We would like to thank anonymous referee #1 for his/her very useful comments. The comments have helped us to clarify the paper, and have added interesting aspects to it. Our response to the comments below:

1) The exponential fraction of the applied exponential piston flow model is not critical to the age interpretation results. We have compared the age interpretation results for 70, 80, and 90% of exponential flow within the EPM. See table below (MTTs in years):

Date	MTT for		
	70%	80%	90%
	EM within EPM		
14/07/2004	4	4	4
1/02/2005	35	34	32.5
27/08/2007	2.5	2.5	2.5
26/03/2008	127	157	174
24/04/2008	40	39	38
4/06/2009	4.5	4.5	5
13/04/2010	91	87	90

We used this model because it produced good matches of long-term tritium data in similar hydrogeologic situations. This is explained in the paragraph following p.4738 line 11.

According to the suggestion of referee #1, we have compared the parameters of the piston-flow-section of the total flow with the hydraulic parameters of the unsaturated zone, with the assumption of piston-flow in the unsaturated zone. The comparison has the following result which we added as a new section on page 4743, line 20. For better illustration, we also added another figure (9b) with a cross section perpendicular to the stream (see below). At this stage we are uncertain if this new section should be included in the manuscript in full length or in a shortened version because the overall emphasis of the manuscript is not on piston versus exponential flow:

8 Piston flow fraction and unsaturated zone

Matching the measured tracer (tritium) output data via a transfer function to the known input data allows us to establish the age distribution parameters of the transfer function. It does not allow us to directly establish where in the total flow volume of the hydrologic system the various parts of the flow models apply. The fraction of transit time through the piston flow part of the total flow volume of the exponential piston flow model (EPM), however, can be calculated as TT_{PF} = MTT x (1 – f), with MTT the mean transit time through the total flow volume, and f the fraction of exponential to total flow volume. In the following we are comparing the piston flow part of the total volume with the depth of the unsaturated zone to estimate the maximum fraction of exponential flow within the EPM.

In the unsaturated zone it is commonly assumed that water percolates vertically downward and is best approximated by piston flow (PF) (Cook and Boehlke, 2000). Even though soils can be anisotropic, predominantly vertical flow can be assumed, with mixing of water limited to water parcels that entered the surface only days, weeks, or months apart. Such mixing of water of similar age in the unsaturated zone is negligible compared to the mixing in the total flow system where, for example, at the discharge point of a groundwater system, water flow lines with years, decades or longer age differences can converge.

The minimum fraction of PF within the EPM may be estimated by comparing the depth of the unsaturated zone with the flow length of PF within the EPM using the hydraulic parameters of the unsaturated zone. The flow length of the PF fraction of the EPM should be large enough to account for at least the thickness of the unsaturated zone.

The parameters for calculating the length of the PF path within the EPM (L_{PF}) are shown in Table 3. With the flow velocity in the unsaturated zone (FV_{UZ}), $L_{PF} = TT_{PF} \times FV_{UZ}$. At the time of minimum thickness of the unsaturated zone at high winter baseflow, the calculated TT_{PF} at the catchment outflow weir is 0.50 years for an EPM with 80% exponential flow. With FV_{UZ} assumed to be constant, a measured recharge of 0.45 m/year (annual total flow volume / catchment area), and an effective porosity of 0.16, the calculated FV_{UZ} is 2.8 m/year. The effective porosity was estimated as the weighted average of water held at 0–1500 kPa tension in the subsoils of three sites representing the soil types in the catchment (Stenger, unpublished). Using these values, then L_{PF} = 1.41 m. This length of piston flow of 1.41 m is close to the average thickness of the unsaturated zone in the wet season of 1.38 m (weighted average of three monitoring sites representing major soil types).

A higher fraction of exponential flow within the EPM would result in $L_{PF} < 1.41$ m, which would result in insufficient PF length because at the very least the flow through the 1.38 m thick unsaturated zone would be required to be piston flow. With these assumptions, the maximum fraction of exponential flow within the total flow volume of the EPM is 80%.

Clearly, the significantly larger length of PF compared to the thickness of the unsaturated zone in summer low flow conditions indicate that at least in summer considerable piston flow also occurs in the saturated zone, along parallel flow lines. L_{PF} would reach values of 20 m at summer baseflow (TT_{PF} = 7 years) and 84 m at summer drought conditions (TT_{PF} = 30 years) at the flow velocity of the unsaturated zone, but observations at several monitoring wells indicate that the average thickness of the unsaturated zone varies seasonally only by approximately 1.5 m.

