

Response to the Comments of Anonymous Referee #2

We would like to thank anonymous Referee # 2 for his/her constructive comments. Our responses are:

Specific Comments

The main focus of this paper was to illustrate the use of radon in investigating groundwater and surface water (GW-SW) interactions at a catchment scale. By including hydrograph separation technique and chloride mass balance in the study, we wanted to assess the applicability of these complementary methodologies in the Victoria alpine catchments. Radon is a good tracer of groundwater inflows, but radon data is not often available. On the other hand, major ion chemistry data and river discharge are routinely measured in Australia by the state governments. Using commonly measured parameters to study GW-SW interactions will be useful to water resource managers who may want to include GW-SW interactions as part of their investigative study but do not have the resources and technical expertise to measure radon. This explanation was briefly discussed on Page 5238, Lines 10-11 and will be emphasized in the revised paper.

Other tracers, such as major ions, oxygen-18 and deuterium, were considered to estimate groundwater input in the Ovens River. Sodium concentration was considered, but the high Na:Cl ratios in the river samples from the upper catchment, as discussed on Page 5253, Lines 24-26 and Page 5237, Lines 21-27, suggests that there is an additional sodium input in addition to rainfall. On the other hand, there are no occurrences of halite in the Ovens Catchment, and chloride in groundwater and surface water is derived from rainfall. Since chloride behaves conservatively in this catchment, chloride was therefore chosen a groundwater tracer in this study. Oxygen-18 and deuterium were measured in groundwater and surface water: the Ovens River has $\delta^{18}\text{O}$ values of -5.8 to -7.5 ‰ and $\delta^2\text{H}$ values of -37 to -44 ‰, whereas the groundwater in the catchment has $\delta^{18}\text{O}$ values of -4.5 to -7.5 ‰ and $\delta^2\text{H}$ values from 30 to -40 ‰. The ranges of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ for groundwater and surface water overlap, making them less useful in tracing groundwater inflows in the Ovens River. The oxygen-18 and deuterium data was not present in the paper as they added little.

More statistically based methods, such as End Member Mixing Analysis (EMMA) require knowledge of the chemical composition of the several possible water sources for the stream. Water composition data for rainfall and soil water were not collected for this study because it is difficult to collect a representative data for these water sources in a large catchment, such as the Ovens Catchment. In addition there are no bores that sample the unsaturated zone, making it difficult to characterise the composition of interflow. The successful applications of EMMA have been in relatively small catchments where the compositions of the various water components are likely to be relatively constant; it is difficult to apply this technique to larger catchments such as the Ovens which has heterogeneous geology and soils.

As stated previously, the focus of this paper was to demonstrate the use of radon in studying groundwater inflows at a catchment scale. Thus, the bulk of the discussion in the paper focused on radon and compared the radon derived baseflow fluxes with those derived from a more established method, hydrograph separation technique. It was not our intention to convey the idea that the radon derived estimates are the 'true' values of baseflow contribution. In fact, uncertainty analysis

of gas exchange rate constant (k) and radon concentration of groundwater (C_i), and impact of ignoring hyporheic exchange were included in the paper to illustrate the possible errors in using radon to estimate baseflow flux. The discussion, particularly Section 5.5, will be revised to avoid this issue.

Figure 9 was an attempt to illustrate the difference between radon-derived baseflow fluxes and chloride-derived baseflow fluxes. Using a scatter plot in analysing the discrepancy is a good suggestion. If it is found useful, scatter plots of radon- vs chloride-derived groundwater influxes for all of the data points will be included in the revised paper.

Figure 7 does show the highest groundwater inflow occurs in the middle catchment, rather than in the upper catchment. Two explanations account for this observation. 1) Basement highs that occur between 65 and 72km deflect groundwater flow, inducing upward head gradients and causing the high groundwater influxes; 2) Despite the widening of the valley, the river is moderately incised with steep banks. Moderately high gradient is still maintained between the watertable and the river, producing the observed high groundwater fluxes. Another important observation from figure 7 is that except for some of the large baseflow input, baseflow input in the lower catchment do not vary much between high flow (figure 7a) and low flow conditions (figure 7b). On the other hand, baseflow in the upper catchment (and to a degree, in the middle catchment) increases at high flows by more than 50%. This reinforces the finding that the hydrological loading of groundwater in the fast responsive aquifers in the upper and middle catchments following recharge induces a greater amount of baseflow in these catchments. These interpretations will be clarified in the final paper.

