Response to: Interactive comment on "Desiccation-crack-induced salinization in deep clay sediment" by I. Jolly (Referee)

By: Baram, S., Ronen Z., Kurtzman D., Küells C., and Dahan O.

The authors would like to thank the referee I. Jolly for the comprehensive review of the manuscript. The comments helped us to improve the manuscript and to correct some type errors missed by us. Below are our comments to the review.

Comment 1: The science looks generally sound but I do have one issue of concern with their interpretation of the stable isotope profiles beneath the permanently flooded waste pond and channel. The deuterium and oxygen-18 profiles are very enriched in the near surface and then come to an approximately constant less-enriched value (the authors call these value depleted but they are still enriched compared to the local meteoric water line so I would refer to them as being less enriched) below this zone (δ -5 per mille for deuterium and δ -2 per mille for oxygen-18). They interpret this less enriched zone as being a zone of mixing of the enriched wastewater infiltrating downwards and rainwater, which infiltrates down the desiccation cracks from the banks and margins of the waste source. While this may be plausible, it is dependent on the cracks being extensive enough and with enough horizontal orientation to allow rainwater entering the cracks exposed in the banks and margins to make it to under the ponded areas. Given the random nature of the cracking I would have expected that this would have led to much more variability in the isotope values in this zone (i.e. the mixing looks too perfect). In fact the isotope profiles looks like classic steady-state diffusion profiles created by capillary rise from a water table.

I decided to do a few quick diffusion calculations to see if the depth at which the profiles become approximately constant can be explained by diffusion of the very enriched wastewater downwards. Assuming the ponds were first filled with manure 50 years ago (as stated in the Baram et al., 2012b, hence t = 50 yr) and the volumetric water content below the pond is _0.4 (Fig. 1). The self diffusion coefficient for deuterium is 2.2 x 10ˆ-9 mˆ2/s. Assuming a range of possible tortuosities for clay to be somewhere in the range of 0.3 to 0.7, the effective diffusion coefficient would be in the range of 2.64 x 10ˆ-10 mˆs/s to 6.16 x 10ˆ-10 mˆ2/s. The depth of diffusion is given by sqrt (4 * Deff * t) which for this range of tortuosities gives a range of depths of 1.30 to 1.97 m. The depth where the deuterium (and oxygen-18 values) starts to become constant is approximately 2 m so this could explain the shape of the upper part of the profile.

Reply to comment 1: It is true that diffusion and slow matrix advection of enriched wastewater from the land surface contribute to the isotopes profiles under the waste lagoon. The fact that the profile is slightly concaved up can be intuitively interpreted as upward advection. However, one should bear in mind that in this case, both the relatively enriched and depleted sources (rainwater and wastewater, respectively) are located at the top of the vadose zone profile. In the following response to comment # 1 we explain why it is most probable that the source of the depleted (or less enriched) source is rainwater percolating through the crack system, and in reply to comment # 2 we elaborate on, why an upward net water flux is not the case under the lagoon and channel.

Despite the random nature of the desiccation cracks, previously published field observation from this site (Baram et al., 2012 Journal of Hydrology, 424–425: 165-171) indicated preferential infiltration of rainwater that reaches the subsurface under the pond and its banks. Moreover, chemical and microbial data indicated extensive microbial oxidation of the nitrogen-compounds that propagate with the wastewater infiltrating into the vadose zone (Baram et al., 2012 Journal of Environmental Quality, 5:1623-1632; Sher et al., 2012, FEMS Microbiol. Ecol., 81:145-155), supporting the presence of vertical and horizontal desiccation cracks under the pond. Comparison between the isotopic profile under the background, which is located away from the pond and is unaffected by wastewater infiltration, and the isotopic profiles under the pond and its margins shows similar values in the subsurface (Fig. 4a vs. 4c and 4b vs. 4d). In addition the salinization trend down to depth of ~3 m (Cl^- profiles Fig. 6) under the pond resembles the trend at the banks, and shows more than a twofold enrichment with depth.

Due to the dominance of preferential infiltration at the site, we believe that the depletion in the isotopic values under the pond results predominantly from mixture between rainwater that redistribute into the clay matrix following preferential infiltration events and between the propagating wastewater. The process becomes more dominant as the depth increases, since the water in the deeper part are subjected to more preferential infiltration events.

<u>Comment 2:</u> The authors state that the profiles cannot be caused by capillary rise as the water table is too deep (47 m below ground) and the land surface is permanently covered by wastewater. However, as was shown by 2 papers by Walvoord et al. (2002) in Water Resources Research it is possible to have upward movement of moisture in very deep profiles due to vapor flow.

