Hydrology and geochemistry of lakes and wetlands of the Victorian Volcanic Plains

Report to the Corangamite Catchment Management Authority
CCMA Project WLE/42-009: Milestone Report No. 6


CSIRO Land and Water
July 2007
Report Title
Hydrology and geochemistry of lakes and wetlands of the Victorian Volcanic Plains

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July 2007
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Executive Summary

This is the sixth 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.*

During this period chemistry and hydrological data has been collected from a number of groundwater bored in the vicinity of the three lakes chosen for detailed study. Fortnightly sampling of the three study lakes has continued. A small amount of data has been downloaded from the water level loggers installed in the lakes during the last quarter, and water level loggers have been installed in bores adjacent to the lakes.
1. Introduction

This is the sixth 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*. In this report project activities for the period 1 April to 30 June 2007 are detailed.

A paper has also been submitted to the XXXV Congress of the International Association of Hydrogeologist, to be held in September 07. A copy of the paper is included in Appendix A of this report.

2. Lake and Groundwater Sampling and Chemical Analyses

Fortnightly sampling of Weering Lake, Lake Colac and West Basin has continued throughout the reporting period, with samples collected on the following dates: 02 Apr 07, 17 Apr 07, 07 May 07, 21 May 07, 04 Jun 07, 18 Jun 07. At Lake Weering samples have been collected from both the lake (when water is present) and, from what appears to be, a spring discharging to the lake.

Chemistry and isotope results have been received from the CSIRO Laboratories, Adelaide, for many of the samples collected in the current reporting quarter and for the last quarter. Analytical results for the samples collected have been presented in Tables 1 – 4.

Samples have also been collected from bores in the vicinity of the three study lakes (April 07). Analytical results for these samples have been given in Table 5. For purposes of comparison this table also includes groundwater results from samples taken in the vicinity of the study lakes as part of the earlier project to define the groundwater flow systems on the Victorian Volcanic Plain (refer Cox *et al*., 2007).

Of note are the trends in EC for the 3 study lakes. Weering Lake is showing signs of being a groundwater discharge lake. Over the sampling period EC has risen substantially as incoming water begins to fill the lake and dissolve the desiccated salts. Lake EC however is several orders of magnitude higher than that of the incoming water, leading to the hypothesis that the lake is a groundwater discharge point where salt accumulates. The same applied to West Basin; it too appears to be a terminal lake when comparison is made between the groundwater and lake ECs. Over the sampling period however, the EC of the lake has remained steady, but, unlike Weering Lake which almost dried completely, the volume of water in this lake has remained relatively steady. In Lake Colac EC levels are now falling indicating fresh inflow to the lake. It is thought this fresh inflow may be surface flow from Deans Creek and Barongarook Creek, as a result of recent rains. This will be researched further in the coming months.
Figure 1. Groundwater sampling, April 07
### Table 1. Analytical results for Weering Lake

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* TDS is calculated as the sum of the Cl, SO4, HCO3, Na, K, Ca and Mg ions.

