We thank the editor and the two anonymous referees for their comments on this paper. We have considered their comments and make the following responses (in blue), which will be incorporated into the final version of the paper. The alterations in the manuscript have been highlighted in yellow.

Referee 1

1. First, there is no clear research question or hypothesis, which introduces the analysis and guides the reader through the manuscript: "In this study, the nutrient flux… was investigated…"; "Hence, the aim of this research was to investigate the nutrient flux within a series of such protected turloughs … whilst also examining the nutrient flux within the overall catchment surrounding them." These aims are very open and not specific enough to understand the concept and ideas behind this paper. The presented concepts of the different turlough systems could be used to generate such a conceptual frame for this study (and the study should focus on these systems alone).

Response

We agree now (in hindsight) with the assessment that the objective of the paper was poorly described and that focussing on the turlough systems is a better way to structure the paper. Hence, we will alter the text to refine the focus.

Currently the paper is structured as an investigation of the *turloughs* and the *catchment in general*. These two elements do not completely overlap which is probably why it appears somewhat disordered. The original intention of the paper was to answer the following question:

Are the temporary karst lakes of the Gort Lowlands subject to the same transformation processes as found in permanent lakes and do they impact the surrounding catchment. In other words, do the turloughs operate as sources or sinks of nutrients to the catchment?

As this objective was not clear in the original manuscript, the abstract, introduction, discussion & conclusions have been altered to focus on this issue.

Furthermore, based on the Referees' feedback of the manuscript, we feel that the paper has obviously done a poor job explaining the methodology and the purpose of each section. As such, we have included a new paragraph in the methodology to further clarify the objective, and steps taken in the study.

We also feel that the manuscript could be better served by a new title which could bring more focus to the surface-water groundwater interactions (i.e. the turloughs). For example:

Quantifying the Influence of Surface-water Groundwater interaction on nutrient flux in a lowland karst catchment

2. This unclear statement of research can be found throughout the manuscript. It took me quite a while to read the paper completely, though there was no clear lead to follow through the text. This means the paper needs to be restructured regarding clear objectives such as "…the mixing behaviour of different turlough systems". The chapters should not be structured according to the variables analysed within a chapter, but rather regarding the processes presented in a chapter.

Response
Again, we agree that the focus of the paper was unclear and the manuscript has been altered to fix this. However, regarding the suggestion to restructure the chapters by processes rather than variables, we are not sure whether that will help the clarity of the paper. As per comment 1, we have refocussed the paper to centre on the turlough processes (which included the removal of Section 5.2) and so feel that these alterations have addressed the unclear statement of research.

The processes themselves are separate for N and P. Thus any restructuring would still align the chapters separately for N and P. We thus feel that the structure of the paper is better served by treating them separately, rather than addressing the 'source or sink' in a combined N and P section in the conclusions.

3. Regarding the nutrient fluxes in the streams this paper did not shed enough light on governing processes. I suggest as treating them just as the upper boundary of the studied turlough-systems.

Response
This is a similar comment as made by Referee 2, and we agree that the monthly sampling in the rivers was not carried out at a fine enough resolution to enable a full characterisation of the nutrient loads in such flashy rivers draining the Old Red Sandstone Mountains. Thus the calculation of average loading rates, (and their mention in the discussion) has been removed. Instead, maximum observed loading rates, (i.e. upper boundaries) is stated, but not used for further analysis.

However, the mean river concentrations is still used as an input to the hypothetical model. This is deemed reasonable as the model does not require perfect observed data in order to convey the main concepts of the research.

4. I do not understand why the authors did not compare water level changes and concentration changes in the different turloughs quantitatively? There should be shown if +/-changes of water tables and concentrations are interlinked.

Response
The aim of this paper is to use the hydraulic conceptualisation of the turloughs (i.e. surcharge tanks & flow through systems, as shown in Figure 2) and to compare how nutrients would behave under such configurations using the model (to calculate conservative behaviour of the nutrients – i.e. pure dilution) compared to how nutrients behave in reality. In a surcharge tank turlough, once the turlough is flooded, the water remains unaltered and undiluted for the flooded period. This has been validated by various studies (see response to referee 2 comment 1). Thus, in such a surcharge tank turlough, the fact that concentrations are decreasing over time indicates that some losses/transformations are occurring.

