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Hydrology and Earth System Sciences Discussions

Interactive comment on "A conceptual model of flow to the Waikoropupu Springs, NW Nelson, New Zealand, based on hydrometricand tracer (^{18}O, Cl, ^{3}H and CFC) evidence" *by* M. K. Stewart and J. T. Thomas

Anonymous Referee #2

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A conceptual model of flow to the Waikoropupu Springs, NW Nelson, New Zealand, based on hydrometric and tracer (O-18, Cl, H-3 and CFC) evidence. hessd-2007-0039 (Stewart, Thomas)

General Comments:

This paper delivers an original and highly interesting analysis of a groundwater flow and springs karstic system in New Zealand, bringing together dissolved hydrochemical (conservative tracer), stable isotopic, and geochemical residence time indicators to

back out an interpretation of a double, dual-porosity system for the principal Arthur Marble Aquifer (AMA). The authors have adopted and adapted a modelling framework typically used for catchment-scale karstic-type aquifer analysis, involving interaction between two flow systems. For karstic-type systems typically this invokes a dual-porosity (fissured-porous) medium represented by a Dispersion Model interlinked with a fast drainage channels system represented by more Piston Flow model. The model interpretation suggests instead two interlinked dual-porosity systems for the AMA. Whilst the modelling work is solidly presented and the paper should be published in HESS (with some clarification and minor corrections as suggested for each section below), I do think that the manuscript could be improved if the hydrological/hydrogeological context of the work was given a little more emphasis to the current results and the physicality of the conceptual system presented. In the Results section, I would suggest e.g. separating here (Sub-section 4.1) what is previous evidence (which could be covered then under Section 2) from the estimates given in this current work ("We estimateĚ", "Our estimate Ě"). This would emphasise then the actual results and allow some focussed clarification and explanation here (Sub-section 4.1) of how recharge estimates were derived, as the method has not previously been covered in Section 3 but is then covered somewhat in Sub-section 4.2. Table 1 then might be discussed in Section 5. In terms of the physicality of the results, the permeabilities and porosities of the given aquifers (AMA, TLS, TVUGA) might be emphasised more to undergird the dual-porosity concept and the fissures dominance for the mobile water flow in the AMA particularly (hence use of a dispersion model). Again, the model fits suggest effective dispersion parameters (DP) for the two dispersion systems of the AMA (DP = 0.6 for the deep system; DP=0.12 for the shallow system) - so how reasonable are these in the context of the AMA or other karstic limestone systems ?

Specific Comments:

1 Introduction p.2, Section 1, para 1, line 4. Why not state both names for the Springs but resolve to use just the one term in the text. p.2, Section 1, para 1, line 6. Perhaps

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state eg mg/l Cl to define ‘brackish’ here. p.2, Section 1, para 2. Perhaps start the second paragraph with line 4 starting then as “The p.2, Section 1, para 2, line 2. Put ‘other’ in front of “interesting features”. p.2, Section 1, para 2, line 7. Put ‘some’ in front of “physical, hydrological, ”. This seems rather descriptive rather than summary detail of any important features (or identify here what parameters therefore covered previously as existing evidence). p.2, Section 1, para 3. Again this seems rather descriptive rather than summary detail (eg any transit times ?). I would have thought that whilst analysis does show hydraulic connection (as a pressure pulse) it doesn’t necessarily prove flows connection (which tracing could show). p.3, Section 1, para 4, line 1. Put as “’The current’ paper brings together ‘existing and new’ evidence ” p.3, Section 1, para 4, line 6. Perhaps move line beginning “tritium, CFC ” to end of line 4 (after “ For the AMA”).

2 Hydrogeological Setting p.3, Section 2, para 1, line 7. Use ‘most’ instead of ‘more’. p.3, Section 2, para 2. Since you have used AMA before why not define acronyms for each system (AMA, TLA, TVUGA) here and use them consistently then in text. p.3, Section 2, para 2, line 3. End line with ‘ related to their lithology/geology’. p.3, Section 2.1, para 2, line 1. Try ‘The AMA is the principal aquifer in the Takaka Valley area, developed in karstic Ordovician limestone.’ p.4, Section 2.1, para 1, line 3. Use ‘˜180 kmˆ2’ instead of “about 180 kmˆ2”. p.4, Section 2.1, para 1, lines 4 & 6. Put the bracketed area estimates directly after “covered”. p.4, Section 2.1 para 3. [n.b. refers also to Sub-sections 2.2 and 2.3]. Please give typical estimates of hydraulic conductivity (K) when talking about “permeable”, “impervious”, etc., media. In these sub-sections it would be useful to give summary detail of their hydrology/hydrogeology as existing evidence. p.4, Section 2.2 para 1, line 7. What are “small amounts” (or give supporting ref.).