^ HCO3 is calculated from total alkalinity.
| Date       | 8/01/07 | 22/01/07 | 5/02/07 | 19/02/07 | 5/03/07 | 19/03/07 | 2/04/07 | 17/04/07 | 7/05/07 | 21/05/07 | 4/06/07 | 18/06/07 |
|------------|---------|----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Field Values |         |          |         |         |         |         |         |         |         |         |         |         |         |
| E.C. dS/m  | 7.0     | 6.7      | 5.9     | 6.6     | 5.7     | 7.9     | 6.8     | 5.7     | 6.6     | 6.6     | 6.5     | 6.46    |
| pH         | 8.5     | 8.2      | 7.9     | 8.2     | 8.4     | 8.3     | 8.4     | 8.3     | 7.4     | 7.6     | 7.49    |         |
| DO %       |         |          |         |         |         |         |         |         |         |         |         |         |         |
| Temp Celcius | 22.4    | 18       | 21.6    | 18.6    | 19.9    | 18.3    | 20      | 15.9    | 14.2    | 13.6    | 12.3    |         |
| Analytical Values | |          |         |         |         |         |         |         |         |         |         |         |         |
| pH         | 8.2     | 8.1      | 8.2     | 6.2     | 8.1     | 8.0     | 8.1     | 8.3     | 8.3     | 8.1     |         |         |
| EC         | 5.8     | 5.9      | 6.6     | 6.1     | 6.0     | 7.1     | 6.2     | 6.1     | 6.0     | 5.9     |         |         |
| Alk (pH 4.5) meq/L | 7.0 | 7.2      | 7.2     | 2.1     | 7.3     | 7.5     | 7.5     | 7.4     | 7.9     | 7.4     |         |         |
| Alk (pH 8.3) meq/L |         |          |         |         |         |         |         |         |         |         |         |         |         |
| F- mg/L    | <0.5    | <0.5     | <0.5    | <0.5    | <0.5    | <0.3    | <0.3    | <0.3    | <0.5    | <0.5    |         |         |
| Cl- mg/L   | 1864    | 1865     | 2132    | 1869    | 1853    | 2270    | 1850    | 1890    | 1960    | 1920    |         |         |
| Br- mg/L   | 4.9     | 4.9      | 5.7     | 6.3     | 5.6     | 7.1     | 5.9     | 6.0     | 6.0     | 6.1     |         |         |
| NO3- mg/L  | <0.5    | 1.8      | <0.5    | 344     | <0.5    | <0.3    | 0.4     | <0.3    | 0.6     | <0.5    |         |         |
| SO4= mg/L  | 112     | 118      | 118     | 193     | 183     | 266     | 126     | 129     | 134     | 132     |         |         |
| HCO3- mg/L | 426     | 441      | 442     | 126     | 443     | 460     | 456     | 452     | 480     | 452     |         |         |
| Ca mg/L    | 26      | 27       | 27      | 26      | 26      | 29      | 28      | 28      | 28      | 27      |         |         |
| K mg/L     | 31      | 31       | 35      | 37      | 39      | 37      | 35      | 35      | 35      | 34      |         |         |
| Mg mg/L    | 307     | 317      | 321     | 297     | 296     | 376     | 322     | 325     | 326     | 318     |         |         |
| Na mg/L    | 814     | 810      | 965     | 728     | 849     | 954     | 754     | 771     | 797     | 771     |         |         |
| S mg/L     | 43      | 46       | 46      | 51      | 50      | 92      | 44      | 45      | 46      | 45      |         |         |
| Si mg/L    | 4.6     | 4.8      | 4.5     | 8.2     | 7.8     | 6.8     | 7.9     | 7.6     | 7.6     | 8.1     |         |         |
| Sr mg/L    |         |          |         |         |         |         |         |         |         |         |         |         |         |
| TDS mg/L   | 3579    | 3609     | 4040    | 3276    | 3690    | 4391    | 3571    | 3630    | 3758    | 3655    |         |         |
| Al mg/L    | 1.3     | 1.3      |         |         |         |         |         |         |         |         |         |         |         |
| B mg/L     |         |          |         |         |         |         |         |         |         |         |         |         |         |
| Cu mg/L    | <0.2    | <0.2     |         |         |         |         |         |         |         |         |         |         |         |
| Fe mg/L    | <1      | <1       |         |         |         |         |         |         |         |         |         |         |         |
| Mn mg/L    | <0.2    | <0.2     |         |         |         |         |         |         |         |         |         |         |         |
| P mg/L     | 0.4     | 0.5      | 0.8     | 0.8     | 0.8     | 0.8     | 0.8     | 0.8     | 0.8     | 0.8     |         |         |
| Zn mg/L    | <0.2    | <0.2     |         |         |         |         |         |         |         |         |         |         |         |
| Oxygen – 18 ‰ rel SMOW | -2.57 | -2.76   | -2.68  | -2.87  | -2.86  | -2.75  | -2.85  | -2.79  |         |         |         |         |
| Deuterium ‰ rel SMOW | -25.30 | -25.00  | -17.00 | -16.90 | -16.70 | -15.50 | -14.70 | -18.10 |         |         |         |         |
Table 3. Analytical results for Lake Colac