These slow changes in concentration are certainly an indicator of some process occurring, but without more intensive studies, it is difficult to precisely associate these changing concentrations with a particular change in stage. The problem is that when a turlough stage increases, a volume of water with an unknown nutrient concentration has entered the turlough. This addition of water may increase or decrease the overall turlough nutrient concentration (and load) to a minor degree (or a large degree if the turlough was relatively empty at the start). Thus, while we are confident that nutrient concentrations are dropping due to transformation processes, we cannot isolate the inflows/outflows. Thus the influence of dilution cannot be ruled out and so a quantitative calculation is implausible.

However, if a turlough can be sampled at the start and end of a long constant recession, then it is known that no new water is entering the turlough. In this scenario, dilution can be ruled out and thus any changes in concentration must be linked with transformation processes. Thus, complete quantitative analysis can be carried out over a long recession periods (such as January-February 2012), as has been analysed in the discussion section.

5. There is no proper comparison of modelling results and observations. The authors state first (p 16, l24) that they compare the modelling results to the field data. Whilst on p17,l22 they state that observations could not be compared directly to the modelling results. They even avoid plotting modelling results and observations together in one single Figure (this could be done by normalizing the concentrations). Nevertheless they draw conclusions from the modelling and the literature. This could have been done without any of the field data. In this context it is not clear to me, how the authors could identify denitrification processes within the data (the decrease of concentrations could be caused by mixing processes as well: slower inflow of GW with low nitrate concentrations into the turlough combined with faster outflow of "high" concentrated turlough water).The authors have to find a way to compare the information in the data with the information in the model.

Response

Due to the inadequacies of monthly sampling, it was not attempted to use the model for a direct observed-modelled comparison. Instead, the model was used to present a hypothetical scenario, in order to observe the conservative behaviour of a nutrient input under the specific karstic conduit network configuration (i.e. this characterises the changes in concentration expected from a pure hydrological dilution perspective). We have a lot of confidence in the network configurations of the karst system in this area which has been developed over several years of research and development resulting in the hydraulic model that we use. This is the reason why an observed-modelled comparison was originally not shown on the same plot. However, as the Referee points out, a comparison with normalised data would be beneficial. As such, the model concentrations and observed concentrations have been normalised and presented on the plot together (it should be noted that the modelled concentrations have been altered according to comments from Referee 2 as discussed later).

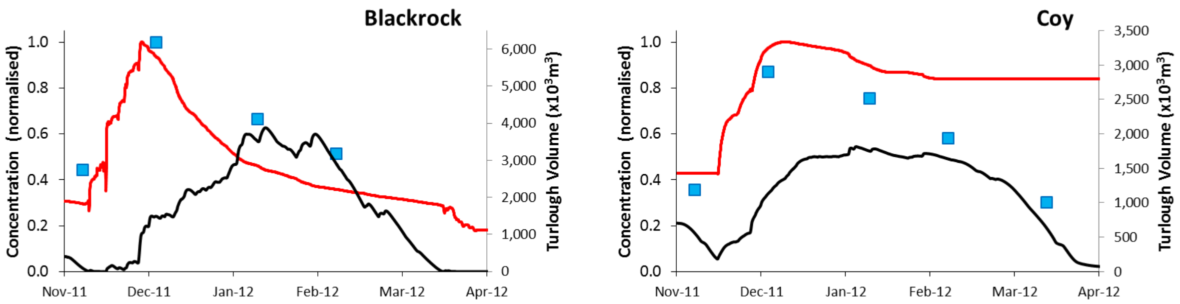

Figure A

With regards to identifying the processes in the turloughs, it is now clear that we had not explained the analysis well enough. The purpose of the observed-modelled comparison is to prove that processes are occurring (in the surcharge tank turloughs at least). Then the Discussion section elaborates on which process is causing the reduced concentrations.

