Review of the paper "*Integrated assessment of the impacts of climate and land use changes on groundwater quantity and quality in Mancha Oriental, Spain*" by Pulido-Velazquez et al., submitted to HESS

Dear Editor,

Thanks for your constructive and helpful review. We have now included our responses (plain font) to the comments from the referee (bolded) and the proposed changes in the manuscript (in italics and under quotation marks). The new text is now included in the marked-up manuscript version with track changes.

General comments

The paper deals with a very far reaching topic (generation of climate and land use change projections; establishing a model chain for a regional 3-D transient case study) with a lot of related issues which leads to the paper loosing it's focus (no clear research question recognizable). Major points include:

- **Methodological weakness since there is no calibration on nitrate measurements so that the goodness of the groundwater quality predictions can't be evaluated**

Although no formal calibration could be done for nitrates, since only scattered measurements were available, a comparison was made in order to check if the MT3DMS model was reproducing the observed values. We compared the maximum values reported with those obtained with the model for the calibration period.

Section 3.3 and the new Figure 8 explain and depict this comparison. This is the completed and updated text:

"The parameter adjustment for the MT3DMS model was hindered by the lack of data, especially by the lack of a continuous time series with at least one record per month. The initial concentration values were interpolated from data reported in the literature (Moratalla et al., 2009). The nitrates entering the aquifer were obtained from the nitrate leaching variable in the SWAT model. Since only few scattered observed values of nitrate concentrations are available for the calibration, the process mainly consisted in matching the maximum nitrate concentrations simulated and their spatial distribution pattern with the ones reported in the literature (Moratalla et al., 2009). Fig 8 shows the results of this match, consisting of a graph in which the maximum nitrate concentrations obtained by MT3DMS are showed, comparing them to the literature-reported maximum value in the observation points marked (plotted besides each location). As can be seen, MT3DMS results match the observed values for the majority of the control points."

- **Uncertainty aspect due to climate change and land use transition models once mentioned (line 69) but not further discussed**

We agree this is certainly a key issue. The uncertainty aspect that you mention referred to the uncertainty associated to the hydrological modelling. A sensitivity analysis was carried out in section 3.1 for the hydrological model SWAT. We have updated the text:

"A preliminary sensitivity analysis was run using the SWAT-CUP software (Abbaspour, 2012), which integrates various calibration/uncertainty analysis procedures for SWAT. From this analysis we obtained that the most sensitive parameters of the model were the SCS Curve Number (CN2), the groundwater

discharge coefficient (α) into surface water, the travel time coefficient from soil to shallow aquifer, the coefficient of water finally lost as evaporation, and the two primary evapotranspiration parameters. The fact that the CN2 parameter was the most sensitive highlights the importance of considering land use changes in the analysis (as they affect the CN2)"

Given that no probability distribution functions could be fitted to all the parameters and data used, no full uncertainty analysis was made. Uncertainty on climate and land use projections was partially addressed by considering a certain number of scenarios, showing the dispersion of results in terms of groundwater recharge, and groundwater quantity and quality (new Fig. 9, 10 and 11).
We added the following text (section 5):

"One essential issue when dealing with assessing future global scenarios is uncertainty. Uncertainty arises from the climate and land use projections, as well as from the impact modelling exercise. Uncertainty on climate and land use projections was partially addressed by considering a set of scenarios, showing the dispersion of results in terms of groundwater recharge, and groundwater quantity and quality. Uncertainty on the impact modelling exercise is quite complex to address, since there are many factors involved (data uncertainty, uncertainty on the model conceptualization, on the model calibration, on the coupling of models, etc). In our case, we just assessed the robustness of the SWAT model results to the calibrated parameters with a sensitivity analysis. Further research would be need on addressing uncertainty in such a complex framework in a holistic and integrated way."