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<td>meq/L</td>
<td>0.9</td>
<td>0.5</td>
<td>&lt;1</td>
<td>0.5</td>
<td>&lt;0.3</td>
<td>0.1</td>
<td>0.8</td>
<td>&lt;1</td>
<td>0.3</td>
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<td></td>
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</tr>
<tr>
<td>F-</td>
<td>mg/L</td>
<td>727</td>
<td>129</td>
<td>323</td>
<td>1080</td>
<td>161</td>
<td>6450</td>
<td>1420</td>
<td>1810</td>
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<td>2290</td>
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<td>mg/L</td>
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<td>&lt;0.3</td>
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<td>1.9</td>
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<td>86.2</td>
<td>6</td>
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<td>380</td>
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<td>489.7</td>
<td>565</td>
<td>284.321</td>
<td>485</td>
<td>703</td>
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<td>297</td>
<td>717</td>
<td>689</td>
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<td>553</td>
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<tr>
<td>Ca</td>
<td>mg/L</td>
<td>36</td>
<td>12.1</td>
<td>25.9</td>
<td>43</td>
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<td>50</td>
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<td>299</td>
</tr>
<tr>
<td>K</td>
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<td>33.79</td>
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<td>8.70</td>
<td>19</td>
<td>13</td>
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<td>29</td>
<td>29</td>
<td>43</td>
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<tr>
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<td>mg/L</td>
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<td>53.5</td>
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<td>123</td>
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<td>250</td>
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<td>160</td>
<td>314</td>
<td>647</td>
<td>140</td>
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<td>811</td>
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<td>802</td>
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<tr>
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<tr>
<td>TDS</td>
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<td>628</td>
<td>1282</td>
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<td>681.19</td>
<td>12418</td>
<td>3399</td>
<td>4100</td>
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<td>51.7</td>
<td>30.5</td>
<td>9.5</td>
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<tr>
<td>223 Rn - Error</td>
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<td>1</td>
<td>0.8</td>
<td>0.6</td>
<td>0.44</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
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</tr>
<tr>
<td>Oxygen – 18 ‰ rel SMOW</td>
<td>5.47</td>
<td>-4.6</td>
<td>-4.6</td>
<td>-4.4</td>
<td>-5.2</td>
<td>-4.47</td>
<td>-5.16</td>
<td>-5.43</td>
<td>-4.08</td>
<td>-3.21</td>
<td>-4.29</td>
<td>-4.14</td>
<td>-2.66</td>
<td></td>
</tr>
<tr>
<td>Deuterium</td>
<td>% rel SMOW</td>
<td>25.5</td>
<td>-28.5</td>
<td>-27.5</td>
<td>-24</td>
<td>-31.5</td>
<td>-18.3</td>
<td>-25.4</td>
<td>-28</td>
<td>-26.4</td>
<td>-16.7</td>
<td>-27.7</td>
<td>-23.3</td>
<td>-14.1</td>
</tr>
</tbody>
</table>
3. Collection of hydrological data

A field trip was undertaken in April at which time data was downloaded from the water level loggers installed in the lakes during the last quarter. One of the loggers installed in West Basin was dislodged and was reinstated more recently (June 07). The data that has been collected is currently being analysed. Water level values for Weering Lake have been reduced and are shown plotted in Figure 5. From the plot it can be seen that it took just over a month for the levels to stabilise. This is a function of the low permeability of the lake soils.