For Blackrock and Coole turloughs, the mixing/dilution process that the Referee refers to is a likely reason for loss of nutrients as these turloughs are known to have a significant flow through component of their hydraulic regime. For the other surcharge tank-type turloughs however, there is a negligible flow-through component. Once the turlough fills, the water remains undiluted.

This can be confirmed by continuous Electrical Conductivity measurements taken at the only estavelle in Coy turlough over the 2012-2013 season (Figure B). These measurements, carried out as part of a PhD thesis (McCormack, 2014), show how constant the hydrochemical signal remains during flooded or recession periods. The only changes in EC are observed during flooding periods when the spring is in contact with new water. Thus, such constant, well mixed, behaviour in the turlough suggests that a process other than mixing/dilution is occurring. The likely process occurring in these turloughs is then discussed in the Discussion section of the paper (reference to this EC study has been added to the 'area description' section of the manuscript).

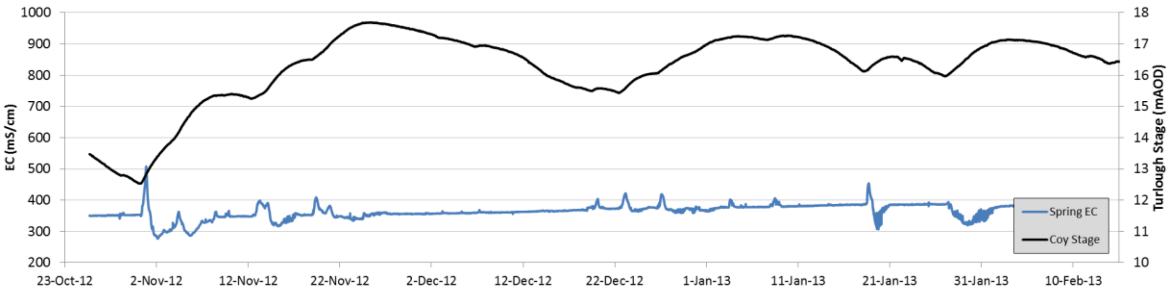

Figure B

Referee 2

General Comments

1 *The Sampling frequency of one month in karst terrain:*
Temporal high-resolution monitoring has proofed that in karst systems significant chances in nutrient transport often occurs in a time frame of hours to days (e.g. Lloyd et al., 2016; Mellander et al., 2013; Pu et al., 2011). The authors state that 'Monthly sampling of turloughs was deemed to be adequate to characterize the system as water is typically retained in the turloughs for long periods. However, for the rivers, monthly sampling only offers a snapshot of concentrations at the time of sampling. '(P 10243, line 5). Personally, I do not agree that the assumption 'monthly sampling of turloughs is adequate enough' can be made without any evidence. For example, if you look at the fluctuating stages over time (Fig. 4) (or the changes in the mean volume of the turloughs over time in Fig. 7 – or Fig. 14 in Gill et al., 2013, for the changes of the turlough water levels in the previous years) than it is more than likely that due to monthly sampling intervals a lot of significant concentration changes of the nutrients (due to dilution or mobilisation processes) are missed. The question is how reliable the temporal resolution is regarding the interpretations made in the manuscript. A higher frequency of sampling over time or e.g. the use of passive diffusion bags that are recording mean values of nutrient concentrations would be more reliable.

Response

The authors accept that nutrient transport in karst systems (particularly springs and other conduit-type sampling points) is often much too fast for monthly samples to capture. However, we believe that this is not the case in turloughs, especially the turloughs of the Gort Lowlands. These turloughs have been studied from a water quality perspective by different research groups since 2006. Over that period there have been several targeted studies on turloughs which have sampled at a much higher frequency. Indeed, the early research carried out by Gill (2005 to 2009) into these turloughs specifically evaluated nutrient concentrations fluctuations both temporally and spatially in order to optimise sampling methodologies (contained in Gill's PhD thesis (2010)). From spatial perspective more than 40 samples were taken in each turloughs at a range of locations and depths which showed the turloughs could broadly be considered fully mixed. Equally, samples were taken every 2 weeks from January to April in 2009 which confirmed that nutrient concentration levels only varied gradually. An example graph for Caherglassaun turlough is shown here in Figure C.