- **No clear paper message – instead in the short discussion and conclusions section some points are introduced that were only slightly or nowhere mentioned before (reevaluation of MOS management plan, stakeholder involvement, MAVT)**

The Conclusions section was re-written. The issues of management plans, stakeholder involvements, etc. are just included as a reflection on future potential applications of the model, based on the impact results for the future scenarios. Since the model points at a recharge reduction and a nitrate concentration increase, it is clear that some actions will be needed to counteract climate and land use change impacts. The new text is as follows:

"Global change must be taken into account in the planning and assessment of management policies for a sustainable development of the Mancha Oriental system, as the expected results without considering global change impacts are likely to be too optimistic. The currently intended program of measures regarding the MOS might have to be redefined under the expected climate and LUC conditions, searching for robust solutions to adapt to global change conditions. The integrated modelling framework developed in this work could be useful for the assessment of the potential effect of adaptation measures to cope with future global change."

Specific comments

L 58: add river stages. Now added.

L 60: use temporal and spatial variability instead of heterogeneity. It has been modified

L 67: add in spatial and temporal detail at and of sentence. The following sentence has been added (section 1): "*representing the spatial heterogeneity and temporal variability*"

L 74: add it before sometimes. Added

L 73 – l 78: unclear as is, needs to be explained in more detail; e.g. it is unclear how conceptual models can be used to adequately assess climate and global change impacts – please provide an example or reference.

An explanation, and the references stated within it, has been added. Modified text:

"Numerical simulation models representing the spatial heterogeneity and temporal variability, if properly designed and calibrated, provide the most adequate way to estimate the impacts of climate and land use changes on groundwater systems. Numerical hydrological models have been used to estimate global change impacts on the surface processes of a watershed (e.g. Caballero et al., 2007; Mango et al, 2011; Shrestha et al, 2013; Ma et al, 2014). Those models are also useful tools to deal with the uncertainties on the impacts of climate change associated to the hydrological processes (Kingston and Taylor, 2010; Xu et al, 2011). In order to assess the impacts of future conditions (climate, land use, water demands, adaptation, etc.) on groundwater systems, some forms of coupling between hydrological and hydrogeological processes must be used (Holman et al., 2012; Pulido-Velazquez et al, 2014). However, integrated models' development continues to be a challenge, as it requires assumptions that hinder detailed assessments about certain variables. The sequential coupling of numerical models can be used as an alternative to adequately assess climate and global change impacts. Those approaches generally employ hydrological models capable of representing the land phase of the hydrological cycle (infiltration, recharge, river flow, surface nitrate flow, nitrate leaching, etc), while groundwater quantity and quality impacts are assessed through groundwater flow and transport models (e.g., Candela et al, 2009; Narula and Gosain, 2013). Their linkage is made through an output-input scheme, in which some of the hydrological models' outputs (groundwater recharge, nitrate leaching, etc.) are used as inputs in the groundwater models. Therefore, sequential coupling is able to keep the necessary detail in the key processes in the system while providing a comprehensive description of the way those processes are interconnected. " (section 1)

L 142-143: What about the period between 1990 and 2010.

The period division corresponds to the usual procedure employed in the climate change impact assessment: control period (1960-90), and future short, medium and long term. The 1990-2010 period was used for the calibration, warn-up and cool-down of the model. We have also compared the future results with the mean values obtained for the calibration period, 1994-2004.

L 150-152: What is your conclusion / explanation from the strongly diverging standard deviation of monthly averaged temperatures; in Figure 2 please refer to GCMs instead of using the number codes.

We have now replaced Fig. 2 by one with the comparison for the Albacete-Los Llanos weather station (the most complete and relevant one). By comparing point values of max temperature instead of averaged ones (previously they referred to the averaged values for the whole Mancha basin), we can now observed a much better fit in the standard deviation. The new text added is (section 2.2):

"The CNRM scenario is the one that better resembles the mean maximum historical temperature, with larger differences in the other two. Regarding monthly standard deviations of maximum temperature, the HADCM3 scenario shows the largest discrepancies with respect to the historical data. "

The number codes have been replaced by the scenario name.

L 152-156: How do you assess the discrepancies between historical monthly mean precipitation and the simulated values for the quality of predicted values?

It is a very relevant but difficult question. For replying to this, we have added the following the text:

"Fig. 2 shows some differences on the mean precipitation monthly pattern, especially in April and

November. Some deviations are also found in the comparison of the standard deviations. There is not a single model that clearly outperforms all in terms of agreement with the observation. In any case, we did not use this comparison for selecting climate projections, since the performance of the model in the past control period does not guarantee improvements in prediction accuracy under a non-stationary climate (Reifen and Toumi, 2009; Teutschbein and Seibert, 2012). Instead, we decide to use a set of models that provides a range of plausible future projections. This will allow to assess the sensitivity of the model results to the uncertainty on the climate projections."