Reply: It is possible to have upward movement of moisture from the deep subsurface due to vapor flow that driven by: 1) a dry top vadose zone (ψ<-400 m), and 2) a significant geothermal gradient in the vadose zone (Walvoord et al., 2002, Water Resour. Res., 38:1308). These conditions, which may prevail below inter-drainage natural land in arid areas, are far from the conditions of the vadose zone below the permanently flooded waste lagoon under Mediterranean climate. The thermal gradients in the investigated site has a negligible if any affect on the water flux and isotopic profile because the upper part of the profile is warmer than the lower part at least for 6 months every year (Figure R1 below). Frequent events of substantial preferential water infiltration change both the matric potential and the temperature of the upper sediment.

Moreover, under upward-flow conditions the chloride profiles have a bulge of high concentration close to the surface (Figure 3 at Walvoord et al., 2002) whereas in the studied site the high chloride concentrations prevail from the bottom of the evaporation zone down to the water table, as expected in a down-flowing vadose zone (Figure 6 in the current discussion paper). Therefore although the isotope profiles looks like classic steady-state diffusion profiles created by capillary rise, other data cannot support such a rise.

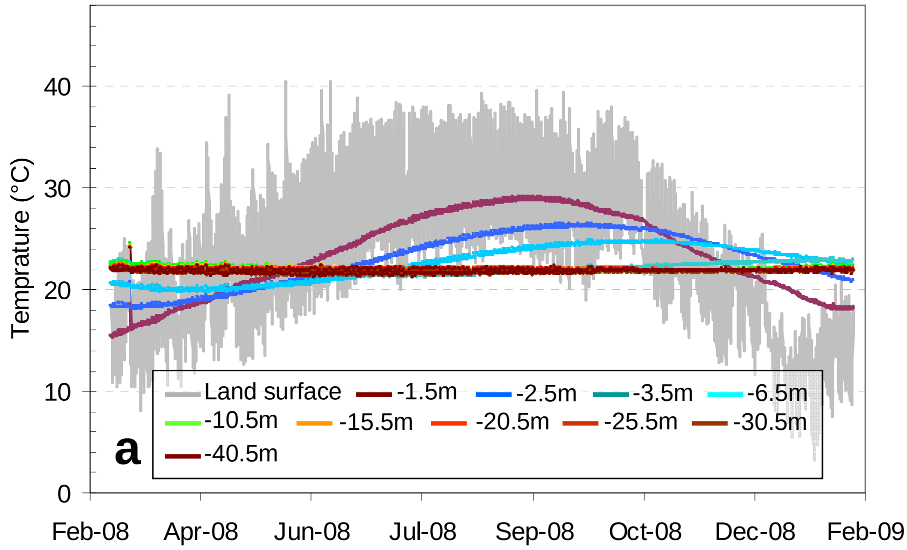

Figure R1. Temperature in the vadose zone profile under the waste pond, measured by 10 thermocouple probes of the vadose zone monitoring system at different depths

Comment 3: It would be interesting to see what the stable isotope concentrations of the underlying groundwater are (do the authors have any data on this?). If they are δ -5 per mille for deuterium and δ-2 per mille for oxygen-18 then a steady-state capillary rise conceptual model may be a possible alternative interpretation. In fact, if the groundwater has this stable isotope composition then all sites could possibly be subject to capillary rise.

Reply: The clayey upper part of the vadose zone was in focus of the isotope analysis therefore we did not obtain the isotopic composition of groundwater. Even if the composition is similar to the deeper vadose zone composition, the depth of the water table is 47 m and the conceptual model suggested by the referee contradicts many observations from this site as demonstrated in reply to comments 1 and 2. The frequent changes in the volumetric water content of the sediment due to down propagation of wetting waves following rain events does not support capillary rise of groundwater to or near the land surface. Redistribution of water following preferential infiltration events leads to gravitational drainage and prevents capillary rise.

Comment 4: Page 13157, line 16 - there is no Barnes and Allison (1991) paper in the reference list - but there is one from 1983.

Reply: Thanks, the comment is accepted. The reference to the paper from 1991 was deleted.

Comment 5: Page 13159, line 4 - the authors state an objective for the study but do not state the hypothesis they are testing in the paper. All studies should have stated hypotheses.

Reply: We agree with the referee's comment. The hypothesis of the study was added at the end of the last paragraph in the introduction, before the research objective.

Comment 6: Page 13159, line 20 - 'in average' should be 'on average'.

Reply: The comment is accepted. The text was changed accordingly to state "on average".

Comment 7: Page 13164, lines 12/13 - have mixed up the oxygen-18 and deuterium values.

Reply: Oops, we thank the correction. The oxygen-18 and deuterium values were changed accordingly to $\delta^{18}O$ –2‰ and $\delta^{2}H$ –5‰, respectively

Comment 8: Page 13168, line 28 - 'Eucaliptus' should be 'Eucalyptus'

Reply: The comment is accepted. The text was changed accordingly to state "Eucalyptus".

Comment 9: Figure 7 - need a legend indicating the depths of each of the temperature sensors

Reply: The comment is accepted. Legend that indicates the depths of each of the temperature sensors was added to Figure 7.