![Figure 2. Piezometers on the edge of Weering Lake (picture April 07)](image-url)
Figure 3. Piezometers in Lake Colac (picture April 07)

Figure 4. Piezometers have been installed on the edge of West Basin (visible on the near shore) and in the well (picture June 07). See also cover picture.
Figure 5. Reduced water levels for Weering Lake

During a field visit undertaken in April, water level loggers were installed in seven observation wells in the vicinity of the lakes study lakes. Observation bore numbers are as follows:

<table>
<thead>
<tr>
<th>Observation Bores proximate to West Basin</th>
<th>Observation Bores proximate to Lake Colac</th>
<th>Observation Bores proximate to Weering Lake</th>
</tr>
</thead>
<tbody>
<tr>
<td>146931</td>
<td>142703</td>
<td>57506</td>
</tr>
<tr>
<td></td>
<td>142712</td>
<td>26657</td>
</tr>
<tr>
<td></td>
<td>26687</td>
<td>36061</td>
</tr>
</tbody>
</table>

The location of these bores with respect to the study lakes can be found on Figures 1, 2, 3 and 4 in Milestone Report No. 5 (Barton et al., 2007). Water level data collected from these observation wells will be used, together with the data from the lake piezometers, to describe a groundwater surface in relation to the lakes.

Work is also progressing on describing the catchments and surface runoff to the study lakes. As accurate lake bathymetric data is currently not available estimates will need to be made.
4. Project Status

Chemistry data continues to be collected for the study lakes. Trends in salinity are shedding light on the lake types.

Hydrological data is now being collected and will provide further insight into the surface- and groundwater inputs to the lakes.

Project timing needs to be reviewed at the end of the next quarter due to staff transfers to the high priority Murray Darling water assessment for the National Water Commission.

5. References


Appendix A


A geochemical approach to determining the hydrological regime of wetlands in a volcanic plain, south–eastern Australia.

Annette B Barton, Andrew L Herczeg, Peter G Dahlhaus, James W Cox
A geochemical approach to determining the hydrological regime of wetlands in a volcanic plain, south-eastern Australia


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Abstract The Corangamite region in south-eastern Australia contains a large number of lakes and wetlands within an extensive, basaltic plain. To assess the impact of land-use change and groundwater pumping on wetland ecosystems, there is a need to develop a better understanding of their hydrology. This paper describes an approach using groundwater and surface water chemistry and stable isotopes to determine the extent that they are surface or groundwater dominant, and whether they are through-flow or terminal in nature. The ionic ratio HCO$_3^-$/Cl$^-$ is higher in surface waters than groundwater, and lakes plot on a continuum between these two water types. Deuterium “excess” (δ$_{xs}$, where δ$_{xs}$ = δ$^2$H – 8*δ$^{18}$O) reflects the deviation of a given sample from the global meteoric water line, with lower values indicating the increasing influence of evaporation, which in turn reflects longer water residence time (terminal lakes) compared with high δ$_{xs}$ lakes that represent through-flow lakes.

Keywords: Groundwater-surface water interactions, wetlands, chemistry, isotopes

1. Introduction

The Western Plains in the Corangamite region, south-west Victoria, Australia, is characterised by an abundance of freshwater and saline wetlands that are believed to be at least partially dependent on groundwater. The low, undulating country of the Plains, lies between the Central Highlands of the Great Dividing Range to the north and the Otway Ranges to the south (Figure 7). The plain slopes generally toward the west, where there is an outlet to the sea, and features cinder cones, maars, lava shields and the ‘stony rise’ landscapes.
Several different shallow groundwater flow systems have been delineated in the region (Cox et al. 2007). In the Central Highlands, the regional gradient is south towards the plains, and the shallow groundwater moves through gravels, sands and silts of buried palaeochannels, and through the overlying fractured basalt. On the Western Plains, the shallow groundwater moves under a very low regional gradient through an extensive, thin (<10 m) confined sand aquifer, underlying the basalt, and through sheets of fractured basalt towards the east and south east. Above the plains, more localised flows occur in the pyroclastic rocks of the eruption points, the fractured rocks of the youngest lava flows and the surficial Quaternary alluvial and aeolian sediments.

Low topographic gradients have resulted in sparsely distributed linear drainage channels usually terminating in shallow lakes. The lakes have a variety of landforms, such as crater lakes, maars, sag ponds, lakes formed in the depressions of the volcanic plains, lakes formed behind basalt barriers, and areas with impounded drainage. Some of the larger lakes are terminal lakes for both surface water and groundwater flow, whereas others are terminal for surface water flow but throughflow for groundwater (Coram et al. 1998). Smaller lakes, especially those formed in volcanic craters and maars are groundwater sinks with little surface water input.

