Hydrol. Earth Syst. Sci. Discuss., 9, C4360–C4371, 2012
www.hydrol-earth-syst-sci-discuss.net/9/C4360/2012/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Climatic controls on diffuse groundwater recharge across Australia" *by* O. V. Barron et al.

O. V. Barron et al.

olga.barron@csiro.au

Received and published: 25 September 2012

Main recommendations

1. The authors clearly specify what is new in this manuscript in comparison to the old report(s) and the new one in Climate Change.

This work has not been previously published as a journal paper. Although, the reviewer is correct, parts of this manuscript relate to work that was reported in an earlier technical report (Barron et al., 2011). The technical report is considered 'grey literature'; it has not been under the same scrutiny of peer review as a journal paper. The technical report was written for an audience of Water Resource Managers and covered much

larger range of the issues associated with climate change impact on groundwater resources, while this manuscript is targeted to a scientific audience and focuses on the subject of climate parameters influence on recharge only. As this manuscript is targeted to a different audience there are different expectations, one example noted by the reviewer is that there is a substantial amount of more thorough analysis conducted for the current manuscript. It contains a higher standard of analysis and interpretation, it should be considered as a separate publication not merely a re-badging of old work.

2. Identify the possibilities and limitations of the WAVES model: make it for reader acceptable to trust the results. Explain the choices of number of layers, effect of model parameters on overall results, etc. In this article, a recharge analysis was conducted using the WAVES model (page 6029, line 4; page6029, line 8).

We agree with the reviewer that there was not enough information on the WAVES model; this will be rectified in the next version of the manuscript.

Groundwater recharge was modelled using a slightly modified version (McCallum et al., 2010) of the unsaturated zone model WAVES (Zhang and Dawes, 1998). WAVES is a soil-vegetation-atmosphere-transfer model that achieves a balance in its modelling complexity between carbon, energy and water balances (Zhang and Dawes, 1998). Its ability to simulate plant physiology allows changes in temperature and CO2 to show impacts on transpiration, and therefore recharge. Using the Penman-Monteith equation (Penman, 1967) for the energy balance allows the evapotranspiration to be controlled by the dynamic vegetation growth responding to the availability of water, nutrients and light (Wu et al., 1994). The modelling of the unsaturated zone using Richards' Equation allows water movement to be modelled under dry conditions (Scanlon et al., 2002). WAVES has been shown to be able to reproduce the water balance of field experiments in many studies around Australia (Crosbie et al., 2008; Dawes et al., 2002; Salama et al., 1999; Slavich et al., 1999; Xu et al., 2008; Zhang et al., 1999) and throughout the world (Wang et al., 2001; Yang et al., 2003; Zhang et al., 1996). WAVES was shown to perform similarly to three other hydrological models in a comparison study of the climate change impacts on recharge (Crosbie et al., 2011). As has previously been done (Crosbie et al., 2010b; Crosbie et al., 2012a), drainage below the bottom of a 4-m soil column is assumed to become groundwater recharge, this is to be considered potential dryland diffuse recharge as other forms of recharge (e.g. focused recharge or irrigation drainage) are not considered in this paper.

Soil data, including hydraulic characteristics, were derived from the ASRIS v1 database (Johnston et al., 2003). The soil profile was modelled as a two-layer system, with 0.5 m topsoil and 3.5 m subsoil with topsoil typically being more permeable than subsoil. A soil column of 4 m was chosen to be deep enough that rooting depth of the vegetation can be varied between perennials and annuals but not so deep as to be unrepresentative of large parts of the study area.

The recharge modelling was undertaken for three vegetation classes: annuals, perennials and trees. The vegetation parameters required by WAVES were taken from the User Manual (Dawes et al., 2004). The annuals (including crops) were modelled as annual pasture, the perennials were modelled as perennial pasture and the trees (including forestry) were modelled as an overstorey of eucalypts with an understorey of perennial grasses. Each climate zone used different parameters for each of the three vegetation types modelled to account for different species present in each climate zone (Crosbie et al., 2012b).

We do not think a conceptual diagram for WAVES is necessary for this manuscript. The conceptual diagram from Zhang and Dawes (1998) is pasted below.

The submitted manuscript to Climatic Change has now been published (Crosbie et al., 2012a), also many of the details will be brought into the next version of this manuscript so the reader does not have to go searching for additional information.

The sentence containing the “only partially validated” comment will be re-written for the next version of the manuscript.