L 169: use combining instead of coupling.

The sentence has been eliminated as requested by the reviewer.

L 173-174: include references for EU scenarios and LUC allocation techniques; it might be an option to move L 188-192 right to that bullet point.

The requested references are included in the end of the section. The content in lines 188-192 and following was separated from the caption in order to avoid a too large caption

L 175+179: use long instead of large. Done.

L 180: latter instead of latest. Done.

L 195-220: Land use change projections parts very hard to follow; consists of a lot of technical terms and would benefit of a restructuring and simplification (maybe a flowchart might help) with concentration on main results used in further progress of the study

The methodological description has been rewritten, also following the reviewer's recommendations.

L 239; insert simulating after properly. Inserted

L 242: delete second and. Deleted

L243-245: what is the difference between the existing couplings between SWAT and MODFLOW and your approach

In our case the coupling is a sequential coupling, i.e. groundwater recharge simulated by SWAT (by HRU) is transferred into the corresponding MODFLOW cells. We have modified the text as:

"The proposed modelling framework sequentially couples the SWAT watershed model with the fully-distributed groundwater model MODFLOW (McDonald and Harbaugh, 1988), and finally the multispecies transport model MT3DMS model (Zheng and Wang, 1999) for simulating the fate of the nitrate leached into the aquifer system. In this approach, SWAT model outputs are used as MODFLOW inputs, and SWAT and MODFLOW outputs are used as MT3DMS inputs (Fig 5). This coupled framework was used to assess the climate and land use change impacts on hydrology, groundwater flow and nitrate leaching and transport in the Mancha Oriental system."

Unlike previous studies, ours assesses the impacts caused by climate and land use change, a specific comment about that was added in the manuscript as follows:

"*This coupled framework was used to assess the climate and land use change impacts on hydrology, groundwater flow and nitrate leaching and transport in the Mancha Oriental system.*" (section 2.4).

L 275: If SWAT is a single plant growth model you simulated only the dominating crop in each of

the 445 HRUs – is that correct?

Yes, only the dominant crop at each HRU.

L 300-303: Is there no Spanish soil database? What is the spatial resolution of the FAO's digital soil map within the study area? Is the parametrization useful given the local conditions?

There is no Spanish data base for all the Spanish territory. The original resolution of the FAO's digital soil map of the world is 1:5.000.000, presenting soil parameters in grid cells of 5' latitude/longitude resolution. Given the large size of the region, this is the map with the highest resolution we found covering the whole area. Updating the study with higher resolution data for soils will be advisable when available.

L 305-306: I don't understand minimum land use unit area about 25 ha
This is the threshold area used by the CLC. If one area devoted to one specific land use is lower than 25 ha, then it does not appear in the CLC associated to that land use, but it is merged with the surrounding ones.

L 307: do you mean validity.
That sentence has been removed (lines 359 and 360)

L 310: how many HRUs are excessive amount?
In the first HRU division the total amount was near 1500 HRU. After that, several filters were applied to reduce the HRU amount below 500, which was considered an adequate number in terms of reducing the computational requirements while holding the necessary detail.

L 320-326: can be deleted and covered by references; please use just one MODFLOW reference instead of 3 (L338, L247-248)
McDonald and Harbaugh (1988) is now used as the standard reference in the paper.

L 334: reference missing after according to
It is Sanz (2011); added.

L327-337: a cross section or a 3D image would be helpful to better understand the geological features of the MOS aquifer.
This would be certainly useful, but in order to limit the length of the paper, we have opted for referring to Sanz et al. 2011, which shows and explains the main geological features of the MO aquifer.

