

# Using hydrogeochemistry and isotopes to trace groundwater flow from Little Forest Burial Ground and surrounding landfills

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## LOCATION AND GEOLOGY

- Multiple tracer-element and isotope approaches were applied at a 1960's-era legacy low-level radioactive waste burial site (Little Forest Burial Ground, LFBG) in the Lucas Heights area (SW-Sydney, Aust) (Fig. 1).
- LFBG is located near past landfill, industrial waste disposal and night soil sites causing potential mixing of leachates.
- The local geology favours the retention of flow and contaminants by the clay-rich soils and the ~14 m shale layer underlying the burial site. This shale has been mined in the neighbouring landfill (Fig 2)
- Local soils experience periodic infiltration and wetting fronts, which can fully saturate the waste trenches (bathtub effect).

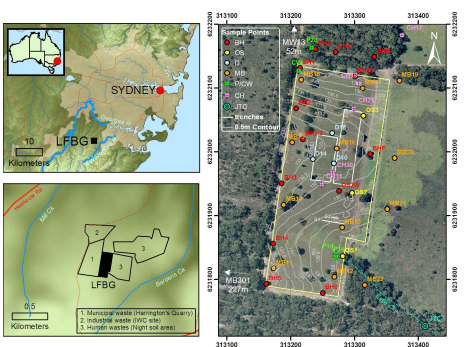


Fig 1. General location of the LFBG and surrounding land uses, topography and sampling wells (Colour code indicates the various groupings of wells refer to legends in Figs 4 and 5).

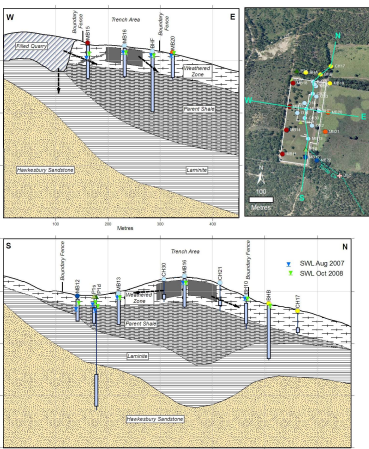


Fig 2. Geological cross-sections with stratigraphy, site features & wells. Vertical bars in wells show screen interval. Triangles show standing water level Aug 2007 (blue) and Oct 2008 (green). Arrows represent generalised groundwater flow directions; light arrow shows change in flow direction during dry periods.

## RAINFALL AND GROUNDWATER LEVELS

- Alternating dry-wet periods are common can be prolonged and are linked to wider climate patterns such as El Niño.
- Rainfall infiltration over the trenches impacts on localised groundwater levels within the trenches. This leads to a perched saturated layer as water flows from the trenches to the surrounding soil. This "bathtub" behaviour in the trenches controls organic matter degradation and contaminant release.

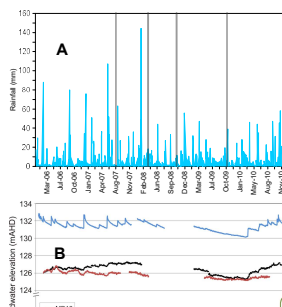


Fig 3. A. Daily rainfall at ANSTO. Vertical shaded lines indicate groundwater sampling times. B. Groundwater levels at P1D, P2D, CW and MB16.

## HYDROGEOCHEMISTRY

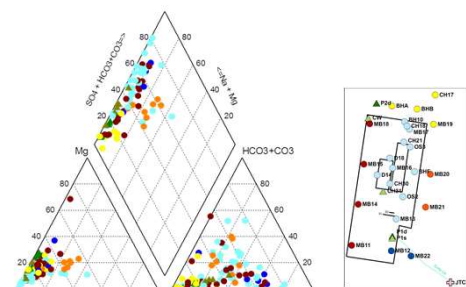
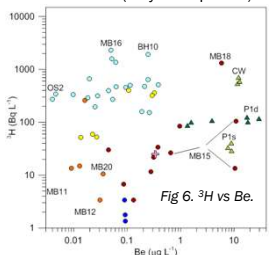


Fig 4. Piper diagram with groundwater major ion distribution. Sample symbols and colour scheme shown in inset map legend.

## ISOTOPES AND TRACE ELEMENTS

Stable isotopes of water, DIC, DOC,  $SO_4$ ,  $^{87}Sr/^{86}Sr$  and  $^3H$  were measured. Selected results in Fig 6, 8A and B. Trace elements (Be, B, Co, Rb, Sr, I, Cs, Pb, Th and U) were determined (only Be reported)



**Beryllium (Fig 6)**  
 1730 kg of Beryllium was disposed of in LFBG trenches, however Be metal and oxides are mostly insoluble in water with solubility depending on pH and particle size. Be is low in groundwater close to trenches (Fig 6) and higher in surrounding shale and sandstone suggesting no movement of Be from the LFBG trenches despite low pH.