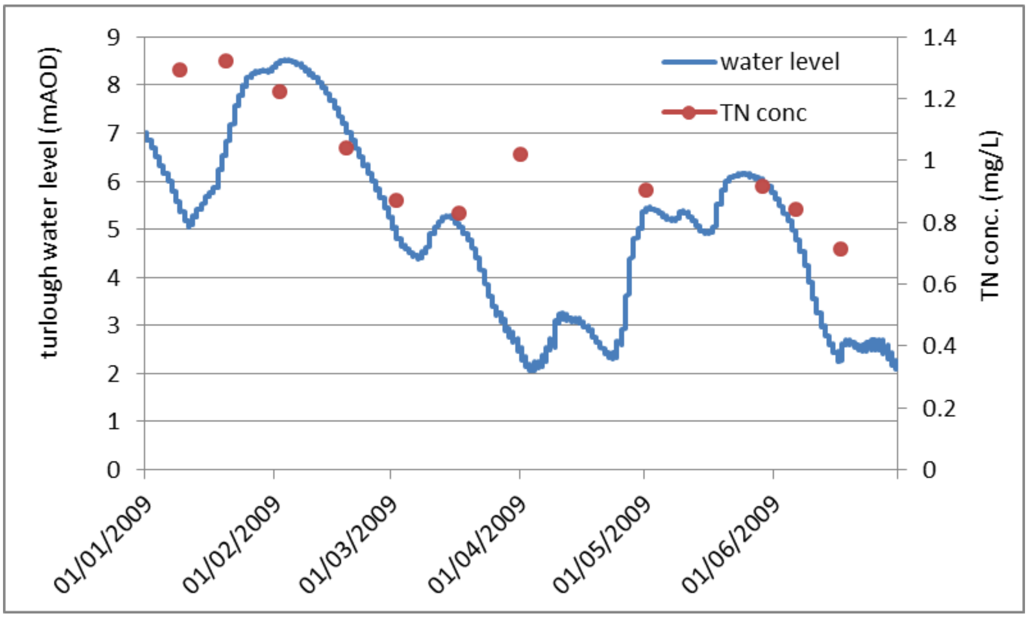

Figure C

Equally, another extensive research project into turloughs entitled *Turlough Hydrology, Ecology and Conservation* (Waldren et al., 2015) used monthly sampling of turloughs to study interrelationships between hydrology, invertebrates, plant communities and algae. This was a multi-disciplinary project carried out by environmental scientists, engineers, zoologists, botanists and ecologists and resulted in several peer reviewed publications a range of ecohydrological issues (e.g. Cunha Pereira et al., 2010, 2011; Kimberley et al., 2012; Porst et al., 2012 etc). Further unpublished data (in Waldren et al., 2015) as part of this project, has revealed similar patterns in 2006/07 in nutrient concentrations during recession (as to the patterns we are presenting in our paper) both for turloughs in the Gort lowland chain as well as for other turloughs outside of this area (particularly surcharge tank-type turloughs), which were studied as part of the extensive research project (reference to these studies has been added to the methodology section of the manuscript). An example, for the 2007 N profile in Caherglassaun is given in Figure D.