3 Sampling and Methods p.5, Section 3.1, para 1, line 3. Delete “following methods outlined in”. p.5, Section 3.1, para 1, line 4. “Field-filtered” means 0.45 microns (um) ? “High-purity” means 2% ? p.5, Section 3.1, para 1, lines 8-10. Give reference(s)

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to general or standard methods. “auto” should be hyphenated here. p.5, Section 3.2, para 1, line 3. Insert ‘sample’ in front of “evaporation”. p.6, Section 3.2, para 1, line 2. Put as “Standard Mean Ocean Water”. Delete “water” after “standard” at end of line. p.6, Section 3.2, para 1, line 3. This is measurement ‘precision’ rather than “error” as it relates to replicability and not accuracy ? Is this a 1 sigma (1s) estimate .... better to put all precision and/or error estimates in text as 2 sigma (95% confidence interval) ? p.6, Section 3.2, para 1. Give (general) reference to O-18 principles in hydrology. p.6, Section 3.2, para 2, line 2. Use “Quantulus 1220 ultra-low background, Liquid Scintillation Counter”. p.6, Section 3.2, para 2, lines 3-6. Delete sentence starting “Measurement precision was greatly improved ”. p.6, Section 3.3, para 1, line 1. Put ‘ambient’ in front of “CFC”. p.6, Section 3.3, para 1, line 4. Cite references as (Busenberg & Pummer, 1992; Vanessa Fox (GNS Science), pers. comm.). You can refer to Vanessa Fox’s involvement and training by USGS in Acknowledgements. p.6, Section 3.3, para 1, line 9. Define UHP (%). p.7, Section 3.4, para 1, line 2. Use ‘This distribution of ages may be described ’. p.7, Section 3.4, para 1, line 4. HOW do you quantify the inputs to estimate effective recharge ? p.7, Section 3.4, para 1, line 5. put ‘effective’ in front of “recharge” and delete end of sentence “ the effects of the recharge process is considered below”. p.7, Section 3.4, para 1, line 10. Give general reference for convolution (eg Maloszewski ?). p.7, Section 3.4, para 2. Equns. 3a and 3b imply piston and exponential functions, respectively, whereas the text states exponential flow then piston flow. CHECK. p.8, Section 3.4, para 1, line 2. Note the use of the 1-D version of the ADE assumes therefore little effect of any transverse mixing. x is the ‘linear’ flow distance. p.8 Section 3.4, para 2, line 7. Identify Eq. 5 as therefore a simple two-component mixing model. Identify the 5 parameters needed (line 8). p.8 Section 3.4, para 3, line 6. ‘metamorphism’. p.8 Section 3.4, para 3. I feel it would read better if this whole paragraph were put BEFORE para 2 in this sub-section to emphasise why the DDM model might be adopted.

4 Results (see also Major comment above) p.9, Section 4.1. A lot of this section goes through the hydrological settings of the aquifers in the context of previous work, which

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I feel would be better placed as contextual material in Section 2. The actual Results are prefaced here by “We estimate ” etc. p.9, Section 4.1, para 1. Are there any discernible LAGS to these AMA recharge sources ? p.9, Section 4.1, para 2, line 3. WHEN do the lower reaches run dry ? Relate to other aquifers feeding rivers ? p.9, Section 4.1, para 2, lines 3-4. Perhaps move these first 3 sentences to before the line starting “Most of the flows ” (Line 8). p.9, Section 4.1, para 3, line 1. Is the Takaka River therefore seasonal (identify the seasons) ? p.9, Section 4.1, para 3, line 4. Refer to Figure 4 in general (not just Fig. 4a specifically) for relevant place names. p.10, Section 4.1, para 1, line 4. Mueller (1992). p.11, Section 4.1, para 1, line 2. Delete “ and subsequent investigations have not given further information”. p.11, Section 4.2, para 1, line 4. Use ‘reasonable characteristic averages’. p.11, Section 4.2, para 2, line 3. Use ‘any of the rivers studied’ p.11, Section 4.2, para 2, line 6. Replace “i.e.” with ‘e.g.’ p.11, Section 4.2, para 2, line 8. Replace “will be” with ‘should be’. p.12, Section 4.2, para 1, line 1. Where is the evidence for asides such as “(Much of the excess Ĕ.)”. (line 2) How are the averages weighted (precipitation amount ?). p.12, Section 4.2, para 2, line 3. Is the delta-18O value of -7.77ppt intra- or inter-annual (I suspect the latter as longer-term, give period) ? p.12, Section 4.2, para 3, line 4. Insert ‘annual’ in front of “average”. p.12, Section 4.3, para 3. How are delta-values to be corrected (cf. line 7, for the selection of winter rainfall) ? p.12, Section 4.2, para 4, line 1. Replace “negative” with ‘light’. p.12, Section 4.2, para 4, line 3. Delete “However”. p.13, Section 4.2, Para 1, line 4. What is the level of confidence for the Student t-test ? p.13, Section 4.2 Paras 3 & 4. If you are going to compare the flow-weighted means then what error bounds are you putting on the models to assess that there is a better fit and/or what goodness-of-fir criterion (cf. para 4, line 1 suggesting that the more complex model better matches the observed delta-values) ? p.13, Section 4.2 Para 4, line 10. Remove brackets around last sentence (rather than it presenting as an aside). p.14, Section 4.3. Why are hydrochemistries not discussed first to bolster the flow models and support then the stable isotope estimates (ie then moving logically through to the more sensitive system tracers) ? p.14, Section 4.3, para 1, line 5.