Annual rainfall varies from over 1000 mm in the elevated areas of the Central Highlands to less than 500 mm on the eastern edge of the Western Plains. The vast majority of the volcanic plains in the Corangamite region receive between 600 and 700 mm annually, with winter and spring as the dominant wet seasons. In times of abnormally high rainfalls, the lakes have been known to fill and merge, flooding large tracts of farmland. To manage the flooding, two major drainage channels were built in the 1950s and 60s to drain the larger lakes into the river system to the west.

Many of the more than 1400 declared wetlands of the Corangamite region are recognised as being of international ecological value, in particular the twenty-seven Ramsar listed wetlands which include Lake Corangamite, Australia’s largest, inland, permanent, saline lake. Sustained rises in lake salinity levels over the last 50 years has focussed attention on the impacts of human activities on wetland health (Williams 1995, 1999; Adler & Lawrence 2004; Nicholson et al. 2006). Since the commencement of European settlement 160 years ago, widespread land-use and water-use changes have occurred. The extensive cultivation of pastures and crops has involved the clearing of natural vegetation and irrigation using groundwater resources; and flood mitigation/drainage works has brought hydrological changes through the diversion of surface water flows from the lakes.

In order to assess the impact of groundwater pumping and changes to surface flow systems on the wetlands, research has been instigated to quantify the groundwater and surface water inputs to the lakes and hence improve understanding of their sensitivity to changes in groundwater recharge and discharge. In this paper the groundwater and surface water chemistry, including stable isotopes, is presented and a method described to distinguish between surface water, groundwater and evaporation dominated lakes.

2. Approach and Method
A reconnaissance sampling of lake surface waters was undertaken with the aim of investigating a method for the rapid assessment of the groundwater dependence of the lakes of the region. It was hypothesised that a combination of isotopic and chemical parameters could be used to assess the groundwater dependence of the wetlands. The approach taken was to
firstly obtain an understanding of the types of wetlands present and then undertake further, more in-depth research, into a few select “typical” lakes.

Forty-six lakes were visited on the initial reconnaissance field trip in July (winter) 2006, when it was ascertained that only a small fraction (around 2%) of the more that 1400 declared lakes and wetlands in the region (DCNR 1995) still contained some water. Like much of Australia, this area has been experiencing a prolonged period of below average rainfall, and in 2006 the 10 year rainfall average was at a record low.

Samples were obtained from 24 wetlands on the first sampling trip (Figure 8). Electrical conductivity (EC), pH, dissolved oxygen (DO) and temperature were measured on site using a calibrated field kit. The surface water grab samples were subsequently analysed in the CSIRO laboratories in Adelaide, South Australia, for chemistry and stable isotopes of water.

A second set of samples were collected three months later, in October 2006 (Spring), although some of the lakes previously sampled had dried out and could not be sampled. Since January 2007 a fortnightly sampling program has been maintained for three of the lakes (West Basin, Lake Colac and Weering Lake).

3. Results

3.1 Chemistry

The chemistry of the lake waters is shown in Figure 3 where anion and cation concentrations have been plotted as a function of total dissolved solids (TDS). The dissolved solutes of the Corangamite lakes are in general dominated by Na⁺ and Cl⁻ ions and the dominance of Na⁺ and Cl⁻ over the other ions increases linearly as a function of TDS. Calcium and HCO₃⁻ remain low throughout the entire salinity range indicating control of these dissolved ions through precipitation of carbonate minerals. The low salinity waters (TDS < 2,500 mg/L) have higher proportion of HCO₃⁻ and alkaline earth ions (Mg²⁺ and Ca²⁺) relative to other ions than the more saline waters (>2,500 mg/L). Hence the lakes probably have a substantial
fraction their solutes derived from mineral weathering and a lesser fraction from marine aerosols.

