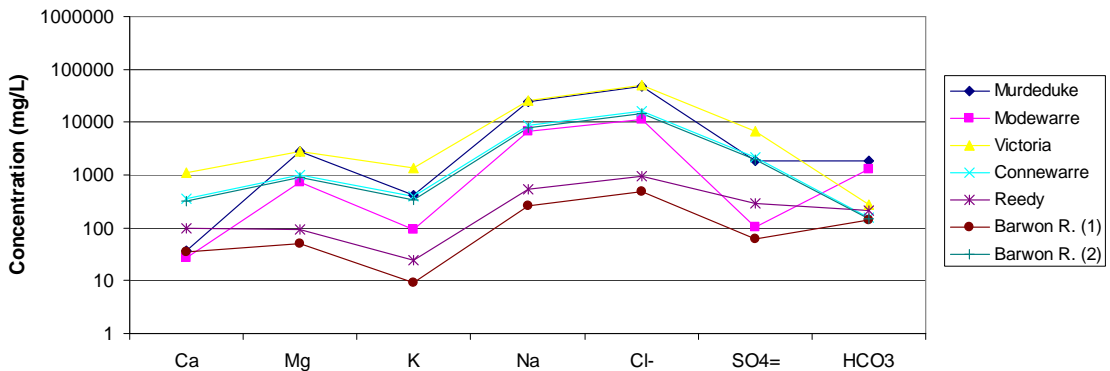
\* TDS is calculated as the sum of the Cl, SO<sub>4</sub>, HCO<sub>3</sub>, Na, K, Ca and Mg ions.



Subfigure a. Warrion/ central region lakes



Subfigure b. Lakes west of Corangamite



Subfigure c. Eastern region lakes

Figure 3. Schoeller plots for the Corangamite lakes and tributaries.

In Figure 3 the Schoeller plots of the chemistry of the Corangamite lakes have been shown divided into three groupings: western, central and eastern. Some tributary rivers have been shown for reference purposes.

In all the lakes  $\text{Na}^+$  and  $\text{Cl}^-$  are the dominant cation and anion respectively. Lake Weering stands out as having exceptionally high values of both  $\text{Mg}^{++}$  and  $\text{SO}_4^-$ . Several lakes have relatively high  $\text{HCO}_3^-$  ranging up to 2000 mg/L measured in Lake Colongulac, which is about 10 times higher than seawater.

### 3.3. Stable isotopes

Stable isotope results have been reported in Table 3 while trends between the July and October sampling events are shown in Figure 4.

**Table 3. Laboratory stable isotope results**

Sample Name	Sample Number	$\delta^{18}\text{O}$ ‰ VSMOW	$\delta^2\text{H}$ ‰ VSMOW
Lake Tooliorook	1	3.80	29.9 29.6
Kooraweera Lakes	2	-2.92	-17.1
Lake Bullen Merri	3	2.53	15.3
Lake Gnotuk	4	3.11 2.93	18.7
Lake Purrumbete	5	1.70	12.7
Lake Corangamite	6	1.99	14.3
Lake Struan	8	3.77	25.2
Cundare Pool/Lake Martin Inlet	10	2.55	14.3
Lake Weering	11	1.52	10.6
Lake Colac	14	2.67	19.8
The Basins (West Basin)	15	3.66	19.2
Lake Murdeduke	16	3.45	24.4
Lake Modewarre	17	3.41	23.1
Barwon River Mouth (Caravan Pk)	20	0.29	6.7
Lake Victoria	21	3.13	19.4
Connewarre Lake	22	1.32	12.0
Reedy Lake	23	1.10	6.7
Inlet to Reedy Lake (Barwon R.)	24	-3.42	-18.6
Gnarkeet Chain of Ponds River	25	-0.99	-5.1
Lake Colongulac	26	2.53	21.8
Barongaruk Creek	27	-4.11	-19.5
Breamlea Inlet	28	2.61	16.7
Connewarre Lake Inlet	29	0.74	6.2

The majority of the lakes that are most enriched in  $^2\text{H}$  and  $^{18}\text{O}$  have changed little since the previous sampling (Figure 4). These include lakes Bullen Merri, Gnotuk, Purrumbete, Colac, West Basin, Murdeduke and Modewarre. Lakes showing moderate increases include lakes Tooliorook, Kooraweera, Corangamite, Struan, Victoria and Reedy. Lakes Weering and Martin have shown significant movement along the trend line. For Lake Martin the water sampled was taken from the inlet and hence is believed to be stream inflow (refer Barton *et al.*, 2006). It is surmised that the rise in isotope concentrations here, is due to a reduction or cessation in flow. In the case of Lake Weering where there is no tributary inflow, the increase in isotope concentration may be due to the lake becoming progressively decoupled from the groundwater table.