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replace “rocks” with ‘lithologies’. p.14, Section 4.3, para 2, line 1. If Ca, HCO3 and Sr show “effects of interaction with carbonate rocks” are these parameters also then indicators of water maturity (residence times) ? This is certainly seen in groundwaters in the UK Chalk. p.14, Section 4.3, para 3, line 1. If the major ions indeed suggest (conservative) mixing with seawater then this could be shown directly on Cl-correlation plots. p.14, Section 4.3, para 3, line 1. What does “low flow” and “high flow” mean (in relation to mˆ3/s) ? Does “low flow” represent therefore baseflow (supported therefore by the shallow system) ? p.14, Section 4.3, para 3, lines 3-5. Hand calculation would suggest the % mixing with seawater is given taking the Cl content of the freshwater effectively as zero ? p.14, Section 4.3, para 4, line 1. Do you not have delta-2H values to check for evaporative concentration effects ? p.14, Section 4.3, para 4, line 4. Use ‘The two end-member components of mixing ’ p.14, Section 4.3, para 4, line 5. What does “low Cl” and “high Cl” mean (in relation to mg/l) ? Reflect again here why the “deep system” is isotopically heavier end member. p.15, Section 4.3, para 1, line 1. Show the regression line equation and s(y,x) on Fig. 5b. Is this really a fit as the Shallow system seems to be an extrapolated end-member value ? pp.14 & 15. References to Figs. 5a & b. Looking at these plots I would suggest that in fact there are two sloped represented in these figures with samples Q$>$10mˆ3/s and delta-18O$>$-7.5ppt on shallower slopes ? Again, for Fig. 5b plot the characteristic seawater signature (scaled accordingly). Note in captions also that the plotted Main Spring and Fish Spring points reflect average values taken from Table 6. p.15, Section 4.4, para 1, line 5. remove brackets around sentence (so it’s not an aside). p.15, Section 4.4, para 2, lines 8-10. How does applying the recharge model of Table 4 get you the precipitation-weighted mean altitudes ? Has an altitude regression been applied to precipitation and/or delta-18O of precipitation (is this implied in para. 3) ? p.16, Section 4.4, para 1, line 3. How is it known that recharge is predominantly from sinks unaffected by evaporation ? p.16, Section 4.4, para 2, line 4. Perhaps state here the half-lives of the CFC’s. p.16, Section 4.4, para 2, line 9. What temperatures and atmospheric pressures of recharge have been used ? p.16, Section 4.4, para 3, points 1) & 2).

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How is it known that CFC's have not been subject to degradation or contamination ? Or are these presumptions for modeling purposes ? p.16, Section 4.4, para 3, point 3). It is likely that any subsurface samples (although less so for surface waters) does have an excess air component. The USGS approach using N2/Ar to define the excess air component (and RT, if you can presume the altitude/atmos. pressure of recharge) is fine if you can preclude any denitrification sources for N2. Is the argument then that because the CFC-11 ages are similar to H-3 then this presumption is reasonable ? Note that eg Herzberg & Mazor (J. Hydrol., 41: 217-231) suggest that sinks and sinkholes might be associated with excess air entrainment (point 4). p.17, Section 4.4.1, para 1, line 2. Measurements are given in Table 7 and NOT Table 6 as reported. p.17, Section 4.4.1, paras 2 & 3. Fig. 6a gives the time-series fit of the EPM, DM and DDM models (the latter invoked because of the inferred two-component mixing between a deep and shallow system from Fig. 5) to the time-series data of Table 7 for H-3. Fig. 6b could be clarified (in caption) as to what the y-axis ("Function") represents - how does this relate to eqns. Given in the text ? Is this an RTD of the range of models (n=?) fit to Fig. 6a under some given fitting criteria, and how are shallow and deep qualified here ? The SD is then the s(y,x) fit of the residuals about the model. p.17, Section 4.4.1, para 4, line 5. Use '' (i.e. close to an exponential model where f=1), ' p.17, Section 4.4.1, para 4. Could the summary details of the model fits for Main Spring (and Fish Spring) be tabulated and referred to as necessary. p.18, Section 4.4.1, para 2. Could the explanatory material (lines 1-4) not be included earlier on introducing the use of CFC's (p.16). p.18, Section 4.4.1, para 3. Does the Result that CFC-12 has younger age estimate suggest that there might indeed be an excess air component ? p.19, Section 4.4.2, para 1, line 6. Why is an error of +/-0.2 assigned to the parameter b (how is it estimated (also +/-0.1 for line 8) ? Refer to Table 8 for the Summary detail. p.19, Section 4.4.3, para 2, line 3. Use 'R. van der Raaij, GNS Science, pers. comm. 2006)'. p.19, Section 4.4.3, para 2, line 7. Why would zero tritium and CFCs imply 100-years residence time (at least) for the deep component. p.19, Section 4.4.3, para 3, line 5. Why is it reasonable to presume that the older water component comes