The composition of the more saline lake waters (TDS $> 2,500$ mg/L) is similar to that of seawater and the more saline groundwaters. Therefore, it is believed that the source of most of the dissolved ions for the both the saline lakes and groundwaters are derived from marine aerosols deposited by rainfall. The ratio of Cl/$\text{Br}^-$ in all lakes are slightly higher than that of seawater (290) which demonstrates the dominance of the marine origin of Cl$^-$ and, by inference, Na$^+$. The linear relationship for the majority of the ions points to evaporation processes as the dominant control of salinity levels in the lakes.

3.2 Stable Isotopes

Evaporation leads to increases in the ratio of $^2\text{H}/^1\text{H}$ and $^{18}\text{O}/^{16}\text{O}$ of residual waters with the isotopic concentrations evolving linearly in $\delta^2\text{H} - \delta^{18}\text{O}$ space (Rozanski et al. 2000). The degree of evaporative enrichment is dependent on atmospheric relative humidity over the lake and the surface water temperature. Results for the stable isotopes of water for the two sets of lake samples collected are shown in $\delta^2\text{H} - \delta^{18}\text{O}$ space in Figure 10. Those lakes that lie further to the right along the trend line have undergone a greater degree of evaporation relative to the rate of inflow. The lake water balance can be simply represented by a balance between the relatively light isotopic composition of inflow, and the tendency of evaporation to remove the lighter isotope preferentially to the heavier isotope thereby enriching the remaining water in the heavier isotope. In a semi-quantitative way the lakes increase in residence time (Residence time = total volume/total input rate) the further they lie to the right of isotopic trend line.
Figure 10. Plot of lake and groundwater stable isotopes of water showing similarities in the isotopic signatures of groundwater and rainwater and the trend line for the lakes.

The data have been presented together with isotope values for groundwater sampled from shallow (<25 m) bores in the vicinity of the lakes as well as monthly isotopic data for Melbourne rain. Groundwater samples tend to plot within the domain of the average monthly values for Melbourne rainfall. As the isotopic composition of groundwater is virtually indistinguishable from that for rainfall, the evaporation trend observed for the lakes would be almost identical for the two types of inflow, viz groundwater and surface water.

4. Discussion

4.1 A preliminary evaluation of lake types

In plotting the ratio of HCO$_3^-$/Cl$^-$ as a function of TDS (Figure 11) it can be seen that the ratio ranges over some three orders of magnitude with an overall decrease with increasing TDS. The freshest lakes (TDS <2,500 mg/L) tend to have higher HCO$_3^-$/Cl$^-$ which is indicative of surface and inter-flow runoff components which tend to have a higher component of HCO$_3^-$ due to mineral-solution reactions that produce HCO$_3^-$ as a by-product. Lakes with salinities >2,500 mg/L show HCO$_3^-$/Cl$^-$ < 0.08 reflecting a higher saline groundwater component to the water balance. Therefore one may be able to separate the lakes into two groups: low salinity (<2,500 mg/L) and high HCO$_3^-$/Cl$^-$ (> 0.08) that are surface water and inter-flow dominated; and higher salinity (>2,500 mg/L) and low HCO$_3^-$/Cl$^-$ (<0.01) that are groundwater dominated. The intermediate group may represent mixing between the two end-members.
Accepting the \( \text{HCO}_3^-/\text{Cl}^- \) ratio as an indicator of surface water and groundwater dominance, we can further categorise the lakes by plotting the \( \text{HCO}_3^-/\text{Cl}^- \) ratio with respect to the deuterium excess (Figure 12).

