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Hydrology and Earth System Sciences Discussions

Interactive comment on "Implications of deep drainage through saline clay for groundwater recharge and sustainable cropping in a semi-arid catchment, Australia" *by* W. A. Timms et al.

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Referee: The paper is well written, the experiment is well planned and the analysis of the field data is (mostly) technically correct. I have very few technical comments on the paper but my major concern is the overstating of the importance of the results. The use of phrases such as "unique study" (P10054, L4) and "for the first time" (P10057, L14) should be applicable at a global scale when published in an international journal rather than just applying to the Lower Namoi. I would suggest that that the authors need to expand their lit review from focusing on the Namoi to the rest of Australia and the world

and then put their results into a wider context.

Reply: The referee has prompted the authors to consider some issues in more detail, leading to an improvement in the content and expression. We thank the Referee for drawing our attention to recent publications and an unpublished university thesis that are of relevance. Meta-searches of international journal literature for this paper was completed mainly prior to 2010, and there have been a number of new papers published since that we have added to a more comprehensive review, including many of the papers provided by the Referee. We are convinced that our study provides a valuable integrated approach that is unusual, in this environment. That is, field observations of soil and groundwater combined with soil-water modelling studies for cropping on a Vertosol soil in semi-arid, summer dominant rainfall conditions are rare. No comparable studies have emerged with further searches, except for Tolmie et al. 2011 who focused on field measurements to verify earlier models. Although this detailed field and modelling study is specific to a soil type, land-use and climatic environment, we delete the term 'unique' as there may be such studies of which we are not aware.

Tolmie et al. 2011 states: "There were few data for deep drainage under dryland farming in the Murray-Darling Basin before this study (Tolmie and Silburn, 2003). Petheram et al. (2002) reviewed the data available Australia-wide and noted the need for more data in areas of summer-dominant rainfall. Without independent data, the models cannot be validated and there is greater uncertainty in assessment of salinity risk." As noted by Crosbie et al. 2010a, "some previous studies to develop quantitative recharge relationships met with limited success because of the limited geographical coverage of the studies, lack of details on the study sites, and high variability in the data." A relative lack of studies in the New South Wales region was also noted by Crosbie et al. 2010a, however, this review did not include deep drainage field and modelling studies (Ringrose-Voase et al. 2003; Abbs and Littleboy, 1998; both major peer-reviewed studies that are readily available). Deep drainage studies are important to provide potential recharge values for partially confined shallow aquifers, but instead the review

included hydrogeological studies of potential recharge rates to confined aquifers in this area (Coram and Jaycock, 2003; Berhane, 2001).

Referee: P10054, L3 - (UNEP 1992) defines semi-arid as having P/PET of between 0.2 and 0.5. Only using rainfall can include some temperate regions (east coast of England?)

Reply: We have edited this statement as follows: "Average annual rainfall of 450-500 mm coupled with relatively large rates of potential evapotranspiration (>2000 mm) conspire to limit the quantity of water available for plant growth in semi-arid areas of the Murray-Darling Basin, Australia. The precipitation to potential evapotranspiration is 0.23-0.25"

Referee: P10054, L4 – is this study unique because it is the first in the lower Namoi?

Reply: See earlier response. Field observations of soil and groundwater combined with soil-water modelling studies for cropping on a Vertosol in semi-arid, summer dominant rainfall conditions are rare. This field and modelling study contributes important data on deep drainage that could potentially recharge shallow aquifers, in the Namoi and in other similar soil and climate conditions in the Murray-Darling Basin and worldwide.

Referee: P10054, L14 – was the deeper groundwater from the confined aquifers?

Reply: Generally, yes deeper groundwater is from confined or partially confined aquifers.

Referee: P10054, L22 – why were piezometers installed in the unsaturated zone?

Reply: The depth to the saturated zone was unknown prior to this study, and the installation of piezometers at both $\sim$18 (partially saturated) and 21m depth (saturated) enabled a rise in groundwater level and saturation to be detected. The possibility that increased recharge and rising groundwater levels could occur with changed landuse in this area of the Murray-Darling Basin has previously been difficult to detect because piezometers have short screens and exhibit partially confined behaviour when the sat-

urated zone above the screen increases.

Referee:P10054, L27 – the saline groundwater could not discharge in the area but could it discharge further downstream?

Reply: Yes, the brief statement in the abstract is correct. The possibility of broader implications beyond the Namoi catchment is discussed in Section 5.6.

Referee:P10055, L1-9 – this paragraph needs references

Reply: We have added Abbs and Littleboy (1998) and Crosbie et al (2010).

