

General comments: In this paper the authors are trying to examine the contributions to total recharge from point sources, relatively to diffuse recharge, in 3 sites with Karstic limestone aquifers, which are known as extremely heterogeneous. Their tools to evaluate and compare between point and diffuse recharge are mainly measurements of chloride and $\delta^{18}\text{O}$ concentrations, geochemical analysis of rain water, groundwater and surface water, and defining their relations. The paper is very difficult to read and comprehend for many reasons.

Author Reply: The authors would like to thank the Referee 1 for the comments. The corresponding replies are listed as follows:

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1. Karst systems are spatially varied. If one looks for systematic understanding of karst (including point and diffuse recharge) he should follow the temporal variations of the system in few representing locations. The author's analysis is based on spatial averaging, which in general not suitable for studying karst systems, as they found at their conclusions.
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Author Reply 1: We are aware of few studies conducted the way Referee 1 suggested, most recently being the Lauber et al. (2013) in this volume (doi:10.5194/egus-10-11311-2013). They stated that: *“Artificial tracers are powerful tools to investigate karst systems. Tracers are commonly injected into sinking streams or dolines, while springs serve as monitoring sites. The obtained flow and transport parameters represent **mixed information** from the vadose, epiphreatic and phreatic zones, i.e., **the aquifer remains a black box.**”*

We acknowledge that the suggested investigations (temporal variations of point and diffuse recharge of the system in a few representing locations) could add valuable knowledge to the topic. However, we would like to note that the aim of this study is not to understand or determine, in detail, flow paths or recharge at discrete locations, but the critical evaluation of one of the **important hydrological function in groundwater basins, assessment of validity of widely used recharge estimation method (application of conventional chloride mass balance (CMB) method) in karstic aquifers.** We have therefore focussed on obtaining information in regards as spatial coverage of the basin since it forms an important criteria of the reliability evaluation. The spatial distribution of data in this context adds mainly to fill the gap or to avoid that the aquifer remains as a ‘black box’ as Lauber et al. (2013) suggested. Spatially distributed data are lacking in many karstic aquifer studies. We have critically evaluated the validity of conventional CMB for karstic aquifers, and suggest extending the method to include both point and diffuse recharge components (page 11425, line 24-26) into chloride mass balance method. This is a major outcome of the study. Moreover, for the testing of the validity of conventional CMB method requires spatial distribution of chloride in groundwater. We found that the conventional CMB method was not suitable for recharge assessment (though widely used) in point recharge dominant basins due to two main reasons:

- a. Chloride concentration in recharge flux crossing the watertable plane is not equal to ambient groundwater chloride concentrations, hence violating a basic assumption inherent in the conventional CMB method.
- b. When groundwater mixing occurs (between point recharge and ambient groundwater), it is an impossible task to get representative samples of recharging water at that mixing point for groundwater chloride measurement.

Therefore we have suggested in the last sentence of the Abstract: *“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”*

It is noted that there are many articles have been published on limitations of conventional chloride mass balance methods, its uses and misuses but failed to recognise **non-applicability** of the equation in point recharge dominant groundwater basin. **This work is the only study in this regard** and hence we suggested the following in the last sentence of the conclusion:” *The duality of the recharge mechanism in karst aquifers suggests that modification to CMB method may be required in order to include both point and diffuse recharge components into the CMB method.*”

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2. For their analysis the authors report about 3 sites, with large amount of location, geological details and measurement sites, which include ground water wells, lakes, caves and surface water basins. Moreover, the provided maps (Figures 1-2-3) does not bring enough information for the average reader to find his way in this huge amount of geographical and geological information, leaving the paper suitable only for local hydrologists familiar with the research region and its problems.
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Author Reply 2: We acknowledge the referee’s point that a lot of local hydrological information is presented in the study – admittedly, only in the narrative. This was done to provide the reader with an overview of the complexity of the areas that are subject to recharge assessments. It was our intent to only display in the figures the most significant elements discussed in the paper, namely the location and spatial distribution of measurement sites relative to sinkholes or drainage wells, as they are essential to later illustrate how they feature in the validity tests for conventional CMB method.