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from the porous matrix (how permeable is this ?). Are you implicating the primary fissures distribution/apertures at depth as the source/restricted permeability of the AMA at this depth. Is there other evidence of this (other than reference to the drawdown) ? p.20, Section 4.4.3, para 1, line 2. Remove the brackets around the statement about drawdown.

5 Discussion pp.21&22. paras 1&2 (each page). Could this information (essentially on classical systems) not be relayed in the Introduction section setting the general conceptual model of dual porosity aquifers and karstic systems. p.22, Section 5.2, para 1. It would be useful to give reason as why there might be development of two dispersion systems in the AMA, as implied by the two-component mixing of a young and old component (although this is posited later in Discussion). p.22, Section 5.2, para 1, line 4. Do you mean 'unlike that illustrated in Fig. 9a' or 'like that illustrated in Fig. 9b'. It is the latter which shows a double DP system; the former shows a 'classic' karstric system (DM interlinked with PM model). p.22, Section 5.2, para 1, lines 5-7. The two following sentences starting "Springs generally draw oin deeper " relate to the 'classic' dual-porosity systems discussed in the Section (5.1) above so perhaps move these sentences up. This then allows the next Section (5.2) to dwell on the difference from the 'classical' model. p.22, Section 5.2, para 2, line 2. I am not entirely clear why conduits (major solution channels) are invoked specifically unless it is to invoke focussed transport towards the springs complex (later the presence of the diorite sill at depth is invoked to deflect flow to the springs ?). The idea of a solution channel network is mentioned again on p.23, Section 5.2, para 1, line 2. But how is this seen in the modeling then ? p.22, Section 5.2, para 2, line 9. Use 'head potential' instead of "pressure". p.23, Section 5.2, para 1, line 3. "High piezometric levels" implies artesian conditions ? p.23, Section 5.2, para 1, line 4. Use '- on average about 80% ' p.23, Section 5.2, para 2, lines 4-7. Do you mean that for the dispersion system diffusive exchange is invoked between the (mobile water) fissures and the (relatively immobile water) porous matrix ? Or is it diffusion from channels (secondary fissures) ? How is this adopted in your modelling ? Why is it possible that older water is resident in " less

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accessible parts of the porous matrix". Surely the porous matrix is low-permeability and any exchange is then diffusively controlled rather than head-potential controlled. p.24, Section 5.3, para 3. Perhaps place this as first hypothesised explanation (which is rejected) before adopting second.

6 Conclusions p.25, Section 6, para 3, line 4. Does the system really "burst" upwards at the Main Springs complex ? p.25, Section 6, para 5, line 1. Use 'is likely to be' or 'is presumed to be' instead of "are believed to be" dependent on strength of evidence. p.25, Section 6, para 1, line 1. Use 'apparent paradoxical results' instead of "almost paradoxical results". p.25, Section 6, para 1, line 2. Use '(in contrast to most other karstic springs investigated elsewhere)' p.25, Section 6, para 1, line 5. Use 'A searating buried diorite intrusive '.

References p.26. Bergmann et al. Any Editors for the volume ? p.27. Morgenstern, Taylor. pp. numbers ? p.27 Rapier. pp. size ?

Tables Table 1. Identify in caption that "This work" refers to Table 4 ? Table 3. what do the bracketed numbers mean after groundwater sample names (you already havbe unique identifier numbers, and these are not used/identified on any figure ?) Table 4. Identify Mueller as (1992) and Edgar as (1998). "See conceptual model below" ? Perhaps identify section in text, and refer to Eq.4 for (b). Table 5. Give Charge Balance errors to evaluate the data quality if these are full hydrochemical analyses (or are they summary data ?). Table 7. Cl data is given too (from where - locality ?)

Figures Fig. 1. Note specifically the diorite sill in caption. Fig. 6b. What does the y-axis ("Function") represent ? Fig. 9. Identify on (a) and (b) where the conceptual systems are e.g. dispersion versus piston-flow.

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