Referee:P10056, L17-8 – the models are available (MIKE-SHE, MODHMS, TOPOG and Hydro-GeoSphere are examples) but they are not widely used for groundwater management in Australia. The PRAMS and SWAMS models in WA would be the exception.

Reply: The statement has been modified to read ". . .available but rarely applied".

Referee: P10057, L4 – there are older studies, e.g. (Jolly 1989)

Reply: The authors are aware of older studies of stream salinity in the Darling catchment however, these do not identify increases in groundwater salinity. As the focus of this paragraph was leakage through soil causing increased groundwater salinity, we have added the Jolly reference Section 5.6 discussion of potential catchment impacts.

Referee: P10057, L5 – a recent review of field studies of recharge/deep drainage in Australia identified 725 estimates of recharge in areas of less than 500 mm rainfall, 205 of these were on Vertosol soils (Crosbie et al. 2010).

Reply: The Crosbie et al. 2010 review is an important and useful contribution to recharge studies in Australia. However, it is not clear what the methods for these 205 studies were, as these details from the database do not appear to have been published. The database supplied in supplementary material (Crosbie et al. 2010) indicated 135 sites with clay soils in a rainfall zone of 400-500 mm/year but does not appear to report

whether or not these were Vertosols. Of the 135 sites, four were located in NSW, and by referencing the original publications, two sites appear to be on Vertosols. For land that has been cleared for cropping on Vertosols, our findings provide a tighter range of deep drainage values (3.2-9.5 mm yr-1) than Tolmie et al (2004) who reported highly variable values of <1 mm yr-1 to 200 mm yr-1. Crosbie et al (2010) reported clear relationships between deep drainage and factors such as soil clay content, land use, and rainfall, that Tolmie et al. (2004) was unable to develop with more limited data.

We've also added reference at this point in our paper to the classic field study by Kennett-Smith et al (1994) in the south western Murray Darling Basin. Although rainfall is not summer dominant in this region, many of the sites were on heavy clays or Vertosols and a few sites in semi-arid areas of south western NSW were included. They found as clay content in the top 2 m of the profile increased from 0 to 20%, recharge decreased by an order of magnitude to 3 mm yr-1. The Vertosol soils at our study sites are clearly important to limiting our deep drainage and potential recharge values.

Referee: P10057, L14 – A proper literature review would have revealed that there are many similar studies that have been carried out, this may be the "first time" such a study has been carried out in the Lower Namoi though. The study that I am most familiar with was carried out in the same department under the same funding source. At Brays Flat the recharge under several land uses was investigated using a water balance and found no recharge during the study period due to the sodic subsoils, numerical modeling estimated the long term recharge rate to be a small fraction of a mm per year (Crosbie et al. 2008). At the same site chloride profiles were taken down to the water table to reveal salt storage equivalent to several hundred thousand years of accumulation for a recharge rate of a small fraction of a mm per year (Crosbie 2006). The recommendations for land management on the site were that farming practices should not sacrifice profit to reduce recharge as the areas under cropping-pasture rotations were not the cause of the saline scald (Mitchell 2007). Other examples are the Brigalow sites in Qld where the increase in deep drainage has not yet hit the water

table (Silburn et al. 2009; Silburn et al. 2010 in press; Tolmie et al. 2004) and the Mallee where a lot of the early work on this topic was completed (Cook et al. 2001).

Reply: It was stated that this is the first time that direct soil and groundwater measurements have been combined with soil water use modelling in this environment. That is, a semi-arid vertosol soil, commonly found beyond the Namoi catchment, as reviewed by Crosbie et al. 2010. Our paper compared findings with studies on Vertisols in Queensland by Silburn et al., 2011; Silburn and Montgomery, 2008 on P10074, L12-15, and are in agreement regarding long lag times. The Brays Flat study is an interesting study of very low recharge rates below trees and pasture in a catchment dominated by Yellow Sodsols, not Vertosols. Crosbie et al (2010) found that the vegetation and soil type were critical determinants in forming relationships between average annual rainfall and average annual recharge, while climate zones were not.

Referee:P10058, L15 – I am guessing potential evapotranspiration here is pan evaporation, it seems too high for something like Penman-Monteith or Preistley-Taylor. Need to be more specific.

Reply: It has been clarified as requested that potential evapotranspiration is Class A pan evaporation, as sourced from Bureau of Meterology climate data.

Referee:P10058, L17 & 19 – Is the site 20 or 30 km from Walgett?

Reply: The Denham and Sefton Park sites are 20 and 30 km from Walgett respectively. The second statement on L19 has been corrected to clarify this.

Referee:P10058, L20 – the slope over this distance has little meaning, a local slope from a DEM at the study site would be better (even though it will still say it is flat)

Reply: The slope of <1% was cited from a previous study in the introduction to the study area. Our findings reported a local slope of 0.04% measured by RTK Trimble GPS survey (P10066, L1).