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3. There is no clear research approach. In the abstract the authors declared that “We studied three groundwater systems in karstic settings dominated by point source recharge in order to assess the relative contributions to total recharge from point sources using chloride and $\delta^{18}\text{O}$ relations.” However, deeper into the study the entire approach is unclear: do the authors know the degree of recharge through point source, in the different sites, in advance, and verify it with geochemical data? Or is it the opposite – they evaluated the geochemical composition, and with it they managed to evaluated the degree of point source recharge?.
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Author Reply 3: What we did (objective) is provided on– page 11425, line 20-26. The research approach is given on page 11426 under Methods (line 9-13) as follows: “*Hydrological functions of sinkholes and characteristics of point recharge were assessed using chloride Vs $\delta^{18}\text{O}$ relation, groundwater mixing, identification of groundwater flow paths, chloride distribution within and outside point recharge zones, estimation of volume of point recharge and comparison to total recharge predicted using conventional CMB method for the three study basins.*”

As mentioned above, we believe the paper has not deviated from the above methodology and systematically followed each as given in Results and Discussion : Page 11429, Section 3.1 – characteristics of point recharge; page 114320, Section 3.2-Groundwater mixing zones; page 11431, Section 4.1-Point recharge estimates; page 11432, Section 4.2- chloride distribution in diffuse recharge and point recharge dominant zones; page 11434, section 4.3-Recharge calculation by the conventional CMB method. Research outcome is contained in Conclusion and in the Abstract.

In page 11424, Abstract, line 3-6 should be read as :”*Our study shows that the assessment of relative contributions to total recharge from point sources using chloride and $\delta^{18}\text{O}$ relation, does not provide conclusive evidence of the indicative recharge mechanism.*” We thank the Referee for raising this issue and the text will be revised. We used chloride Vs $\delta^{18}\text{O}$ relation to dispute Ordens et al. (2012) claim, that contribution to total recharge from sinkholes are minor, and not to estimate point recharge.

The method of point recharge estimate is given in Section 4.1 for each study basins.

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4. The quantification methods and results are unclear. For example: which mathematical procedures and which data were used in the reported tables 1-2?
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Author Reply 4: The aim is to test the validity of recharge calculated using the conventional CMB equation in karstic aquifers. Therefore chloride in groundwater resulting from point and diffuse recharge (duality) was taken, from Table 1, chloride in 'point recharge zone'. The equation (1), (which is the conventional CMB equation) was used for recharge calculation.

In page 11434, line 12-13 will be revised as follows: “ *For the three case studies described in this paper, recharge from conventional CMB was estimated using equation (1) and chloride in point recharge zone given in Table 1. The conventional CMB estimated total recharge is less than the point recharge component (Table 2).*”

5. In their conclusions the authors wrote: “This paper presents case studies that concur with the findings of Hallberg and Hoyer (1982), Gunn (1983), Tihnasky (1999), White (2003), Bakalowicz (2005), Goldscheider and Drew (2007) and Taylor and Greene (2008) that karst systems have a distinct hydrologic function resulting from a duality of flow regimes in infiltration and recharge, and in preferential groundwater flow paths.”

My impression is that the authors did not bring generally new findings or methodology regarding recharge and spatial distribution of water quality in karst systems, and therefore their publication is more suitable as local report but not recommended for HESS.

Author Reply 5: Authors agree that knowledge of duality of flow regimes in infiltration and recharge, and preferential flow paths are not new. The approach we have taken is to show our study is consistent with previous work conducted elsewhere and hence to demonstrate that this is not a local issue.

What is new in this paper is a clear finding that the application of conventional CMB method for recharge estimation in karstic aquifers is not valid (even though it is widely used as in Ordens et al. 2012). To date, limitations of the CMB method have been mentioned in literature, but the particular aspect (of reliability in point recharge dominant basins) has not been investigated and hence erroneous recharge estimate are often being made using conventional CMB in point recharge dominant groundwater basins. Furthermore, we suggest that the duality of the recharge mechanism in karst aquifers needs to be incorporated into CMB method in order to appropriately include both point and diffuse recharge components.

Specific comments:

Page 11425, lines 14 -19: The paragraph does not mean anything. Claiming that karst is complex and cannot be studied using conventional methods is fundamental fact. There is no need to use 5 references to say it.

Author Reply: This is to provide background information to place our work in context. This was followed from typical approach in journal publication, particularly to describe what other work has been done that facilitates this paper. **What previous works have not done is the aim of the paper** and which is given in page 11425, line 20-26.

Page 11428, lines 16-17: I could not understand the difference between “irregular annual volumes” (50,000-200,000 m³) and amounts in “rare occasions” (19,000,000 m³).