Table 3. Hydraulic parameters for the Toenepi catchment at winter baseflow condition

Transit time through the piston flow part of the total flow volume	**TT_{PF}**	**$= MTT \times (1 - f)$**	**0.50 years**
mean transit time through the total flow volume	MTT		2.5 years
fraction of exponential to total flow volume	f		0.8
Flow velocity in the UZ	**FV_{UZ}**	**$= ABV / CA / EP$**	**2.8 m/year**
annual baseflow volume	ABV		6.8×10^6 m^3
catchment area	CA		15.1 km^2
effective porosity	EP		0.16
Length of piston flow path within the EPM	**L_{PF}**	**$= TT_{PF} \times FV_{UZ}$**	**1.41 m**
Avg thickness of UZ			**1.38 m**

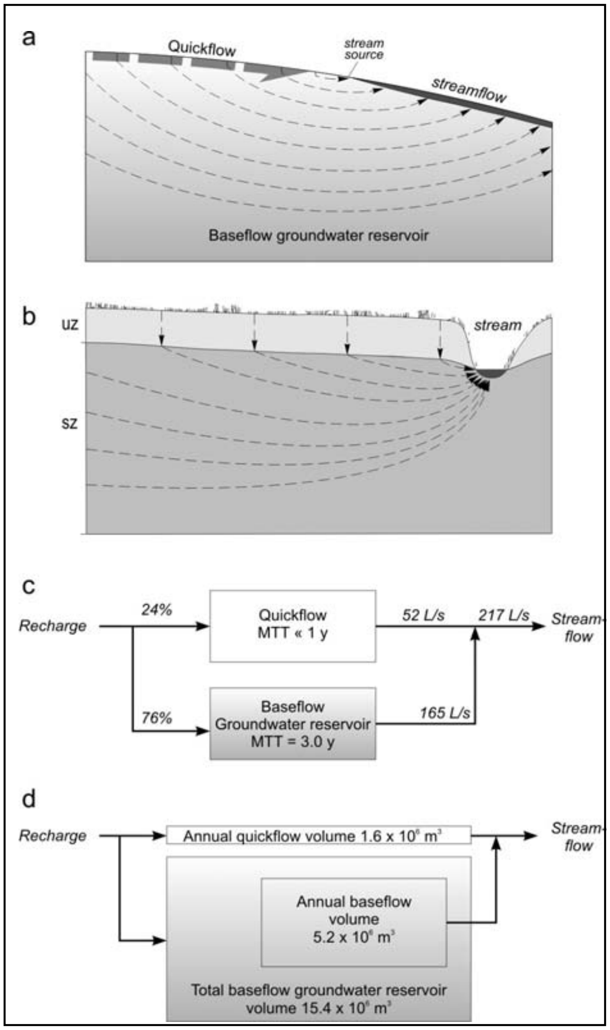

Figure 9. Conceptual flow model a) parallel to the stream, b) perpendicular to the stream, UZ-unsaturated zone, SZ-saturated zone, c) fractions of quickflow and baseflow, and d) comparison of water volumes, with the size of the boxes proportional to the volume of the various volumes.

2) We thank the referee for highlighting this mistake. We have corrected this and the corrected text and figure is below:

P.4738, line 27

For the tritium input function we used the tritium record from Kaitoke near Wellington (Fig. 1), with a scaling factor 0.9 to account for the latitude of the Toenepi catchment (400 km north of Kaitoke, Fig. 4a) (Stewart and Taylor, 1981; Stewart and Morgenstern, 2001). In addition, seasonal variation can affect the tritium concentration of recharge to the subsurface. For example, evapotranspiration preferentially removes summer precipitation during the recharge process. Using climate data from the meteorological station in the Toenepi catchment (Fig. 3) through 2004-2009, we estimated the monthly infiltration as the difference between precipitation and potential evapotranspiration (Fig. 4b). Potential evapotranspiration was calculated according to FAO-56 (Allen et al., 1998). The annual tritium input concentration C_{in} was then corrected by weighting the tritium concentration C_i by the estimated average infiltration I_i for the i-th month:

$$C_{in} = \frac{\sum_{i=1}^{12} C_i * I_i}{\sum_{i=1}^{12} I_i} \qquad (1)$$

The change in tritium input is insignificant, the average annual tritium concentration of rain and the corrected tritium input concentration are shown in Fig. 5c for comparison. This small difference would result in an age difference of only a few months. Therefore, uncertainties in the input correction process have an insignificant effect on the dating result and further refinement of the infiltration estimate is not necessary in these climatic conditions.