L 347-348: it is unclear if pumping values used in MODFLOW are taken from SWAT outputs (assuming optimal irrigation) or from real farmer data like stated in l 318

Crop management parameters in L318 refer to seedtime, harvest time, and amount and type of fertilizer applied. SWAT calculates the pumping from the irrigation needs according to those practices and the soil and meteorological conditions, and then those values are transferred to MODFLOW. A clarification was added (section 2.5):

"Then, the crop management practices (fertilizer application, seedtime, irrigation and harvest timetable; the water source, hydric stress threshold, etc.) were introduced in the SWAT model using the ArcSWAT interface. The crop management parameters were based on the standard practices of the farmers in the watershed."

L 350-359: can be deleted and covered by reference.

The original paragraph has been synthesized as (section 2.7):

"MT3DMS (Zheng and Wang, 1999) is a 3D groundwater solute transport model that solves the groundwater transport equation using a finite-difference approximation, discretizing the spatial domain into cells in which equal characteristics and solute concentrations are assumed."

L 360: model instead of mode
It has been corrected

L 371-375: This sentence is obsolete since in the following one the most sensitive parameters are repeated. However, the explanation of the CN2 parameter in relation to climate and land use needs to enhanced; it is unclear as it is.

The text has been corrected. Modified text (section 3.1):

"*The SWAT calibration procedure followed four steps, consisting on river flow, groundwater recharge, crop yield and nitrate leaching calibrations. A preliminary sensitivity analysis was run using the SWAT-CUP software (Abbaspour, 2012), which integrates various calibration/uncertainty analysis procedures for SWAT. From this analysis we obtained that the most sensitive parameters of the model were the SCS Curve Number (CN2), the groundwater discharge coefficient (α) into surface water, the travel time coefficient from soil to shallow aquifer, the coefficient of water finally lost as evaporation, and the two primary evapotranspiration parameters. The fact that the CN2 parameter was the most sensitive highlights the importance of considering land use changes in the analysis (as they affect the CN2)."*

L 386: which table?

The table was removed; the reference has been deleted

L 390-393: Can you also give us some information about the changing spatial and temporal patterns of recharge since this is important for pollutant input.
The variation of the mean groundwater recharge across global change scenarios for the future periods is presented in Fig. 9. We have also produced and analyzed graphs showing time series of total annual groundwater recharge across global change scenarios, as well as maps for representing spatial variation of groundwater recharge. Although we agree that the spatial and temporal patterns are important for the analysis of the impacts on groundwater quantity and quality, the results are quite different among the climate scenarios, and we were not able to identify particular patterns. So we have finally opted for not increasing the number of figures in text, in the absence of a clear interpretation.

L 393: replace offer by in. Done.

L 399-421: Please combine and condense discussion about nitrate leaching. Avoid use of the term calibration since you compare SWAT results with results from another modeling study (btw, it should read table 2 in L 416).
We have modified and reorganized that paragraph and removed the word calibration. Modified text (section 3.1):

"*With regard to nitrate leaching, there is no possible comparison with historical data, as there are no historical records. Given the usual absent of data, the calibration of nitrate loads is often based on observed nitrate concentrations in the existing piezometers and the crop growth component. Nitrate leaching calculations uses SWAT-predefined functions, information on fertilizer types and application, soil characteristic (including initial NO3 concentration), and other factors such as the percolation factor affecting NO3 transport."*

L 411: what are the SWAT predefined functions, are they applicable to the MOS aquifer?

We now refer to them as "SWAT leaching equations". SWAT calculates nitrate leaching through the soil. SWAT calculates the amount of mobile nitrate in a soil layer using the total nitrate concentration in that layer, the amount of water flowing through it (surface runoff, lateral flow and percolation), the soil porosity and the soil saturated water content. Once this mobile nitrate is calculated, it is distributed among the flows according to the soil percolation coefficient and the amount of water associated to each flow. Those specific functions can be found in the SWAT Theoretical Documentation manual, so it has not been included in the manuscript. They are applicable in the MOS aquifer since the groundwater levels do not influence the soil water content (groundwater table is located below the lower layer of the soil).

L 423-426: Can you give some numbers on the goodness of your calibration on heads? In Fig. 7 please use individual y-axis scales and enlarge the plots for readability. For some wells the dynamics between observed and computed time series is very different.