Author Reply: Typically annual volumes change from 50,000 m³ to 200,000 m³ (four fold). However there was a record that indicate creek flow reached to 19,000,000 m³ in 1988. This was a 'rare occasion' of very high flow.

Section 3.1: What is the meaning of "lack of intermediate data points" if you put it in numbers? Which "gap" is an evidence of sinkholes recharge and which is an evidence of the absence of such recharge? The entire logic and arguments here are not clear. Monitoring bias can be used to criticize any measurement results.

Author Reply: In page 11429, line 10-11, We have referenced to Ordens et al. (2012) where their conclusion was based on 'a lack of intermediate data points between groundwater chloride and rainwater chloride in the chloride Vs $\delta^{18}\text{O}$ plots'.

Gaps were put into numbers in Page 11429, Line 20 and in line 22 as: "*The widest gap between groundwater chloride and rain water chloride is about 83mgL⁻¹ in the Uley South aquifer (Fig. 4a). In the Blue Lake capture zone where average annual rainfall is about 160mm greater than Uley South, a gap of 43mgL⁻¹ exists*"

Page 11431, lines 8-11: The conclusion brought here is obvious and well known for karst systems-their non-homogeneity of spatial distribution in many characteristics of geochemical components is well known. The contradiction with the fact that the system is in steady state (statement made by the authors) is irrelevant. Steady state is a characteristic of the system during time, and karstic hydrological systems can be highly varied in space but steady in time. There is no contradiction here.

Author Reply: Non-homogeneity in karst system is well known only to hydrogeologists experience with such aquifers. The purpose of inclusion of this statement is to show that our study findings are in line with other similar works. Please note that this is not the main conclusion of the study. The main conclusion is the proof of conventional CMB method is not valid in recharge estimation in karstic system.

Regarding the steady-state, what we have stated is "groundwater system is under steady-state in terms of salinity and chloride mass". This means that salinity/chloride in groundwater has not changed over time even though fresh water pockets exists in these systems.

Page 11432, lines 3-4: In which area the MUSIC model was operated. It is not clear.

Author Reply: Drainage wells are in Mount Gambier Blue Lake capture zone. We will revise the page 11432, line 3-4 as follows: "*Nguyen (2013) used the urban storm water model MUSIC (2009) for quantifying storm water runoff to drainage wells in the Mount Gambier Blue Lake capture zone*".

Page 11432, lines 15-18: What is the meaning of average annual recharge of 2.5×10^6 m³? What can the reader do with this number? How it helps to distinguish between sink holes recharge and diffuse recharge?

Author Reply: This is the point recharge taking place via two sinkholes in the Poocher Swamp. In this particular case, the entire fresh water bubble associated with the Poocher Swamp was as a result of this recharge; this volume is particularly interesting from a local groundwater management point of view. Distinguishing between point recharge and diffuse recharge is not described in this paper, rather point recharge and total recharge calculated from conventional CMB was compared. Distribution of chloride in diffuse recharge and point recharge dominant zones are compared and contained in the next section in page 11432, Section 4.2.

Page 11433 lines 13-19: Most of this section is true, but again, not new. What is the contribution to science of the sentence "...it is generally not possible to get a representative average, or weighted

average of chloride samples by measurement: : :”. If the authors are not bringing any new findings or methods to correct this ‘not possible’ situation, this declaration is meaningless.

Author Reply: Whilst it is clear to the experts in karst systems, many hydrologists and hydrogeologists apply conventional CMB method to karstic systems taking average or weighted average groundwater chloride concentrations to estimate basin recharge. This is not valid. That is why we have highlighted that it is not possible to get representative samples, when mixing occurs. **The new contribution to this debate presented in the paper is case for invalidation of application of conventional CMB to karstic aquifers.**

Page 11435 conclusions: The conclusions are that we cannot estimate anything with the measurements. Once again I have the impression that other than some specific measurements in karst system, the paper has no significant “take home message”.

Author Reply: What we have concluded is ‘we cannot estimate recharge using conventional CMB method’. Take home message is provided clearly in Abstract (line 13-18) and Conclusion (line 14-20).

1. It is perceived that simplified assumptions in the conventional CMB and the inability to obtain representative chloride concentrations make direct application of the conventional CMB method to point recharge dominant groundwater basins questionable.
2. The duality of the recharge mechanism in karst aquifers suggests that modification to CMB method may be required in order to include both point and diffuse recharge components into the CMB method.