

Reply to reviewer 1

Dear Dr. van Geldern,

We would like to thank you for reviewing our manuscript and for providing constructive and useful comments. Below are our responses to your specific comments.

The line number referenced in this reply are from the revised manuscript (attached as Manuscript_revised_2.pdf).

We have answered comment 1 and comment 2 together.

Comment 1: L95-100. Publications from the authors themselves (and others) exist of the topic of SIW in urban systems. This usage is not restricted to the validation of hydrodynamic models but has also been used to detect for instance sewer infiltration. A few studies on urban system and SIW exist and I think this is the place in this study to cite them? It is not the case that SIW are totally new to urban systems (this sentence reads a bit like that) and the authors should be aware of that as they already cited Jameel et al (2016) above.

Comment 2: L101-119. This paragraph reads a bit like an abstract or a brief version of objectives, methods, results and conclusions. I suggest it is enough here to state where the study occurred and the respective objectives. This is also the place to cite the other studies (that I also reviewed) that already explored the Salt Lake Valley (SLV) metropolitan area by stable isotopes (Ehleringer et al. 2016, Jameel et al., 2016). Please outline here briefly which questions were not asked and/or could not be answered by these earlier studies that already used SIW in the SLV area and how this relates/led than to this study. Here the reader get's the impression that SIW are applied for the very first time to the study area, which is not the case.

- Based upon your and reviewer 2 comments, we have rewritten the entire introduction section (including line 101 -119) and have highlighted the limitations of the previous work, the novelty of our current work and included past work on urban water systems.

The restructured section of the introduction relevant to your comments is included below (L 74– 105 in the revised manuscript).

In urban settings, stable isotopes and other geochemical tracers have been used successfully to understand effects of stormwater control measures on urban stream (Jefferson et al., 2015), detect infiltration rates in urban sewers (De Bénédictis et al., 2005; Kracht et al., 2007), partition waste water and groundwater in urban sewers (De Bondt et al., 2018) and determine the age of drinking water in a PWSS (Waples et al., 2015). Recent studies have also shown that stable isotopes of tap water in urban areas can be used to characterize active water management practices, identify linkages between socioeconomic factors and water management practices, and quantify the effects of climate variability on water resources (Ehleringer et al., 2016; Jameel et al., 2016; Tipple et al., 2017).

Here, we collaborated with the Jordan Valley Water Conservancy District (JVD) to conduct an isotopic survey of waters from their service area within Salt Lake Valley metropolitan area (SLV) of northern Utah, USA (Fig. 1). JVD is a multi-source public water distribution network (Fig. 1) and we attempt to understand mixing between water sources at various sites (subsequently referred to as distribution sites) distributed

on the transmission lines using SIW. This work extends the earlier work of *Jameel et al., (2016)* and *Tipple et al., (2017)* beyond identifying broad water management patterns of a PWSS and explores the capacity of SIW to provide quantitative, spatially- and temporally-resolved estimates of source contributions within a well-defined and characterized PWSS.

We conducted our study during a 6-month period (May 2015 – October 2015), and using information on the production volume from the different sources, we analyze the stable isotope data at a monthly resolution within a Bayesian framework to generate quantitative estimates (with uncertainty) of the contribution of individual sources at the distribution sites. These analyses reveal basic information on supply and transport dynamics within the system, reflecting the physical structure of the supply system and the geographic distribution of sources. Finally, we combine the monthly analyses to characterize the spatial structure of the system in terms of contribution areas for the different sources across the supply network. Our results suggest that SIW-based Bayesian isotope mixing models (BIMM) could be a powerful and useful tool to interrogate PWSS, provide observational validation to hydrodynamic models, track contaminants and disinfectants within the supply system, and monitor water rights in PWSS managed by or for multiple stakeholders. This technique can be particularly useful in understanding water management practices of urban centers in the developing world which are undergoing rapid expansions and are generally decentralized, which makes conventional hydrodynamic techniques difficult to apply.

Comment 3: L138. Switch units. Please refer to SI units first (cubic meters or liters); you can then add imperial units (gallons) in parentheses if necessary.

- We have switched the units.

Comment 4: L136-150. It is of interest what kind of treatment is necessary before it can be sold/distributed. The various processes involved might be very basic or technically challenging (i.e. from simple sand bed filtering to ultrafiltration and/or chemical treatment). Some of these processes might also influence the stable isotope ratio because of secondary processes such as evaporation or mixing. In addition, this might change over the year and the specific treatment location and therefore add additional bias to your data. Any ideas how to deal with that?

- We thank you for pointing this out. We measured the isotope value of source water before entering the water treatment plant (i.e. influent water to WTP) and the isotope values after the water was treated (i.e. effluent water from WTP). We did not observe any difference in the isotope values of the influent and effluent samples. The residence time of water in these WTP are small and the effect of secondary evaporation should also be minimal. We have added a sentence in the manuscript in this regard. (L 156 -159 in the revised manuscript):

“For source water samples obtained from water treatment plants, we measured the isotopic composition pre- and post-treatment (i.e. influent to the WTP and effluent from the WTP). We did not observe any significant isotopic difference between pre- and post-treatment samples (differences in $\delta^2\text{H}$ and $\delta^{18}\text{O}$ less than 0.7 ‰ and 0.2 ‰ respectively).