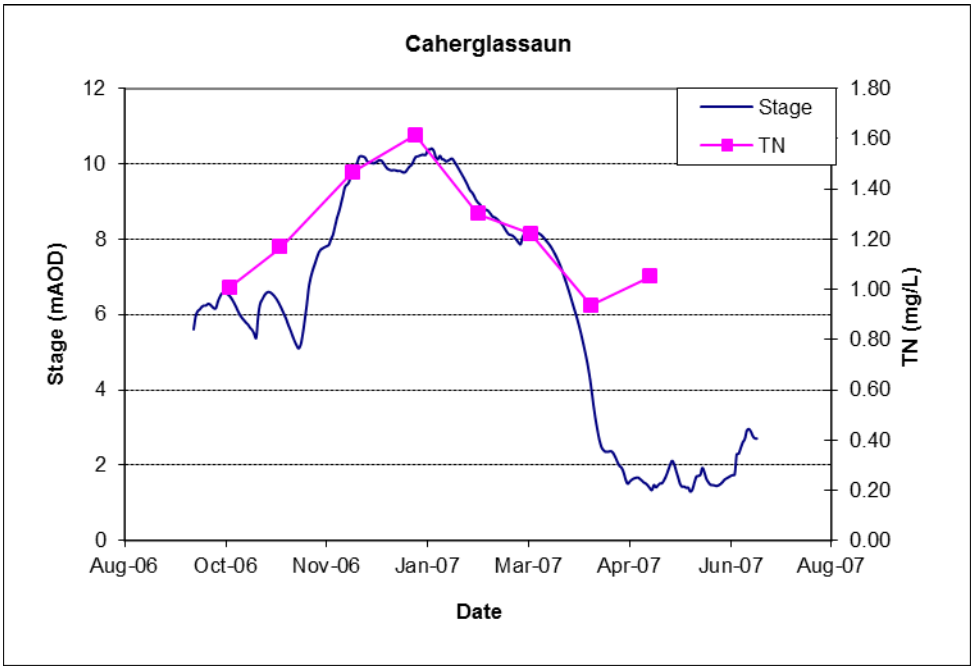

Figure D

While the water level (and nutrient load) in the turlough may change significantly over the flooding season, the nutrient concentrations do not due to the large dilution and dampening effects imparted on the inputs by each turlough (in addition to the cumulative dampening impacts of any upstream turloughs).

The only turlough that does not have any attenuation/dilution before water reaches it is Blackrock turlough. Thus, out of all the turloughs it is likely that the monthly sampling frequency is least robust there. However, this was addressed in the manuscript; for example, it is pointed out that denitrification can't be calculated in Blackrock turlough.

2 *In relation to the sampling frequency the validation of the model:*
In Fig. 9 (and in the manuscript itself) the validation of the model with the field data is missing. It should have been easy to plot the simulation plots together with the real nutrient concentrations. I also doubt that the model input of the river (SA1) in Fig. 8 is realistic in relation to the time chosen. The shape looks familiar as proven in a lot of studies, but the time frame is unusual (e.g. steady increase of concentration for 7pprox.. 1 month) (e.g. compare with Bende-Michl et al., 2013, or Schwientek et al., 2012). In Gill et al., 2013, there are 'final calibrated model results for Owneshree river section' for the area shown which also leads to the interpretation that the concentration input signal should be different. In general, the question remains: Could one sample once a month representative enough for the continuous, modelled curve?

Response

As per the response to Referee 1, observed (normalised) results have been added to Figure 9. It should be stressed that the model is not validated in the common sense for nutrient data. The model is already hydraulically validated, as shown in previous journal articles (Gill et al., 2013; McCormack et al. 2014). In this study, we are using the model (which assumes conservative nutrient behaviour) to present how conservative nutrients would behave in the turlough system when it is modelled as a network of pipes and tanks. The flow-through turloughs behave as expected by the model, but the fact that the surcharge tank turloughs do not, must therefore indicate other attenuation processes. These processes are then discussed in the Discussion section.

Regarding the model input signal in the river, we accept that it is unrealistic when compared to typical river nutrient signals. The reason for using that signal was to an attempt to incorporate recorded measurements into the model, even though the sampling interval was lacking. However, we acknowledge that this input signal was not realistic and so have changed the signal to a more realistic one (shown in Fig E).