Figure 11. \( \text{HCO}_3^-/\text{Cl}^- \) as a function of TDS
The deuterium excess, $\delta_{xs} = \delta^2H - 8*\delta^{18}O$, reflects the deviation of a given sample from the meteoric water line and hence is an indicator of residence time and a measure of evaporation. Lower values indicate the increasing influence of evaporation. Most of the groundwater samples have a deuterium excess of between 7 – 12, which is slightly less than the local meteoric water values of 13, while the lake waters have a $\delta_{xs}$ generally between 5 and -5. If there was a large flow-through of groundwater, then the $\delta_{xs}$ would approach that of groundwater $\delta_{xs}$ values. Hence, plotting the $\delta_{xs}$ values data as a function of $\text{HCO}_3^-/\text{Cl}^-$ provides a means of at least qualitatively distinguishing between the water source of the lakes – surface water or groundwater – and whether they are through-flow or have long water residence times. Four end-members can be defined:

1. groundwater dominated, through-flow (high $\delta_{xs}$, low $\text{HCO}_3^-/\text{Cl}^-$);
2. groundwater dominated, long-residence (low $\delta_{xs}$, low $\text{HCO}_3^-/\text{Cl}^-$);
3. surface water dominated, through-flow (high $\delta_{xs}$, high $\text{HCO}_3^-/\text{Cl}^-$);
4. surface water dominated, long-residence (low $\delta_{xs}$, high $\text{HCO}_3^-/\text{Cl}^-$).

These 4 types have been illustrated in Figure 7.

Many of the lakes do not fall clearly within one type but sit between two or more groups. Furthermore variation in hydrologic condition (e.g. rising or falling groundwater tables, or changes in surface runoff) may result in a change to the lake’s status.

### 4.2 Method assessment

This method provides an initial classification of the lakes, however further research into the hydrology of the lakes is required to obtain a more quantitative description of the groundwater and surface water inputs. However, known physical and hydro-geological aspects of specific lakes can be compared with where the lakes lie on the $\text{HCO}_3^-/\text{Cl}^-$ versus $\delta_{xs}$ plot, as a preliminary method of validation. West Basin, for example, is a crater lake with little surface water catchment and no outlet. It is logical that that this lake falls in the region of an evaporating or terminal lake ($\delta_{xs} = -10.9$) with high groundwater dependence ($\text{HCO}_3^-/\text{Cl}^- = 0.03$). Lake Colac, on the other hand, is a larger, shallower, lake with tributaries on the south and an outlet to its north. It plots ($\text{HCO}_3^-/\text{Cl}^- = 0.2$, $\delta_{xs} = 1.3$ & -1.6) as a surface water
dominated lake and between the terminal and through-flow types. This is consistent with the period of sampling when the lake was experiencing a prolonged dry period with diminishing surface flows. A third lake is Weering Lake which is essentially a shallow depression in the flat landscape with no defined inlet and outlet. The HCO$_3$/Cl ratio for this lake is very low, 0.003, indicating a groundwater dominated lake. Between the first and second sampling events $\delta_{xs}$ varied markedly between 11.9 and -1.6. This possibly indicates a decoupling of the lake from the groundwater table as it continued to dry out.

Further investigation into the lake types is proposed and additional data is being collected. Fortnightly sampling of the three aforementioned lakes (West Basin, Lake Colac and Weering Lake) is being undertaken and groundwater levels in the vicinity of these lakes are being monitored. This data will provide a basis to estimate the water balance of the lakes and make comparison with the conclusions given in this paper. It is recognised that the period in which the sampling discussed in this paper was undertaken, was one of the driest on record and came at the end of an historic 10 year average low. The on-going drying of the lakes points to the fact that inflows, either of groundwater or surface water, have been limited. On-going sampling, together with improved rainfall conditions, will provide data sets that will enable further testing of the method described.

5. Conclusions

In this paper a method has been described which uses water chemistry and stable isotope data to distinguish between the dominant water source (groundwater or surface water) and flow regime (through-flow or evaporating/terminal) of a series of wetlands. Specifically, this method adopts the HCO$_3$/Cl ratio as a measure of groundwater and surface water dominance and deuterium “excess” ($\delta_{xs}$, where $\delta_{xs} = \delta^2H - 8*\delta^{18}O$) as an indicator of lake water residence time. The research lakes are found to lie on a continuum between four end member lake types, viz: groundwater dominated, through-flow; groundwater dominated, long-residence; surface water dominated, through-flow; and surface water dominated, long-residence.

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References


1 This statement relates to data collected by the Australian Bureau of Meteorology at the Colac Shire Office weather station number 090147.