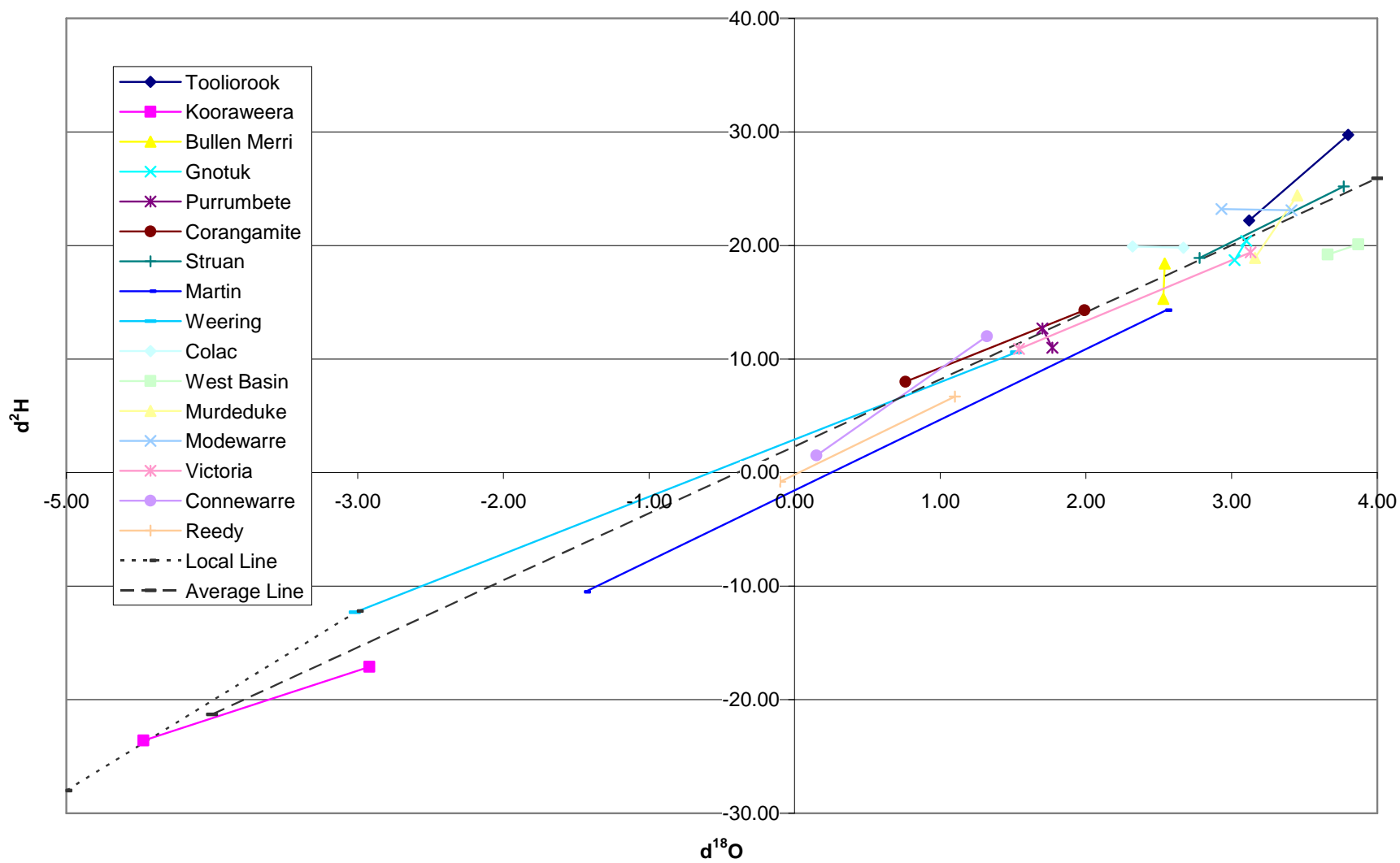


Figure 4. Lake stable isotope trends shown in  $\delta^2\text{H} - \delta^{18}\text{O}$  space. The local line represents average monthly values for Melbourne rain.