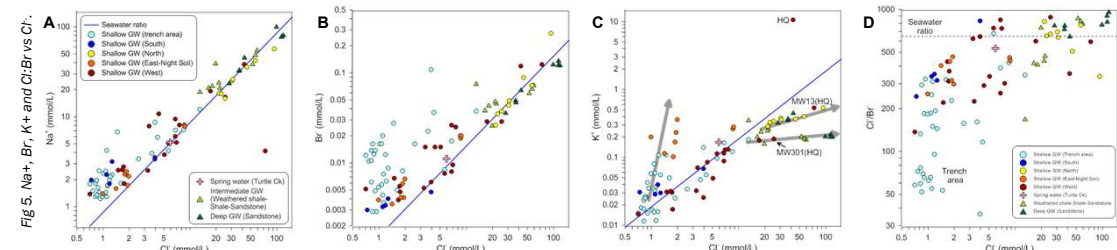
## CONCLUSIONS

- The LFBG groundwater hydrogeochemistry is controlled by the local geology, land uses and wet-dry rainfall patterns. The main lithological-controlling factor is the extent, thickness and heterogeneities of the weathered and intact shale layer (Fig 2).
- Shallow perched water bodies contain most of the contaminants originating from the trenches and can convey water from the trench area to the north infiltrating downwards and following the gently dipping shale lens. Infiltration towards the southeast is limited by the shale lens being closer to the surface favouring run-off versus infiltration.
- Ionic ratios generally follow those of marine derived rainfall. However, in some instances they diverge due to natural processes such as evapotranspiration ( $SO_4^{2-}$  and  $Ca^{2+}$ ), cation exchange processes ( $Na^+ K^+ Mg^{2+}$  and  $Ca^{2+}$ ) as well as contaminant interactions ( $Br Cl Na^+$ ).
- Beryllium concentrations are consistent with inputs from Harrington's Quarry landfill and increased solubility of shale Be in low pH areas. There is no compelling evidence that the Be disposed at LFBG has been leached into the local groundwater.
- Carbon isotope ratios show the importance of organic degradation processes in the leachate, night soil and within LFBG trenches. This is also shown by  $\delta^{21}O$  enrichments linked to methane production in the leachate and in some samples within LFBG trench area. Sulfur isotope trends are also consistent with bacterial sulfate reduction particularly in groundwater to the north of the site.

Acknowledgements: Elissa Bishop and Judy White from WSN for providing leachate samples, pumping data and access to groundwater data.

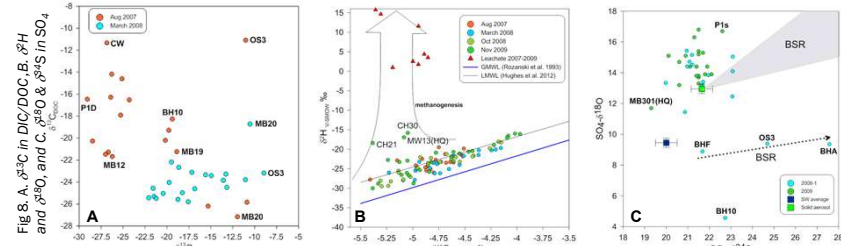
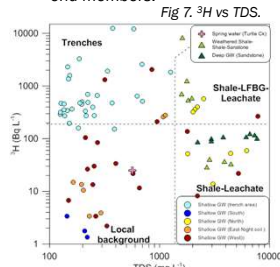
## Major Ions (Fig 5)

A. The  $Na^+$  vs  $Cl^-$  plot showing seawater origin of major solutes, slight  $Na^+$  enrichment points to cation exchange processes which indicates the shallow soil potential to retain contaminations. B. Br enrichment compared to the seawater line is observed in trench wells indicating interaction with the waste. C. KCl ratios show contribution from different contaminant sources – the upward arrow indicates night soil contribution/mixing and the sideways arrows indicate landfill mixing as well as  $K^+$  exchange with clay minerals. D. Low Cl:Br ratios indicate interaction with LFBG trenches while other samples show a mixing trend with background.



## Tritium (Fig 7)

Tritium is found in both LFBG and landfill leachates. When plotted against TDS (Fig 7) we can differentiate between LFBG, leachate and natural end members.



## Stable isotopes (Fig 8)

Carbon stable isotopes (A) from DIC and DOC are linked to groundwater levels. During dry conditions (Aug 2007) isotopic values tend to natural soil signatures while during wet conditions (Mar 2008) interactions with the waste control isotopic signatures. Similar interactions with LFBG trenches are seen in water stable isotopes (B) with methanogenic  $\delta^{21}O$  enrichment in samples close to trenches and in landfill leachate. Sulfate isotopes (C) reinforce the marine origin of solutes in rainfall and also indicate evaporative concentration of sulfate is occurring in the soil column of vegetated areas surrounding the site. Bacterial sulfate reduction is also seen to the NE of the site which could be related to groundwater becoming more confined or mixing with night soil leachates.