Referee:P10062, L24 – It is usually better to cite the original paper rather than a sum-

mary in a tech report (Walker et al. 1991)

Reply: This citation has been changed to Walker et al. 1991.

Referee:10066, L10 – Need consistency in units, earlier in the paper tension was referred to in kPa rather than hPa.

Reply: The units have been revised for consistency.

Referee:P10067, L9 – was the deeper groundwater from a confined aquifer? If it is then it ha little relevance to the salinity of the soil or shallow groundwater.

Reply: We agree. However, since the deeper partially confined groundwater is relatively fresh, the possible downwards movement of saline porewater could be an issue in the future, as has been found a few kilometres to the east on the Cryon Plain (Barret et al 2006).

Referee: P10068, L4 – losing streams and disconnected streams are not mutually exclusive (Brunner et al. 2009; Brownbill et al. 2011).

Reply: We agree. The statement was intended to convey that the river could be losing, or the river could be disconnected. That is the river could be losing-connected, or losing-disconnected.

Referee: P10068, L6 – The groundwater may not discharge to the surface water in the immediate area, but what about further downstream?

Reply: We agree there could be downstream discharge. Discussion of this possibility was not included in the manuscript, but will be acknowledged in an additional sentence.

Referee: P10068, L10-11 – Having a water level above the screen does not make an aquifer confined.

Reply: Confined groundwater conditions were indicated by levels above the screen intakes and low barometric efficiencies of 30% for D1d and 18% for D2d and clay

stratigraphy above.

Referee: P10068, L12 – the BE seems low to me for a confined system, considering the ksat I would suggest that even the water table aquifer is semi-confined

Reply: We agree. BE cannot be relied on alone to indicate confining or unconfined conditions.

Referee: P10068, L21 – Is this surface loading or recharge?

Reply: The very small groundwater level responses in the deep aquifers occur rapidly and are more likely to be surface loading. L12 stated “Groundwater levels in confined aquifers below the study area have been stable since 1984”.

Referee:P10069, L6 – this sounds like preferential flow down the casing rather than an increase in groundwater level. If the water level in the sump is below the screen then how did it get in there? If the groundwater level had actually risen to above the bottom of the screen then the observation could not be below the bottom of the screen. The 0.1 m of water observed is still 0.9 m below the screen.

Reply: Yes we considered this possibility and state in the paper that there is considerable uncertainty in how to interpret the observations. Line 17: “However the actual recharge could be less due to preferential inflow around the bentonite seal that fills the annulus around the PVC pipe at 9m depth. This estimate of recharge at just one of four locations during one major rainfall event is therefore subject to considerable uncertainty and requires further verification.” We consider that it is possible that a saturated unit within the screen depth flowed for a short time, producing water in the sump between 11.8 and 12.5 m b.g. (equivalent to $\sim$1.4 Litres). Whether or not the water in the sump represents recharge, the % of rainfall as recharge is very small (<0.6% of average annual rainfall) and does not change the conclusions of the paper.

Referee: P10069, L14-26 – I do not think this is a valid calculation as the water in the sump probably does not represent a rise in the water table (see comment above)

Reply: See reply above.

Referee:P10069, L25 – there are other methods available such as age based tracers, but I agree, it is very difficult to estimate such low rates of recharge especially when using a water balance approach

Reply: We agree.

Referee:P10072, L3-8 – How much does the episodic deep drainage modeled at 5m get attenuated before it reaches the water table at 20m? Considering the ksat values it could take years. A constant rate of recharge will show up in the groundwater hydrograph as a flat line, this is exactly what is shown in figure 8. The assumption of a constant recharge in the groundwater model is appropriate considering the available data (although probably wrong).

Reply: We agree. This has been revised to read "Groundwater modelling assumed constant annual recharge (Merrick, 2001), in contrast to the highly episodic nature of deep drainage. This assumption is appropriate considering the attenuation of episodic events through a 20 m thick vadose zone."

Referee: P10072, L6 – There is also a history of episodic recharge in the groundwater literature (Crosbie et al.; Lewis and Walker 2002)

Reply: The Crosbie et al. 2011 reference, published after this manuscript was submitted, and the Lewis and Walker 2002 reference have been added to the references cited.

Referee: P10074, L3-4 – the lag times between deep drainage and recharge has been studied for decades (Cook et al. 2002; Jolly et al. 1989; Leaney et al. 2011)

Reply: Yes, these references have been added with the other literature cited on lag times in this paragraph (L15).