Comment 5: L176. This is unclear to me. You measured the isotope ratio of some wells for a specific(?) month and then used this value also for all other months of this study? Or the other way around: you used isotope values measured outside the sampling interval of this study and used them here? Please clarify.

- The isotope values of all the wells were measured at least once during the sampling period. If the isotope value of a well (or wells) was not measured in a given month during which it was in operation, the mean value from other month(s) were used. We have edited this text in the manuscript. The modified sentence in the revised manuscript (L 160 - 164) is included below:

“Distribution sites and surface water sources (Provo River and Wasatch creeks) were sampled 1-3 times per month. Groundwater wells were sampled 1-5 times respectively, during the entire study period (May 2015 to October 2015). When a given well was not sampled in its month of operation, the mean value observed for the same well during other month(s) of our study period was used to characterize water supplied from that well..”

Comment 6: L186 Use italic characters for the delta symbol (Coplen 2011; Brand et al., 2014) throughout the text.

- Done.

Comment 7: L192 ‘van’ missing in citation: “(van Geldern and Barth, 2012)” => place under “V” in reference list (not “G”).

- Thank you. We have corrected it.

Comment 8: L295 Not sure if the term ‘deuterium excess’ has so far been introduced. If not you cannot use “d-excess” without giving the full name here. And: please use either ‘deuterium excess’ or d (but not ‘d-excess’).

- We have written deuterium excess instead of d-excess.

Further: I do not think that a d-value of “~10‰ is high”. This is the normal expected d-value from the GMWL? Or do you mean that the d-values from well 64S are higher compared to your other sources? Please clarify.

- Indeed the value of 10‰ is normal and not high. We meant high in a relative sense and we have clarified in the text (L 306).

Comment 9: L300/301 round d to one decimal or less (5.1‰ or 5‰ but not 5.19‰).

- Done.

Comment 10: L471-482 I think this is an important point and this cross-check was announced earlier in the manuscript (section 2.5). I suggest giving this section a more prominent position either earlier in the discussion and/or upgrade to a sub-chapter in section 3.

- Thanks for the suggestion. We have included this as a separate sub-section in section 3 (section 3.4 in the updated manuscript, L 480 - 493).

Further: From my first impression of Table 1 the numbers are in quite good agreement although some discrepancies between the BIMM (this give V, right?) and the areal contribution (A) exist for some sources. This raises the question if the stable isotope method is really necessary to identify sources if it can be done rather easy without measuring isotopes in many cases? The authors should more highlight the differences rather than the agreement between the two approaches. If both approaches come to comparable results, then I cannot see a reason running SIW?

- To clarify, V is the fractional volumetric contribution of each source that we obtained from the water company (Jordan Valley Water Conservancy District, Table 1 in the revised manuscript). For each month, the water company collects the data on the total water supplied by the different sources in the supply system; we did not calculate V but rather this was preexisting data and was also used as a prior in our analysis. The calculation of A serves as a secondary crosscheck to our isotope-based results. The value of A is calculated using the values obtained from BIMM (L 287-291 in the revised manuscript).
- Indeed, we learn new information from this analysis. For example, we generally expect that if according to the water company, a given source is supplying 60% of the total volume in the system, then that source should also serve approximately 60% of the area in the distribution system. If V is comparable to A, we learn in which region that 60% of the V is distributed. Where V does not scale well to A, as indicated by the reviewer, we still learn something new about the system (e.g., heterogeneity in water use etc.). We hope this answers the comment.

We have included the monthly contributions of the different sources (V) as obtained from Jordan Valley District in the revised manuscript (Table 1). We hope including this table will help in differentiating between V and A easier.

Comment 10: L486 'Distinct sources' (in terms of their isotope values) are a very critical point. If various sources in a system are NOT distinct (enough) the isotope approach will give no unique solution or will simply fail. I notice this is mentioned again in lines 496-498. Please include here a statement that the BIMM is not only 'limited' but will not work (or gives no useful solution; it will probably calculate something...).

- We have added a sentence in this regard that the model will yield results that might not be useful for practical purposes if the source isotope values are not distinct.

Below is the excerpt from the updated manuscript (L 508-511).

"In PWSSs with negligible isotopic and geochemical variability between the sources, the capacity of the BIMM to characterize the system would likely be limited and it will provide results with limited practical applicability."

Technical corrections and minor comments

Table 1 Please clarify in the captions which of the values (A or V) is the result if the BIMM (aka received from the isotope mixing model).

- We have rewritten the caption. The updated caption reads: "Table 2: Comparison between volumetric (V) and areal (A) contributions of the different sources from May 2015 to October 2015. V for each source was calculated from the monthly supply data of each source (see Table 1). A was calculated using methods described in section 2.5. JVTP and SETP are considered as separate sources in May and June 2015 and combined sources from July to October 2015. Sources contributing less than 1% of the total volume have been grouped together as "Minor sources" for June, July and August 2015. All values are in percent."

P4L88 space character after parentheses

L156 Fig. 1 (not fig. 1)

L164 delete 'as'

L184 t-test (t is italic)

L185 delete 'in' (before 'for')

L192/193 delta symbol italic; R italic

L2010 space character missing before parentheses

L231 space character missing '1 assigned'

L256 comma missing before 'respectively'? L256 fig. => Fig

- We have rectified all the typos.

L196 space character between number and unit ($\pm 0.3\%$); change throughout the text; NIST style convention #15; see:

- Done.