The plots have been enlarged by reducing the number of points included in the figure; the R-squared coefficient of the graphed points, and we now include the R-squared values. Modified text (section 3.2):

"MODFLOW calibration has been carried for the same period as the SWAT model (1994-2004 period), using 24 piezometers . Fig 7 depicts the calibration results obtained in 4 piezometers located in different zones of the Mancha Oriental aquifer. The seasonal fluctuations are mainly due to pumping during the irrigation season. The R-squared coefficients for the goodness of fit for heads are 0.69, 0.62, 0.27 and 0.72 respectively. The model performance closely resembles the historical records at the observation wells and, therefore, the MODFLOW model has been adequately calibrated."

L 428-434: Please show in example for you procedure of matching observed nitrate groundwater concentrations. How did you assess the temporal development of your computed nitrate concentration time series? What transport parameters did you use? Again, I think the term calibration might be misleading.

The new figure 8 shows the spatial fit of the observed and simulated nitrate concentrations in all available control points. We used advection and diffusion parameters, as explained in section 2.7. We have changed the word "calibration" by "parameters adjustment". The text has been replaced to adapt it to the changes. Modified text (section 3.3):

"The parameter adjustment for the MT3DMS model was hindered by the lack of data, especially by the lack of a continuous time series with at least one record per month. The initial concentration values were interpolated from data reported in the literature (Moratalla et al., 2009). The nitrate load entering the aquifer was obtained from the nitrate leaching variable in SWAT. Since only few scattered observed values of nitrate concentrations are available for the calibration, the process mainly consisted in matching the maximum nitrate concentrations simulated and their spatial distribution pattern with the ones reported in the literature (Moratalla et al., 2009). Fig 8 shows the results of this match, consisting of a graph in which the maximum nitrate concentrations obtained by MT3DMS are showed, comparing them to the literature-reported maximum value in the observation points marked (plotted besides each location). As can be seen, MT3DMS results fit the observed values for the majority of the control points."

L 435-441 delete since repeat from L 428-434 . Done.

Please integrate in fig. 8 and 10 in the bars some internal shading or structures so that one can right away identify the displayed combinations of cc and lulc scenario; as is the discussion is difficult to

follow. We have changed these figures.

L 449-454: please try to provide a more detailed discussion of the precipitation-recharge nexus, e.g. to what extend do you find the difference in precipitation between the three cc scenarios and in the 3 different time periods also in the computed recharge patterns (in particular since you conclude that cc seems to be the main driver of change).

The text has been modified to properly address your comments. Modified text (section 4.1):

"*The results for all climate change scenarios agree in a reduction of the mean recharge over the 21st century, specially in the long-term (Fig. 9), and a reduction with respect to the historical recharge in the last decades, estimated as 310 Mm^3/year. The values of the short-term mean recharge are similar for the CNRM and HADCM3 scenarios, despite the fact that the precipitation is higher in CNRM than in HADCM3 (Fig 3). In this case, the difference in precipitation is not fully transferred to recharge. However, in the ECHAM5 scenario a lower precipitation results in a lower groundwater recharge. A remarkable recharge reduction can be noticed in the long-term for the ECHAM5 and CNRM scenarios, associated to the steep decrease in precipitations (Fig 3); whereas the HADCM3 scenarios show no decrease in either average recharge or precipitation.*"

L 466: insert as after much. Inserted.

L 459-462: see comments on L 347-348: did you use optimal model irrigation or real irrigation values of the corresponding farmers? Return flow from irrigation might be lower in the latter case since farmers might consider weather forecasts.

SWAT assumes optimal irrigation: the amount of water pumped is the one that corresponds to the irrigation needs to maximize crop yield. Modified text (section 2.6):

"Recharge and pumping values were obtained from the SWAT model outputs, assuming that farmers pump the optimal amount of water required by their crops."

L 472: did you experience the same crop yield differences for the various crops you simulated?

Given the uncertainties regarding the crop yield assessment under climate change (with a very complex cross-effect of increasing CO_2 concentration and increasing temperature), we have decided to remove the sentence explicitly pondering the effects on crop yield, and focus on impacts on groundwater.

L 473: assigned and but instead of by
Removed.

L 491: How does the different main driver for groundwater quantity relate to the driver identified for recharge? Is this due to pumping for irrigation?