The points used for modeling recharge in the current study were chosen to represent different climate zones rather than where detailed field estimates of recharge have been undertaken. WAVES has been demonstrated to be capable of reproducing field observations at a point scale (Crosbie et al., 2008; Dawes et al., 2002; Salama et al., 1999; Slavich et al., 1999; Xu et al., 2008; Zhang et al., 1999) as well as being capable of representing the trends in recharge under different soil and vegetation combinations at a regional scale (Crosbie et al., 2010a; Crosbie et al., 2010b). As we are confident that WAVES is correctly simulating the process of recharge but do not have the data available to verify the magnitude of the recharge, the results will mainly be reported in relative terms.

Other comments and remarks:

3. page 6026, line 27: for development of an adequate climate adaptation strategy. But also for fresh water resources management now and in the future

The statement used in the manuscript was to imply climate adaptation strategy in terms of fresh water resources availability and management. However since it does not seems to be clear we will add the following text to the paragraph:

...are important for development of an adequate climate adaptation strategy and adequate fresh groundwater resources management

4. page 6027, line 4: Australia has a highly varied and variable climate. Okay clear. Can you also tell us how representative these results are worldwide? Upscaling possibilities? Elaborate on that.

At this stage we have not considered the worldwide applicability of the results. It is only very recently that a global database of recharge estimates has been compiled (Kim and Jackson, 2012), this work suggests that recharge behaves similarly around the world. However, there has been much more work done on comparing runoff around the world with much larger datasets [e.g. Peel et al. (2001)], in this context Australian hydrology (along with Southern Africa) has been shown to be quite different to the Northern Hemisphere. It is probably best if comparing results globally is left for a future study.

5. page 6027, line 15: this study aims to investigate: at a point scale and at a continental scale. So, on two completely different scales. How is the upscaling process? Can they be interlinked?

This sentence was poorly worded and will be changed in the next version of the manuscript. It was not intended to suggest that point scale results would be upscaled to the continental scale. The point scale results will be aggregated to the climate zone scale and then the continental scale.

6. page 6027, line 19-20: examine the influence of other climate variables such as vapour pressure deficit, temperature and solar radiation: I do not think these climate variables are really examined in this manuscript. E.g., these terms are lumped in section 4.1 (Relative importance of climate characteristics in recharge estimation) and relative importance to annual rainfall is considered, but that is about it. A rephrase of the aim of the paper in this enumeration on page 6027 would be adequate.

The aims will be re-phrased in the next version of the manuscript in response to this comment and also Reviewer 1's comments. Section 4.1 does provide some comments on the individual importance of these climate parameters, including Figure 3. We could have included more detail, but since rainfall had the overall higher relative importance and being mindful about the manuscript size, the manuscript provides more focus on the relationship between rainfall and recharge.

7. p. 6028: line 2: shown in shown

Changes will be made

8. p. 6028: line 2: Fig. 1. In this figure it is definitely not clear (for me) that there are 15 zones. Say 8that in the caption or text. Why are these 7 zones so small? Are they

really different ones?

Yes, these 7 zones cover less than 1% of the continent, and as such 5 of them are not visible on the Figure 2. The caption was adjusted to reflect this limitation of the artwork

...climate types Af, Am, Cfc, Cwa, Dfb and Dfc have limited spatial distribution which is not feasible on this map (a) as combined they cover less than 1% of the continent.

9. page 6029, line 24: how is the group perennials determined? Literature?

This will be explained in the next version of the manuscript.

Three classes of vegetation have traditionally been used in classifying vegetation for field based recharge studies: Annuals, Perennials and Trees (Crosbie et al., 2010a; Petheram et al., 2002). Annuals are mainly shallow rooted crops and pasture; there is no ground cover for part of the year so recharge is highest under this vegetation type. Perennials are generally grasslands where there is groundcover year round; recharge is lower than annuals but higher than the deep rooted tree vegetation.

10. page 6029, line 25: User Manual: sensitivity analysis is implemented in the User Manual?

We do not understand this comment, there is no mention of sensitivity analysis on page 6029, line 29.

11. page 6034, line 24: Figure 4 shows: no: I cannot detect this in figure 4.

The text was changed to make the point more clear:

For instance, temperate climate Cfa covers the eastern regions of the country stretching from the north-east to south-east. It is characterised by the greatest variation in rainfall and its relative importance in recharge estimation. The higher values are related to the most northern modelled points that are similar to in tropical climate (Aw), while the lowest values are found for the most southern modelled points that are similar to under arid climate (BSk) (Figure 4).

12. page 6035, line 4-5: (note that . . . climate zones).: why not?

In the regions with Cfb and Csa/b climate types heavy soils do not occur, so analysis was not conducted for this soil type within this region.

13. page 6035, line 17: R2 P>0.7: is this strong? Note that the symbol R2 P is explained later in page 6037, line 19-20. . . Earlier is better.

The R2 definition and the ranges of the correlation level will be added to the text.