## 4. Selection of Study Lakes

As discussed in the third client report (Barton *et al.*, 2006), there is a need to focus on increasing sampling frequency of a few lakes to better monitor and understand the hydrological processes controlling their behaviours and to develop a methodology for assessing the groundwater dependence of the Corangamite lakes. In selecting the “study lakes” a number of criteria were considered, as follows:

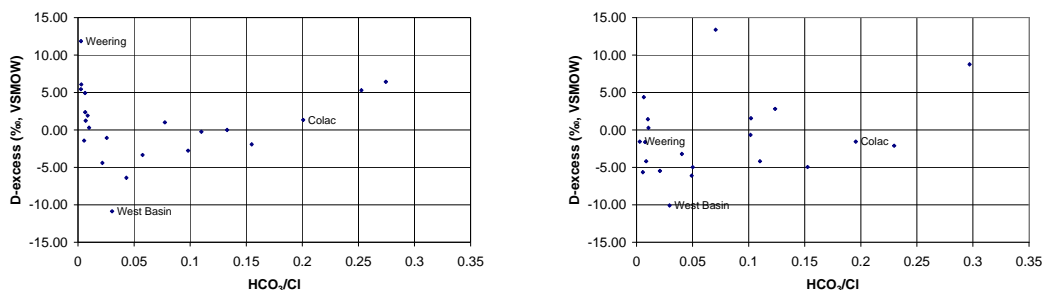
1. The lakes constitute “end members” of the three types defined in the third client report (groundwater dominated/through-flow; surface water dominated/through-flow; groundwater dominated/long residence time).
2. The lakes fall within the Victorian Volcanic Plain region and the main area of interest for the Groundwater Flow Systems project. This is the region where the majority of the groundwater sampling has been undertaken.
3. The lakes lie within, or in close proximity to, the Warrion Water Supply Protection Area – the main groundwater pumping region of the VVP.
4. The lakes will continue to maintain a water body for a while even with no rainfall.

On the basis of the above criteria the following three lakes have been selected:

1. Lake Weering (TDS ~313,000 mg/L)
2. West Basin (TDS ~98,300 mg/L)
3. Lake Colac (TDS ~4,500 mg/L)

These lakes have been shown on the deuterium excess diagrams for July and October, in Figure 5. In the July diagram Lake Weering is seen as a groundwater dominated, through-flow lake, while West Basin is in the groundwater dominated, long residence time quadrant and Lake Colac in the surface water dominated zone. In the October diagram Lake Weering has undergone a shift toward the groundwater dominated, long residence time quadrant. This too, supports the theory of a decoupling of the lake from the groundwater table.

These lakes also provide a range in salinity and chemical composition. Lake Weering is the most saline lake of the Corangamite Basin lakes, with exceptionally high concentrations of  $Mg^{++}$  and  $SO_4^-$  ions. West Basin is rich in  $HCO_3^-$ .



## 5. Work Plan

The intent of this project is to further our understanding of the hydrology of the lakes of the Corangamite Catchment Management Authority region. In particular we are seeking to increase knowledge of their connection with surface and groundwater systems, and hence their response to the hydrological drivers of climate variability and groundwater extraction.

In this report three lakes (Lake Colac, Lake Weering and West Basin) have been identified for in-depth study. It is envisaged that by focussing on a few diverse lakes located in the central region of the Victorian Volcanic Plain a methodology might be subsequently adopted in the analyses of the other lakes.

It is planned that investigations into both the chemistry and hydrology of the three designated lakes will be undertaken conjointly. Regular sampling of the lakes will commence in January 2007 on a fortnightly basis, and will provide a temporal data set of major ions and stable isotopes. This work will be complemented by hydrological investigations into the lake connectivity to groundwater and surface water systems.

It is planned that in the first instance, conceptual models of the groundwater – surface water interactions of the lakes will be developed. This will require the sourcing and verification of significant amounts of data, including bathymetry, groundwater levels and rainfall and evaporation records. It is anticipated that the chemistry investigations will link in with this work to provide corroboration/augmentation of the models.