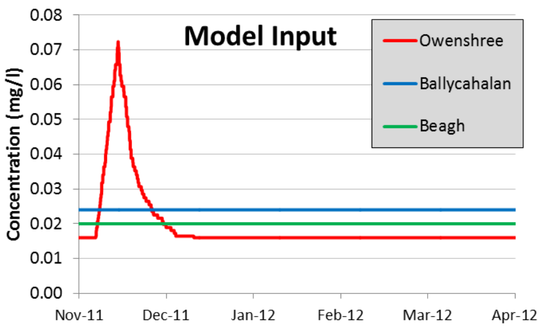

Figure E

This signal has been input into the model and the following results were obtained (Figure F):

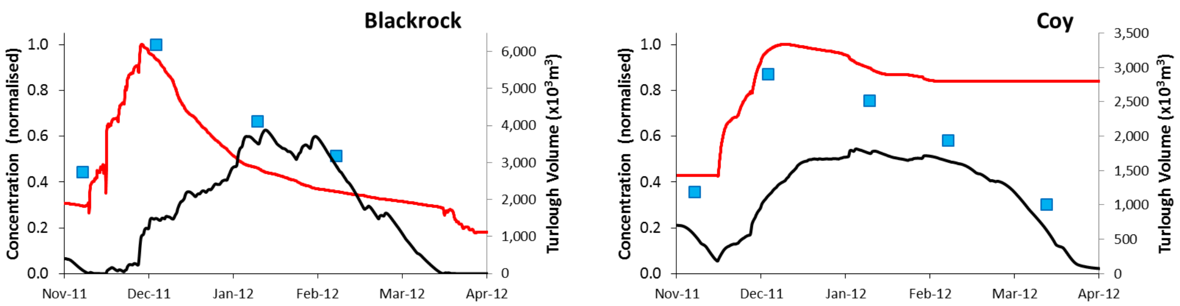

Figure F

3 *The interpretations that were made based on the available dataset*

In general, the author's choice of the graphic depictions of the available dataset makes it complicated to follow the author's interpretations in the text. As example: â˘A ´c Page 10244, line 5-8 (in relation to Fig. 7): 'These spikes could be due to the increased sensitivity of the turloughs to their river inputs during dry periods. During these periods, the turloughs have less capacity to dilute any incoming nutrient plumes and so spikes in nutrient concentrations should be expected'. The interpretation would be more qualitative if the precipitation dataset would be included in Fig.7. â˘A ´c Page 10233, line 22-24: 'The peak in P in July 2012 (Fig. 6) (which was also seen to a lesser extent in the other two rivers) occurs during forestry fertilization season of April- August (Teagasc, 2015) and coincides with a period of heavy rainfall.' It would have been great to have seen the precipitation data for this area plotted in Fig. 6 to be able to verify this thesis with real data.

Response

These plots have been altered to reflect the Referee's valid comments. Precipitation has been added to Figs. 5, 6 & 7.

4 One main interpretations of the study is (page 10222, line 17-22) 'Denitrification during stable flooded periods (typically 3-4 months per year) was deemed to be the main process reducing nitrogen concentrations within the turloughs whereas phosphorus loss it thought to occur mostly via sedimentation and subsequent soil deposition. The results from this study suggest that, in stable conditions, ephemeral lakes can impart considerable nutrient losses on a karst groundwater system.' One example for denitrification is shown in Fig. 10. First of all, it should be recognized that the amplitude of Total N between Point A and B is very low (max. 0.5 mg/l). In addition, there is a sampling interval of one month in a karst catchment (see my previous comment to 'a) the sampling frequency of one month in a karst terrain'). And in general, I miss error bars in the diagram that show the expected accuracy of the method chosen for the analysis of TN. In my opinion, all these facts lead to a high uncertainty of the interpretation.

Response

We acknowledge that the amplitude between points A and B is low, but we are confident in our analysis and quality control methods. Duplicate, and sometimes triplicate samples were recovered and analysed separately. Standard solutions were also tested with each batch to ensure quality control. Samples which did not adequately match the standard or had excessive differences between duplicates were omitted from the dataset (resulting in a number of missing datapoints in the 2011-2012 dataset).

See plot below (Figure G) for 'Figure 10' with error bars (standard deviation) added. This has been added to the manuscript.