14. page 6036, line 2: Under similar annual rainfall R2P is greater in the climate types with winter dominated rainfall (Cs) for all combinations of soil and vegetation.: but Csa and Csb are not shown in K=0.01 md-1. . . Consider this.

The following changes will be made to the text

. . . for all combinations of vegetation and soil, occurring within these regions.

15. page 6036, line 23-26: why only chosen for Cs an Aw (perennial and K=1 md-1)? What can be said about other zones, locations and K's?

These zones are characterised by the largest (Cs) and least (Aw) proportion of the winter rainfall, so they provide the most extreme differences in rainfall seasonality. The perennial vegetation is the dominated land cover class in these regions, while plots for K=1 md-1 K=0.1 md-1 (and heavy soils are not presented in Cs zone) convey a similar message, so we did not want to duplicate the illustration. We will edit the text in the manuscript to address adding similar explanations.

16. page 6037, line 19-25: very long sentence. Make it readable.

page 6038, line 15: K=0.001 md-1?

Noted

17. page 6041, line 14: Section 5.3 Implications for climate change studies. Should this section not be positioned earlier in the paper? As context of the research?

There are some statements in Introduction related to the importance of recharge specifics under current climate in order to define the climate change impact on them. I believe the section in question could be in the beginning of the paper, but we believe this paper is mainly about the specifics of recharge in various climate zones (at least in 8 of them) under current climate, and the applicability of the result to climate change studies is secondary, this is why it was brought up in discussion only.

18. page 6042, line 14-16: However, for the majority of the considered climate types the total annual rainfall had a weaker correlation with recharge than the rainfall parameters reflecting rainfall intensity.: and what about the other climate types?

The changes to this point will be made as follows

Annual rainfall is a major factor influencing recharge. However, for the majority of the considered climate types recharge shows a greater dependency on the rainfall parameters reflecting higher rainfall intensity (<). The exceptions are related to the tropic Aw climate type where the majority of rainfall event are of high intensity (and is particularly high) and arid BSk where the majority of rainfall event are of low intensity (and is particularly low)

19. page 6050: Adapted from Barron et al. (2011).: what is new here? (see my major concern 1).

This is only an illustrative material, which aims to provide spatial information on the climate types in Australia

20. page 6061: (a) K=1 md-1 and (b) K=1 md-1. The same?

Noted

21. Can the author also elaborate about the other 7 Climate zones? Upscaling the results for the considered 8 ones? If not, why not?

It may be useful to point out that the main climate zones covers more than 97% of the continent. However it still may be useful to add some discussion towards this point in a line that the recharge and climate parameters relationship in those zones are likely to be similar to those in the surrounding major climate zones

22. Throughout the paper, punctuations (.) are sometimes forgotten, e.g. on page 6030, lines 21 and 22.

Noted

Barron, O.V., Crosbie, R.S., Charles, S.P., Dawes, W.R., Ali, R., Evans, W.R., Cresswell, R.G., Pollock, D., Hodgson, G., Currie, D., Mpelasoka, F.S., Pickett, T., Aryal, S., Donn, M. and Wurcker, B., 2011. Climate change impact on groundwater resources in Australia, Waterlines Report No 67, National Water Commission, Canberra. Crosbie, R.S., Dawes, W.R., Charles, S.P., Mpelasoka, F.S., Aryal, S., Barron, O. and Summerell, G.K., 2011. Differences in future recharge estimates due to GCMs, downscaling methods and hydrological models. Geophysical Research Letters, 38(11): L11406. Crosbie, R.S., Jolly, I.D., Leaney, F.W. and Petheram, C., 2010a. Can the dataset of field based recharge estimates in Australia be used to predict recharge in data-poor areas? Hydrology and Earth System Sciences, 14(10): 2023-2038. Crosbie, R.S., McCallum, J.L., Walker, G.R. and Chiew, F.H.S., 2010b. Modelling the climate change impact on groundwater recharge in the Murray-Darling Basin. Hydrogeology Journal, 18(7): 1639-1656. Crosbie, R.S., Pickett, T., Mpelasoka, F.S., Hodgson, G., Charles, S.P. and Barron, O.V., 2012a. An assessment of the climate change impacts on groundwater recharge at a continental scale using a probabilistic approach with an ensemble of GCMs. Climatic Change, DOI: 10.1007/s10584-012-0558-6. Crosbie, R.S., Pollock, D.W., Mpelasoka, F.S., Barron, O.V., Charles, S.P. and Donn, M.J., 2012b. Changes in Köppen-Geiger climate types under a future climate for Australia: hydrological implications. Hydrol. Earth Syst. Sci., 16(9): 3341-3349. Crosbie, R.S., Wilson, B., Hughes, J.D., McCulloch, C. and King, W.M., 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. Agricultural Water Management, 95(3): 211-223.