Referee: P10074, L4-5 – this could be modeled quite adequately with a Richard's

Equation based numerical model that had the model domain extended below the water table

Reply: We agree. Many field based recharge studies do not extend to numerical soil-water balance modelling of any type with Crosbie et al. 2008 being a welcome exception. The statement in this part of the paper, from a major CSIRO- NSW Agriculture study of deep drainage and recharge on Vertosols (Ringrose-Voase et al. 2003), referred to several limitations other than the modelling of a water table boundary.

Referee: P10075, L15 – the chloride deposition at Walgett is likely to be substantially less than at Gunnedah, see the groundwater theme at http://www.ga.gov.au/mapconnect/

Reply: Yes, that's possible. We have used available published data for this estimate. Using the map connection to extrapolate values westward, the annual salt deposition is 8.3 as mg/L NaCl, in a range of 7 to 11.6 mg/L NaCl. We used a value of 11.3 mg/L as NaCl.

Referee: P10075, L17 – the 20,000 years assumes no leaching to groundwater

Reply: Yes, we have added this assumption to the statement.

Referee: P10075, L19 – any salt deposited 13,000 years ago would have been leached from the root zone by now even if the deep drainage rate were 0.1 mm/yr (but not yet hit the water table).

Reply: Yes, leaching could have been flushed below the root zone, redistributing salt. The differences in chloride profiles to $\sim$17 m depth shown in Figure 5 suggest that redistribution of salt in the deep vadose zone is not uniform.

Referee: P10075, L26-27 – doubled compared to what? I would have expected at least an order of magnitude increase compared to native veg (although still very small)

Reply: This is double compared with traditional cultivation based practices. The state-

ment has been revised accordingly.

Referee: P10076, L9-10 – what about downstream?

Reply: Yes, we go on in this paragraph to discuss that there is no apparent risk of discharge into streams or onto low lying flood plains in the foreseeable future. Although intended to be generic, we will revised this statement to clarify that we refer to streams and flood plains within and beyond the Namoi catchment.

Referee: P10076, L11 – cf native veg?

Reply: Yes, we've revised this statement to state 'native vegetation'.

Referee:P10076, L15-16 - losing streams and disconnected streams are not mutually exclusive (Brunner et al. 2009; Brownbill et al. 2011).

Reply: To clarify, the surface water in this area is probably losing-disconnected, although in practice, the very small rate of leakage may limit loses.

Referee: P10076, L21-22 – it is already happening, the wetting front is well below the root zone P10076, L24-26 – the time lag could be calculated using the tools recently developed by CSIRO/GA http://www.csiro.au/products/Recharge-Discharge-Estimation-Suite.html

Reply: A significant benefit of deep drainage is that leaching of salt from the crop root zone is occurring. Leaching rates will be relatively high where salt stores are large, and could be enhanced by a series of wet seasons.

Referee: P10077, L1-2 – there are many examples, some cited earlier in this review

Reply: Integrated analyses of flow systems from the ground surface to the saturated zone are uncommon in this semi-arid region of Vertosols, particularly over both dry and wet climatic periods.

Additional references

Crosbie RS, Wilson B, Hughes JD, McCulloch C, King WM (2008) A comparison of the water use of tree belts and pasture in recharge and discharge zones in a saline catchment in the Central West of NSW, Australia. Agric Water Manage 95 (3):211-223

Crosbie RS, Jolly ID, Leaney FW, Petheram C (2010) Can the dataset of field based recharge estimates in Australia be used to predict recharge in data-poor areas? Hydrol Earth Syst Sc 14 (10):2023-2038

Crosbie, R. S., Jolly, I. D., Leaney, F. W., Petheram, C., and Wohling, D. (2010a). Review of Australian groundwater recharge studies, CSIRO Water for a Healthy Country National Research Flagship, Canberra, 79 pp.

Crosbie R, McCallum J, Walker G, Chiew F (2011). Episodic recharge and climate change in the Murray-Darling Basin, Australia. Hydrogeol J:1-17.

Jolly ID (1989) Investigation into the potential for increased stream salinisation in the Darling Basin. CSIRO, Adelaide

Kennett-Smith, A., Cook, P. and Walker, G. (1994). Factors affecting groundwater recharge following clearing in the south-western Murray Basin. Journal of Hydrology 154, 85-105

Lewis FM, Walker GR (2002) Assessing the potential for significant and episodic recharge in southwestern Australia using rainfall data. Hydrogeol J 10 (1):229-237

Tolmie, P.E., D.M. Silburn, A.J.W. Briggs. (2004). Estimating Deep Drainage in the Queensland Murray-Darling Basin Using Soil Chloride. Queensland Department of Natural Resources and Mines Report QNRM03020, Toowoomba.

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