The excessive influxes of groundwater in the middle catchment shown in figure 8 are caused by calculation errors. Wrong values of river length were used to multiple the baseflow flux values obtained from the radon mass balance. The revised figure 8 shown below generally show a much more gradual increase in cumulative baseflow except for the locations where the basement highs occur, such as the distance between 65 and 72km. The strong saw-tooth pattern in groundwater fluxes shown in figure 7 may be caused by how the graphs present without showing data points of the sampling location. The revised figure 7 (with the data points) shows that groundwater influxes generally increase or decrease over several reaches. However, some particular sections of river do have a greater amount of baseflow due to their proximity to basement highs, such as distances between 65 and 72km, and between 166 and 188km. We also admit that the distance between sampling points in the lower catchment are much longer because of the difficult access to some of the flood plains.

As suggested by the reviewer, in addition to range, mean and/or standard deviation will be used in analysing baseflow fluxes and cumulative groundwater inflow whenever it is appropriate, adding value to the discussion. However, we would like to clarify that the range "18-70%" quoted by the reviewer on Page 5240, Line 26 does not refer to the percentage of cumulative groundwater inflow for the Owens catchment. The range refers the percentage of change in groundwater inflow rate per unit of stream length when the lower gas exchange constants were used. This will be clarified in the revised paper.

As indicated in the paper's title, the focus of the paper was to investigate groundwater inflow along the Owens River. The methods used in the paper can only quantify the amount of groundwater inflow into the river. The radon mass balance calculations did show some of the reaches in the

middle and lower catchments having zero values of baseflow, especially during high flow conditions. These reaches may be losing reaches. This finding also makes sense as the river height during high flow conditions is likely above the regional water, causing water to infiltrate the adjacent aquifer. The interpretation of reaches with zero values of baseflow was not clearly stated in the paper, and it will be added in the revised paper.

As indicated in the response to anonymous Referee #1, it is not practical to calculate groundwater fluxes accurately using groundwater heads and river heights in the study catchment. However, an attempt will be made to compare calculated groundwater inflows with the observed increase in discharge during baseflow conditions. Only some sections of the river can be done as some of tributaries are not gauged adequately.

The revised paper will certainly examine the results in a broader context. The Ovens Catchment share many similarities with other catchments in the Murray-Darling Basin in terms of catchment geomorphology. The results from this study can be applied to these catchments, providing a better understanding on the variability of river flows and assisting in maintaining adequate flows in the environmentally, socially and culturally significant basin in Australia. Furthermore, hydraulic loading in respect to groundwater inflow discussed in the paper can occur in other catchments with fast responding aquifers. The lesson learnt from reconciling the difference in baseflow fluxes derived from the three methods can also apply to other GW-SW interaction studies, not just to this study.

Technical Corrections

More references will be added to strengthen the arguments in the introductory section.

Page 5226, Line 12: "Hydraulic loading" refers to the rapid rising of groundwater level in response to recharge events. The rapid increase in watertable produces a high hydraulic gradient toward the river which in turn generates a significant amount of baseflow. The term will be defined in the final paper.

Page 5227, Line 7: "water in unsaturated zone" will be changed to "water in the unsaturated zone".

Page 5227, Line 21: "water budget" will be replaced by "hydrologic budget".

Page 5229, Line 16: The missing word "distribution" will be inserted into "temporal of GW-SW exchange".

Page 5230, Line 8: "pass" will be changed to "past".

Page 5231, Lines 3: "slit" will be changed to "silt".

Page 5233, Line 8 "TPS" is the brand name of the pH/EC multi meter used to measure EC in the field.

Page 5237, Line 10 "decrease" will be corrected as "decreasing".

Page 5237, Lines 21 – 24: The source of sodium is probably from weathering of silicate minerals materials in the unsaturated zone/soil in the upper catchment. See the response to anonymous Referee #1.