Dawes, W., Zhang, L. and Dyce, P., 2004. WAVES v3.5 User Manual, CSIRO Land and Water, Canberra. Dawes, W.R., Gilfedder, M., Stauffacher, M., Coram, J., Hajkowicz, S., Walker, G.R. and Young, M., 2002. Assessing the viability of recharge reduction for dryland salinity control: Wanilla, Eyre Peninsula. Australian Journal of Soil Research, 40(8): 1407-1424. Johnston, R.M., Barry, S.J., Bleys, E., Bui, E.N., Moran, C.J., Simon, D.A.P., Carlile, P., McKenzie, N.J., Henderson, B.L., Chapman, G., Imhoff, M., Maschmedt, D., Howe, D., Grose, C., Schoknecht, N., Powell, B. and Grundy, M., 2003. ASRIS: the database. Australian Journal of Soil Research, 41(6): 1021-1036. Kim, J.H. and Jackson, R.B., 2012. A Global Analysis of Groundwater Recharge for Vegetation, Climate, and Soils. Vadose Zone J., 11(1). McCallum, J.L., Crosbie, R.S., Walker, G.R. and Dawes, W.R., 2010. Impacts of climate change on groundwater: A sensitivity analysis of recharge. Hydrogeology Journal, 18(7): 1625-1638. Peel, M.C., McMahon, T.A., Finlayson, B.L. and Watson, F.G.R., 2001. Identification and explanation of continental differences in the variability of annual runoff. Journal of Hydrology, 250(1-4): 224-240. Penman, H.L., 1967. Evaporation from forests: a comparison of theory and observation, International symposium on forest hydrology, Permagon Press, Oxford, England, pp. 373-380. Petheram, C., Walker, G., Grayson, R., Thierfelder, T. and Zhang, L., 2002. Towards a framework for predicting impacts of land-use on recharge: 1. A review of recharge studies in Australia. Australian Journal of Soil Research, 40(3): 397-417. Salama, R., Hatton, T. and Dawes, W., 1999. Predicting land use impacts on regional scale groundwater recharge and discharge. Journal of Environmental Quality, 28(2): 446-460. Slavich, P.G., Walker, G.R., Jolly, I.D., Hatton, T.J. and Dawes, W.R., 1999. Dynamics of Eucalyptus largiflorens growth and water use in response to modified watertable and flooding regimes on a saline floodplain. Agricultural Water Management, 39(2-3): 245-264. Wang, H.X., Zhang, L., Dawes, W.R. and Liu, C.M., 2001. Improving water use efficiency of irrigated crops in the North China Plain - measurements and modelling. Agricultural Water Management, 48(2): 151-167. Wu, H., Rykiel, E.J., Hatton, T. and Walker, J., 1994. An integrated rate methodology (IRM) for multi-factor growth rate modelling Ecological Modelling, 73(1-2): 97-116. Xu, C., Martin, M., Silberstein, R. and Smetten, K., 2008. Identifying souirces of uncertainty in groundwater recharge estimates using the biophysical model WAVES., Water Down Under, Adelaide, Australia. Yang, Y.H., Watanabe, M., Wang, Z.P., Sakura, Y. and Tang, C.Y., 2003. Prediction of changes in soil moisture associated with climatic changes and their implications for vegetation changes: WAVES model simulation on Taihang Mountain, China. Climatic Change, 57(1-2): 163-183. Zhang, L. and Dawes, W., 1998. WAVES - An integrated energy and water balance model. Technical Report No. 31/98, CSIRO Land and Water, Canberra. Zhang, L., Dawes, W.R. and Hatton, T.J., 1996. Modelling hydrologic processes using a biophysically based model–application of WAVES to FIFE and HAPEX-MOBILHY. Journal of Hydrology, 185(1-4): 147-169. Zhang, L., Dawes, W.R., Hatton, T.J., Hume, I.H., O'Connell, M.G., Mitchell, D.C., Milthorp, P.L. and Yee, M., 1999. Estimating episodic recharge under different crop/pasture rotations in the Mallee region. Part 2. Recharge control by agronomic practices. Agricultural Water Management, 42(2): 237-249.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 6023, 2012.

Water Vegetation Energy and Solute Modelling (WAVES)

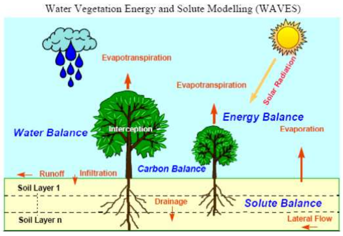

Fig. 1.3: Conceptual diagram showing the major processes modelled by WAVES.

Fig. 1.