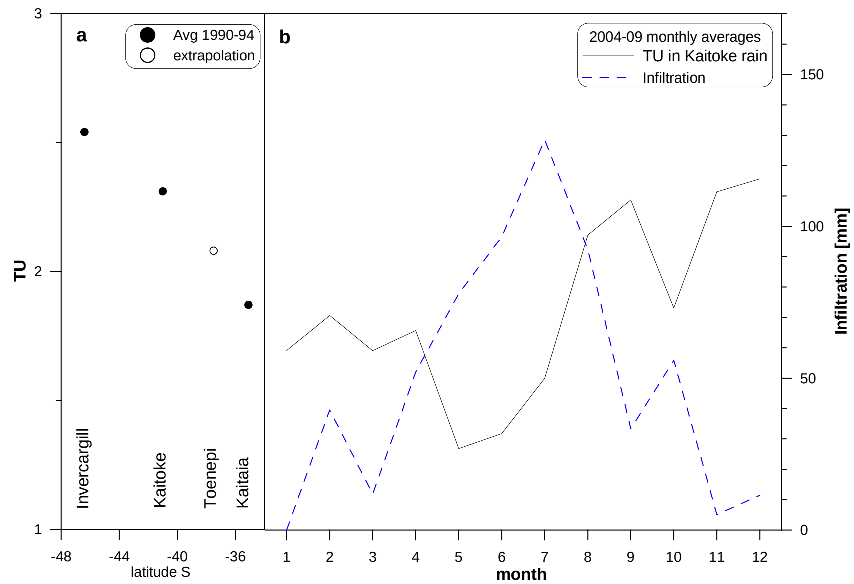

Figure 4. a) Average tritium concentration in rain of three reference stations (Invercargill, Kaitoke, Kaitaia) with the extrapolated value for Toenepi indicating a scaling factor of 0.9 relative to the Kaitoke reference record, and b) monthly variation of tritium concentration and infiltration (as estimated by precipitation – potential evapotranspiration) at Toenepi. Meteorological data are from the Lincoln Ventures Ltd meteorological station in the Toenepi catchment (see Fig. 3).

3) We think there is not yet a theory to support the statement that V(Q) would give information on how saturated the system was and how realistic the relation described by Eq. (2) is. However, the work presented in this paper (and in the recent paper Stewart et al. 2010) highlight that (1) streams often contain much older water components than is generally appreciated, and (2) the average age of stream water varies with flow. We believe that these findings will encourage catchment modellers soon to develop more advanced theories. We also show in this paper, that it is now also possible to test such new models with tracer methods.

4) We agree that the general trend in relationship of SiO2 as f(MTT) is logical and to be expected. However, the parameters in the equation are specific for each geological unit. This equation with its parameters cannot be applied to a different geological unit. We added the following text at page 4744 line 7:

   The correlation coefficient R^2 close to 1 in Eq. 5 shows that there is an excellent match between the measured data and the simulated data using equation 5 (Figure 8c). Such correlations with age over the range of centuries are still scarce in the literature, but will become more common in the future with further improvement of the tritium dating method.

The variation of NO_3 with Q(MTT) depends on the land-use history of the catchment, and on denitrification processes. For better clarification we modified several paragraphs starting at page 4745, line 13:

… according to water age and flow, with higher SiO_2 at times of old water discharge.

We often found phosphate in groundwater systems, in particular aquifers with significant concentrations of hydroxyapatite, to be derived from the aquifer materials (Morgenstern et al., 2004). Therefore a relationship similar to that for SiO_2 would be expected, with increasing PO_4 with water age. However, the data do not show a clear correlation of PO_4 to mean transit time and flow at Toenepi, because the dominant P source is PO_4 derived from fertilisers via surface runoff rather than PO_4 derived from the aquifer materials. However, the trend is visible to some extent, as the highest PO_4 concentrations are observed at the lowest flows with highest mean transit times (Fig. 8c).

A reasonable correlation with flow was found for nitrate by Wilcock et al. (1998). For more recent data (Wilcock, pers. comm.) we found for the periods 2004-05 and 2006-10 the following correlations:

2004-05: $NO_3\text{-}N = 0.642 \times Ln(Q) - 1.15$; $R^2 = 0.62$ (6a)

2006-10: $NO_3\text{-}N = 1.036 \times Ln(Q) - 2.21$; $R^2 = 0.80$ (6b)

The reasonable correlation of nitrate versus flow, and indirectly mean transit time, is due to nitrate originating from pastoral land use being transported via the groundwater flow path to the stream. This contrasts with the dominant surface runoff flow path for P.

Figure 8c shows the simulated NO_3 concentration in the stream (Eqs. 6a and 6b), together with the measured data. Clearly, high NO_3 concentrations occur at times of high flow with young water, while NO_3 is nearly zero at low stream flow with old water. The low nitrate concentrations in the older water are likely to be a result of a combination of effects: nitrate loading in the catchment was lower several decades ago and groundwater nitrate concentrations in the Toenepi catchment are substantially affected by denitrification, particularly in the deeper groundwater (Stenger et al., 2008). Redox profiles in multi-level wells revealed that the upper, younger groundwater layer is oxidised and contains nitrate, while the deeper, reduced groundwater is nearly devoid of nitrate (Stenger et al., in preparation). Knowing the variation of NO_3 with mean transit time enables an improved understanding of the time lags and transfer of nutrients from catchments into streams to be gained.

5) We have corrected this mistake.