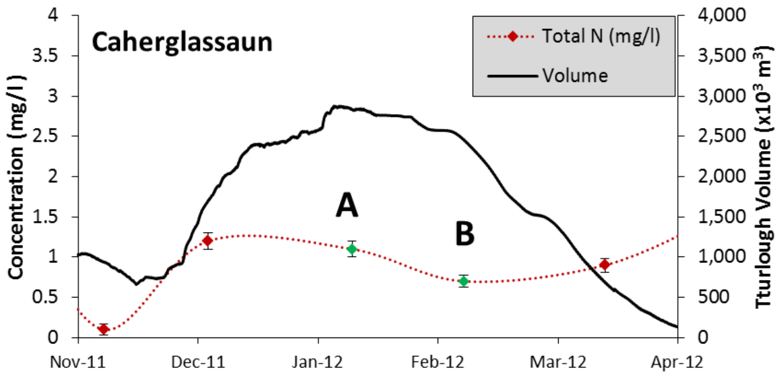

Figure G

We have answered the query regarding the sampling frequency in comment 1.

We must stress that we are not intending to give an exact denitrification rate from the turloughs. Instead, we are trying to prove that it is the most likely cause of N loss. All possible mechanisms were discussed and it was deemed to be most likely to be denitrification. This was then backed up by Fig 10 which showed N loss to be within the range of expected N loss from denitrification in lakes.

Thus we postulate that denitrification is likely to be the predominant (but not only) cause of N loss in the lakes.

Specific Remarks

Page 10223, line 20-23: Give information about the extension of the EU Water Framework Directive.

Additional text has been added regarding the extension of the Water Framework Directive.

Page 10225-10226 (2 Area description and background): I miss references that support the statements e.g. have there been performed some tracer tests (or a geophysical survey), previously?

Reference to previous tracer studies (Drew, 2003) as well as Gill et al (2013) have been added to this section.

Page 10226, line 15: 'Fig. 2c' should be 'Fig. 2a'

Text has been altered accordingly.

Page 10228, line 13: Tell the reader how far away the synoptic weather stations of Met Éireann are to the catchment. Notice the hourly rainfall and evapotranspiration data is not presented to the reader in the following text/illustrations.

Text has been added to provide more detail on synoptic weather data. Rainfall has been added to a number of figures.

Table 1: Add the time frame in the legend.

Time frame has been added.

Fig. 1: First of all, check the scale of your figure as the scale shown does not fit with the scale of the map already published by Gill et al., 2013, (Fig. 1). Secondly, check your text at page 10225 and your figure and adapt to one another. For example: Page 10225, line 3-4: 'The eastern portion of the catchment is dominated by the Slieve Aughty Mountains and underlain by Devonian Sandstone (Fig.1)' The Mountains cannot be recognized in the illustration by the reader as they are not marked and the Devonian Sandstone is presented as 'Old Red Sandstone' in the illustration which makes it hard for the reader to follow. As second example, in the following passage it is written that 'The western portion of the catchment is mostly flat und underlain by pure carboniferous limestone'. In contrast, in the legend are four limestones mentioned without any geological time frame information. In addition, check the legend of your figure: 1) Add information of the geological time frame. 2) Describe the white area of the map (add to the legend) – I assume it is the sea. 3) Is it correct that the rivers are not continuous (e.g. Clonteen River)? 4) Add your symbols for the rain and river gauges - which you have used in the map - to the legend. 5) Some information about the topography in the illustration would help.

- The scale bar on figure 1 is accurate. Perhaps the apparent difference is because the figure of Gill et al. (2013) stretches further to the east and south than the figure in this current paper? The 'zoomed in' figure in this current manuscript is intentional as it provides more clarity and less clutter of labels in the central areas.
- The Mountains have been labelled and a hillshade texture has been added to highlight the mountains.
- Geological descriptions in the text and figures has been corrected to be more coherent. The geological map has been simplified and time frame information has been added in the legend.
- The Sea has been added to the Legend.
- Yes it is correct that many Rivers, including the Clonteen are discontinuous in the West. Smaller streams have been added to the Figure to further illustrate the hydrological contrast between east and west.
- A hillshade texture has been added to indicate the topography. Visual detail on actual elevations in the catchment is left to figure 3 so as to avoid clutter in Figure 1.

References

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