

# Author Reply to Referee 4 Comments

## Hydrological functions of sinkholes and characteristics of point recharge in groundwater basins

By N. Somaratne, K. Smettem, J. Lawson, K. Nguyen, and J. Frizenschaf

The authors would like to thank Referee 4 for his/her insightful comments.

**Referee 4-1:** Point source recharge to karst aquifers through sinkholes is an important hydrologic process in karst systems. In some karst systems point source recharge may be the major process of aquifer recharge, thus gaining additional knowledge in this process is critical. The authors attempted to address this process at three case studies by using environmental tracers, salinity, and chloride analysis of rainwater, surface water and groundwater. The authors also attempted to use the conventional chloride mass balance (CMB) approach to understand diffuse versus point sources recharge.

**Author Reply 4-1:** Agree

**Referee 4-2:** The hydrologic analysis of the three case studies are interesting and should be of help to local water managers trying to manage their karst aquifer. I had difficulty in understanding the authors research design and methods used to answer the questions of point source versus diffuse recharge at the three case studies. The research looks like a body of work using existing data at the sites, ie. total dissolved data at Uley South Basin, chloride data at Mount Gambier Blue Lake, and general geochemical analysis at Poocher Swamp. It was nice to see environmental tracer data but the plots of chloride versus  $\delta^{18}\text{O}$  were not convincing when it came to defining point recharge.

**Author Reply 4-2:** We agree with the comment and methodology section completely revised. The methodology now include: Groundwater sampling method (micro-sampling and grab sampling), salinity profiling using sonding technique, and classification of groundwater using piper diagram. In addition, description of point recharge estimates and calculation of recharge using conventional CMB method is in the methodology section, not in the result and discussion. The new structure is as follows:

Abstract

1. Introduction
2. Description of the study basins
  - 2.1 Uley South basin
  - 2.2 Mount Gambier Blue lake capture zone
  - 2.3 Poocher Swamp fresh water bubble
3. Methods
  - 3.1 Point recharge estimates
  - 3.2 Recharge calculation by the conventional CMB method
4. Results and Discussion
  - 4.1 Characteristics of point recharge-chloride to  $\delta^{18}\text{O}$  relation
  - 4.2 Groundwater mixing zones
  - 4.3 Comparison of point recharge to conventional CMB estimated recharge and chloride distributions in diffuse and point recharge dominant zones
5. Conclusion

The authors acknowledge that existing chloride and hydrochemical data were used. In addition, major ion chemistry and isotope data were collected from Uley South basin in 2008, major ion chemistry, isotope and salinity profiling was undertaken in 2010 and 2011 from monitoring and drainage wells in Mount Gambier capture zone. In 2012, major ion chemistry and isotope data were collected from Tatiara Creek, Poocher Swamp and from aquifer monitoring wells.

Comment on the 'plots of chloride versus  $^{18}\text{O}$  were not convincing when it came to defining point recharge' is correct because of the monitoring bias. What we have shown is (page 11429 and page 11430): "Therefore, a gap between groundwater and rainwater chloride data points in the chloride vs  $\delta^{18}\text{O}$  plot, is not necessarily an indication that sinkholes are not directly recharging the aquifer".

We have included this section because of Ordens et al (2012) comment that "*The observed gap between Cl concentration of rainfall and groundwater should be taken as an indication that the contribution of sinkhole-channelled rainfall that escapes evapotranspiration contributes only little to the total recharge amount, as otherwise more intermediate data points would be observed*" (according to this interpretation, Mt Gambier drainage wells would contribute little to the total recharge, whereas 400 drainage wells are the major recharge component).

**Referee 4-3:** I was very excited to see the recharge conceptual model (Figure 9) for Uley South Basin, but there was no experimental results presented to either confirm or dispute this conceptual model. I had thought this was what the paper was about.

**Author Reply 4-3:** The paper is not about presenting the conceptual model. The conceptual model emanated from results. The objective of the paper is given page 11425, line 20-26. In the revised manuscript, this was expanded to provide clear picture to the reader as follows: "*One of the inherent problems of the presence of karstic features such as sinkholes on hydrological functions may be recharge estimation using conventional chloride mass balance (CMB) method. The fundamental basis of conventional CMB method is that recharge mass flux crossing the watertable plane can be calculated if (Wood, 1999; Gee et al. 2005):*

- Chloride in the groundwater originates from precipitation directly on the aquifer, and no unmeasured runoff occurs,
- Steady influx of water and chloride,
- Chloride is conservative in the system and no other sources or sinks in the aquifer,

*Problems arise holding above assumptions because different recharge processes may operate simultaneously, such as unsteady surface water directly injected into aquifers bypassing the soil zone, and internal runoff. Under these situations, it appears that basic premise of the conventional CMB method is violated.*

*We critically examined the validity of conventional CMB method for recharge estimation in three karstic groundwater basins with particular reference to chloride distributions in point and diffuse recharge zones, groundwater mixing, preferential flowpaths and prediction of groundwater recharge using the conventional chloride mass balance (CMB) method, and compare this to point recharge estimates."*

Following our study, we have concluded that "*The chloride concentration in point recharge fluxes crossing the watertable plane can remain at or near surface runoff chloride concentrations, rather than in equilibrium with ambient groundwater chloride. In such circumstances the conventional*

*chloride mass balance method that assumes equilibrium of recharge water chloride with groundwater requires modification to include both point and diffuse recharge mechanisms.”*

This is the take-home message for the reader.

Figure 9, conceptual model is emanated from data analysis. For Referee 4's interest data used for the conceptual models is described below.

- Page 11426 line 24-26 described inland boundary is dry limestone and topographic rises, indicating allogenic recharge area (Figure 9).
- Page 11426, line 26 to page 11427, line 4 described central part contains numerous sinkholes and short-lived runoff, indicating autogenic recharge zone (Figure 9).
- Page 11433 Line 3-6 describes overall 10 mg/L reduced chloride concentration in the sinkholes areas of the basin. For this to happen, some fresh water has to reach watertable and mix with ambient water. This means direct recharge occur as in Poocher Swamp fresh water bubble. Therefore, some fresh water pockets are shown with point recharge (alongside diffuse recharge) in the Figure 9.

**Referee 4-4:** Lastly, the authors concluded that the CMB does not work very well in karst systems and needs to be modified. That would have been the research contribution of this paper. In other words develop a research effort to collect the needed data to modify the CMB method for karst. Otherwise I do not see any new findings or methods for publishing this work in HESS.

**Author Reply 4-4:** It is correct that this work conclude that the conventional CMB does not work very well in karst systems and need to be modified. This is the take home message for the reader. Note that, to the best of our knowledge no other work exist highlighting this message and therefore challenging the view that conventional CMB applies regardless of point recharge presence or not. **We hope we have provided the research community with sufficient, thought-provoking evidence to further this particular discussion.**

Dr. Werner, Referee 2 and Referee 4 suggested that it would be worthwhile to develop modelling efforts in the future to support the theoretical advancement of the CMB. **This in itself a major task and beyond the scope of this article.**

For the development of such model(s), either theoretical or empirical we have presented sufficient data and a conceptual model. All that is required is estimated point recharge, chloride concentrations in diffuse recharge zone, evidence of mixing (measured chloride concentrations), average annual rainfall and measured or estimated chloride concentration of rainfall.