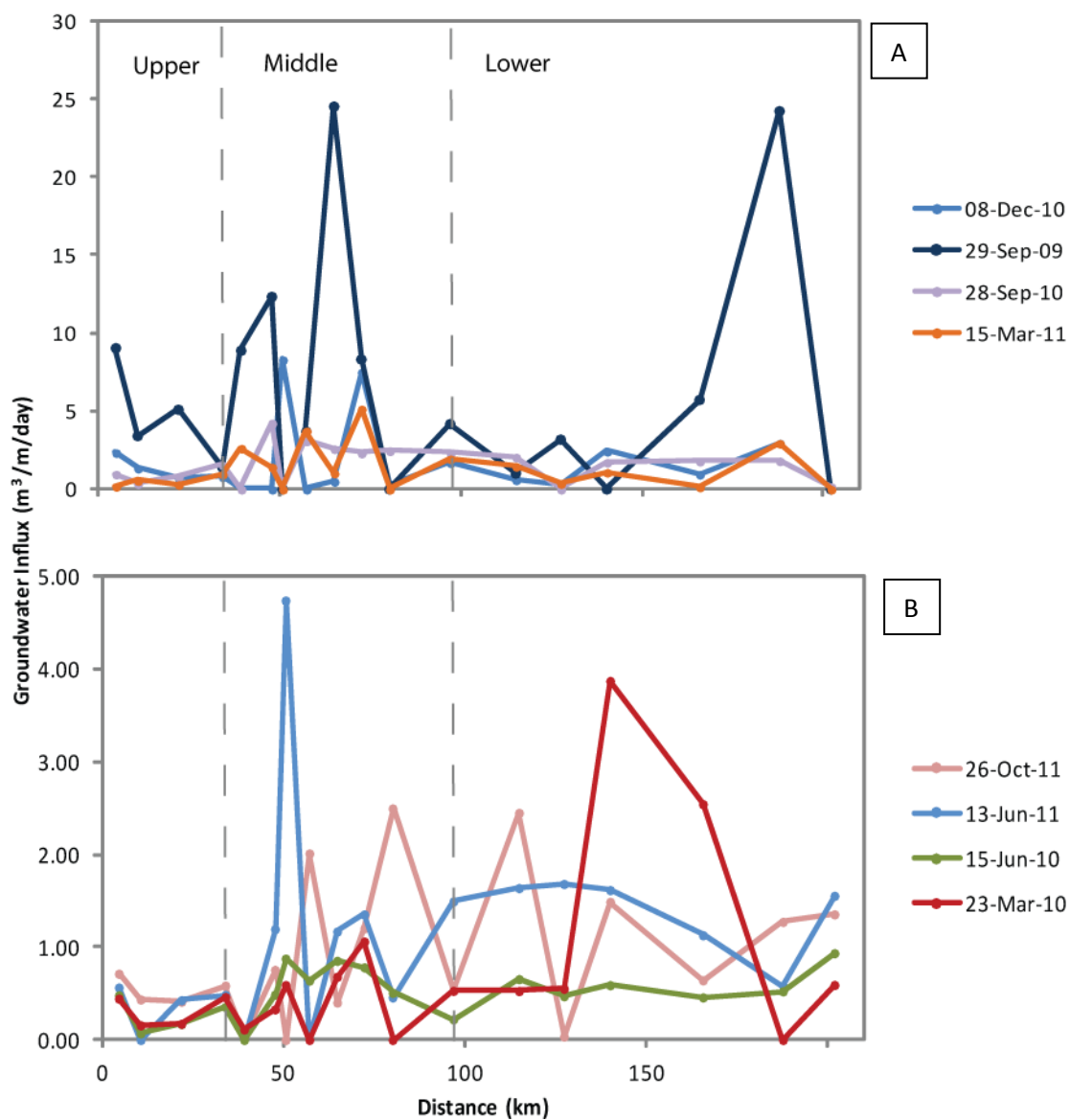
Page 5243, Line 17: "assuming" will be changed to "assumed".

Page 5243, Line 16: To make it more accurate, the sentence will be rewritten as “One method of hydrograph separation techniques is to employ low pass filtering to separate the slowflow component ...”