The conceptual models will provide the backbone of future predictive modelling of lake responses to events such as change or variation in climate, land use and groundwater extraction. The type and complexity of these models, however, will be dependent on required outcomes and the quality and quantity of the input data.

## Acknowledgements

Bob Smith, University of Ballarat kindly assisted with the field work and sampling of the lakes. Phil Davies, CSIRO Land and Water produced Figure 1.

## References

Barton, A., Herczeg, A., Cox, J. and Dahlhaus, P. (2006) *Sampling and analysis of lakes in the Corangamite CMA region*, Client Report 3, Report to the Corangamite Catchment Management Authority, CCMA Project WLE/42-009, CSIRO Land and Water, Urrbrae, SA.

# Appendix A

**Table 4. Field Measurements for CCMA Lakes**

Wetland Number	Rank	Wetland	Date	Time	Sample Number	Easting MGA Z54	Northing MGA Z54	Field Measurements			
								EC	pH	DO	Temp
								mS/cm		%	°C
994938	99	Lake Tooliorook	8-Oct	9:05	1	54700447	5794061	23.9	9.07	47.3	13.8
988822	34	Kooraweera Lakes	8-Oct	9:35	2	54698717	5782880	0.85	8.71	104	13.2
840643	74	Lake Bullen Merri	8-Oct	11:45	3	54684385	5765561	15.61	9.13	82	13.7
839675	73	Lake Gnotuk	8-Oct	12:10	4	54683750	5766342	94.5	8.69	69	15.7
950604	123	Lake Purrumbete	8-Oct	12:35	5	54696189	5759841	0.82	9.12	88	15.8
120710	8	Lake Corangamite	8-Oct	10:30	6	54704437	5768080	-	-	-	-
38768	6	Lake Terangpom	8-Oct	9:55	7						
121897	86	Lake Struan	8-Oct	8:40	8	54711914	5789157	22.8	8.96	96.3	15.6
255870	87	Lake Rosine	8-Oct		9						
280809	16	Cundare Pool/Lake Martin	8-Oct	15:50	10	54731033	5782291	17.1	9.3	155	17.5
351812	90	Lake Weering	9-Oct	8:35	11	54736266	5780594	214	7.97	29	10.2
362762	29	Upper Lough Calvert (Eurack Swp)	9-Oct	9:20	12	54734642	5774708				
292738	17	Lake Cundare	9-Oct		13						
268572	67	Lake Colac	8-Oct	15:00	14	54728512	5760798	7.89	8.89	73	15.9
139554	39	West Basin	8-Oct	14:05	15	54713781	5754977	131	8.95	60.1	16.3
540707	10	Lake Murdeduke	9-Oct	10:45	16	54755445	5769731	107.4	8.77	64	16.4
470630	93	Lake Modewarre	9-Oct	11:40	17	55247914	5763663	33	9.9	105	16.9
704580	72	Breamlea Wetlands	9-Oct		18						
		Barwon R. Mouth (below Cn. Swp)			19						
782634		Barwon R. Mouth (at Caravan Pk)	9-Oct	12:55	20	55281952	5760842	54.6	8.23	67	18
893610	120	Lake Victoria	9-Oct	13:45	21	55290360	5761173	115.4	7.87	58	18.3
770658	2	Connewarre Lake	9-Oct	14:10	22	55279444	5767094	44.5	8.47	84.3	18.4
739680	12	Reedy Lake	9-Oct	14:30	23	55275527	5767723	3.83	8.43	83.8	18.1
		Barwon River (above Reedy Lake)	9-Oct	14:50	24	55270974	5768425	1.95	8.26	70.5	16.5
		Gnarkeet Chain of Ponds River	8-Oct	8:25	25	54716031	5789196	11.57	7.93	44.3	13.1
898723	23	Lake Colongulac	8-Oct	11:25	26	54688241	5769853	67.7	9.03	74	14.4
		Barongaruk Creek	8-Oct	14:40	27	54726639	5753342	2.06	8.69	68.6	13.6
		Breamlea Inlet	9-Oct	12:15	28	55272244	5758982	62.7	8.65	67	15.1
		Connewarre Lake inlet	9-Oct	12:30	29	55274903	5764587	41.3	8.41	76	16.7