Modified text in section 4.2:

"To sum up, the effect of land use change on groundwater levels seems to be higher than the effect of climate change since the LUC modify the amount of pumping, while causing just slight changes in the recharge."

This reflection is also included in section 5 , Discussion and Conclusions.

L 493: no instead of to. Done.

L 494: here you mention uncertainty due to climate variability the only time as a side aspect; I believe you have to work more on this issue

The cycles noticed in the time series are mainly associated to climate variability. We have further discussed the issue of uncertainty in section 5 (see response to General Comments).

L 503: Why does LUCS-4 necessarily lead to the lowest nitrate leaching values?

The figure regarding nitrate leaching was re-elaborated (see Figure 11). According to it, it is the MLTDI land use scenario the one with the lowest leaching. The text has been modified according to this.

Modified text (section 4.3):

"The scenarios associated with the MLTII land use scenario (the largest irrigated area) are generally the ones with higher nitrate leaching, while the MLTDI scenarios offer the lower bound of leaching values (Fig. 11)."

It is very complex to find a reason for that. Regarding that, we have now included the following text (section 5):

"Increasing groundwater nitrate concentrations can be anticipated, due to the continuous intense use of fertilizers in agriculture over time. In this context, economic instruments might have an essential role in enhancing a sustainable management of diffuse pollution for the future (Peña-Haro et al., 2014). However, water quality projections of this study are subject to a high uncertainty, since no formal calibration or validation regarding nitrate leaching was possible. Further improvements of the modeling chain for nitrate leaching, and collection of additional data and field experiments, would be required in order to obtain more accurate assessments. Although some studies have shown that leaching rate may increase under future climate scenarios, the implications of climate and land use change on the rate of nitrate leaching are not yet fully understood, given the complex mix of factors that simultaneously affects the leaching process and the usually lack of enough site-specific data (Stuart et al., 2011)."

In L504-505 you mention that difference between LUC scenarios become for nitrate leaching become significant in the medium and long term, however, in terms of groundwater nitrate concentration luc scenarios do not show a significant effect. Please elaborate how these findings fit together.

These little differences in concentrations as compared to those found for nitrate leaching might be caused by groundwater flow processes that attenuate the impact of nitrate leaching. In addition, despite the leaching differences, there is already a considerable amount of nitrates in the aquifer. For that, the nitrate concentrations in the aquifer, even though increasing, do not suffer a significant growth.

L 510-512: against the end of the 21st century recharge declines but this also means that there will be less nitrate leachate and thus lower nitrate groundwater concentrations. In the next but one sentence the authors state exactly that since the CNRM scenarios have the highest precipitation and thus recharge (I assume). If I'm correct please resolve this inconsistency

We noticed that less recharge does not necessarily imply less leaching comparing Fig. 9 and Fig.11. The main driver of groundwater nitrate concentrations is the maintenance of the nitrate inflow combined with the absence of groundwater nitrate attenuation processes. The text has been modified to reflect that. Modified text (section 4.3):

"Nitrate concentrations in the Mancha Oriental aquifer increase in nearly all the observation points (Fig. 12). Although with a more or less constant nitrate load (nitrate leaching) depending on the scenario, the groundwater nitrate concentrations increase over time, with the highest concentrations for the MLTII scenario. Given the absence of groundwater nitrate attenuation processes, the maintenance of the nitrate leaching load causes an increase in nitrate concentrations over time."

It should generally be made clear that the findings related to future groundwater quality development are more uncertain than that for groundwater quantity since there are only little data available for validating the model chain with respect to nitrate leaching and groundwater nitrate concentrations.

A comment about that has been added at the end of the discussion and conclusions section (section 5). Modified text:
"… However, water quality projections of this study are subject to a high uncertainty, since no formal calibration or validation regarding nitrate leaching was possible. Further improvements of the modeling chain for nitrate leaching, and collection of additional data and field experiments, would be required in order to obtain more accurate assessments. Although some studies have shown that leaching rate may increase under future climate scenarios, the implications of climate and land use change on the rate of nitrate leaching are not yet fully understood, given the complex mix of factors that simultaneously affects the leaching process and the usually lack of enough site-specific data (Stuart et al., 2011)."