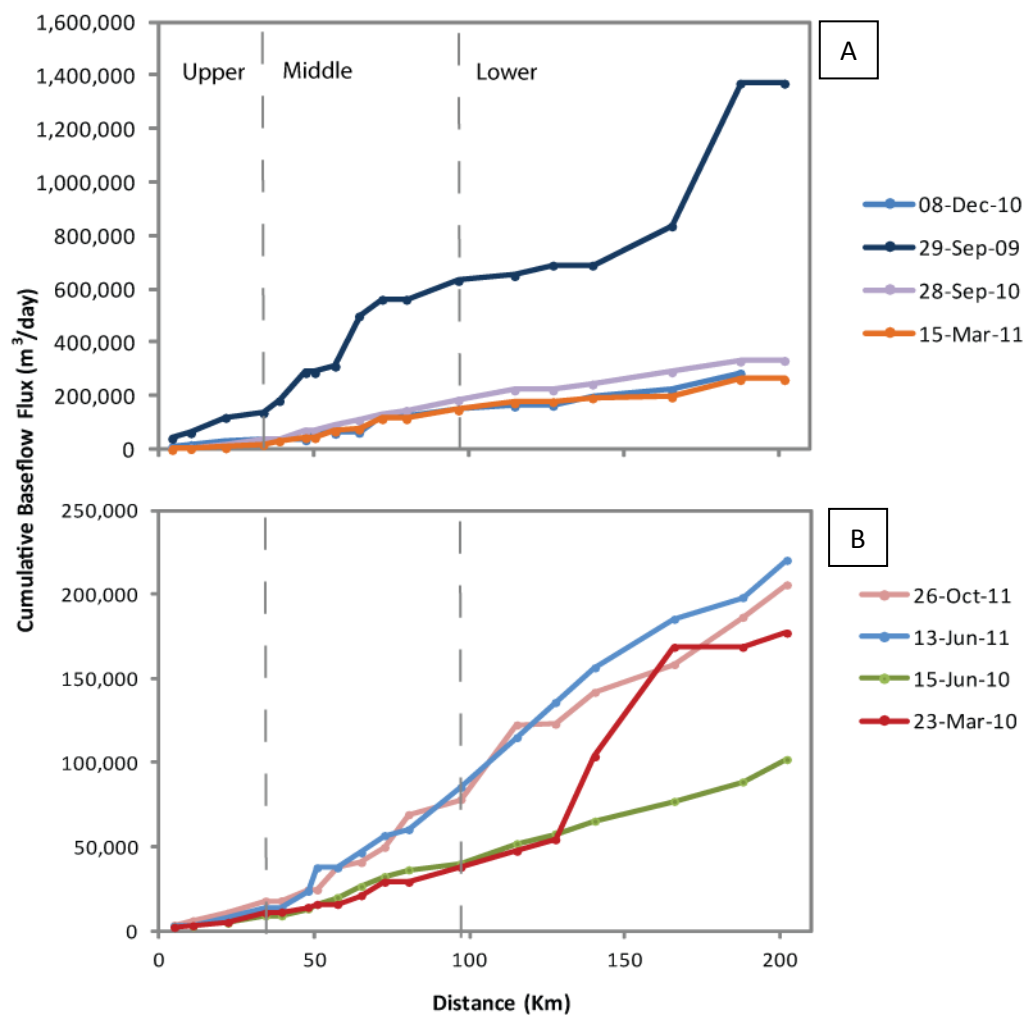
Page 5247, Line 1: The sentence will be written as “For instance, the discharge in December 2010 was greater than that in September 2009, and yet the cumulative groundwater influx for the December 2010 sample round was much lower than that for the September 2009 sampling round.”

Page 5247, Line 24: ‘do’ will be deleted. However, this section will be rewritten to avoid that notation that radon derived baseflow fluxes are the correct values. See Specific Comments above.

Supplementary data “nm” does stand for “not measured”, it will be defined in the revised paper.



Revised Figure 7. Groundwater influxes calculated from ^{222}Rn activities, based on high k values, in flow conditions of $4894\text{--}18\,520\text{ mL day}^{-1}$ (A) and of $995\text{--}2606\text{ mL day}^{-1}$ (B). High baseflows occur in the upper catchment and often increase during high flow conditions. High baseflows also occur 65–72 km and 166–188 km.



Revised Figure 8. Cumulative baseflow estimated from ^{222}Rn activities, based on high k values, in flow conditions of $4894\text{--}18\,520\text{ mL day}^{-1}$ (A) and of $995\text{--}2606\text{ mL day}^{-1}$ (B). High cumulative baseflow usually occur in high flow conditions.