The discussion in general does not very much relate to the specific results shown in the previous chapter

The discussion and conclusion section (section 5) has been quite modified to further include specific conclusions from the results, as well as general conclusions on research limitations and future work.

L 523-526: You did not calibrate or validate on irrigation and nitrate concentrations.

Although no climate and land use change impacts on irrigation were discussed in the paper, the SWAT model irrigation was calibrated, as explained in section 3.1 and shown in table 2. Reported nitrate concentrations were used in the MT3D calibration, as the new Fig 8 shows and it is explained in the new section 3.3.

L 528-531: If the overall goal of the paper is to improve insight into the systems vulnerability and potential adaption options this needs to be better elaborated. Until the last page of the manuscript only L 124-128 cover this issue

The major goal of the paper was to assess the climate and land use change impacts in the Mancha Oriental aquifer. We have rewrite the reference to the adaptation measures within section 5. Modified text:

"Global change must be taken into account in the planning and assessment of management policies for a sustainable development of the Mancha Oriental system, as the expected results without considering global change impacts are likely to be too optimistic. The currently intended program of measures regarding the MOS might have to be redefined under the expected climate and LUC conditions, searching for robust solutions to adapt to global change conditions. The integrated modelling framework developed in this work could be useful for the assessment of the potential effect of adaptation measures to cope with future global change."

L 532-535: As the authors state in chapter 4.1 the groundwater level decline is only predicted until 2020, then it stabilizes and starts to oscillate. This is not what you write in these lines. You also never really mentioned predicted streamflow depletion in the Jucar river.

The paragraph has been corrected to properly reflect the patterns and the reference to streamflow depletions have been deleted. Modified text (section 5):

"The modelling results for all scenario runs point out at the same future trend: a certain reduction of groundwater recharge, which will be further exacerbated in the long-term (except for the HADCM3 scenarios). The combined analysis with the land use change (LUC) scenarios implicitly introduces variations in the amount of groundwater pumping as well. In the end, groundwater levels will be affected by the combined effect of recharge and pumping changes. In this sense, the results show cycles of decreasing and increasing groundwater levels, but without a generalized descending trend. Although climate change seems to be the main driver of the changes in groundwater recharge (the differences among climate scenarios with the same land uses are larger than those introduced by the land use scenarios), groundwater levels seem to be more affected by the LUC because of the effect of changes in pumping..."

L 536+543: threat instead of threaten. Modified.

L 546-549: reads like a repeat to the previous sentences since here you state that the new management plan includes measures to avoid potential future threats. The repeated sentence has been removed.

L 550-566: the conclusions appear to be rather general but include some very important issues which are not fully exploited. They mainly deal with the necessity for reassessing the MOS management plan and options and techniques to do so. However, this was not the focus of the paper (see also above comments).

The paper does not certainly include assessment of adaptation measures, which would need additional scenarios and runs. However, the results obtained with regard to global change, specially the water-quality ones, showing that global change will modify the framework used to assess those programs of measures. Therefore, it is clear that they need to be reassessed in further studies using climate and land use change scenarios (see last comment in the response in page 10).

L712-714: Why are yield results for SWAT and ITAP data identical? Did I overlook something? Since SWAT is a single crop model are the values per crop type averages of the HRUs where the particular crop was planted?

There were errors that have been corrected in the table. Yes, the included crop yield values are the average computed among all the HRU's in which each particular crop was found. The new table is (Table 2):

CROP TYPE	IRRIGATION (mm)		YIELD (Tn/ha)		LEACHING (Kg NO_3/ha)	
	SWAT	ITAP	SWAT	ITAP	SWAT	GEPIC
Wheat	363	350 – 420	7.2	7 - 8	53	45 – 85
Onion	572	550 – 620	5.1	4.5 – 5.5	114	100 – 120

CROP TYPE	IRRIGATION (mm)		YIELD (Tn/ha)		LEACHING (Kg NO_3/ha)	
	SWAT	ITAP	SWAT	ITAP	SWAT	GEPIC
Corn	552	500 – 600	12.2	12 -13	100	90 – 115
Sugarbeet	827	800 – 900	12.8	12.5 – 13.5	74	65 – 90
Barley	282	250 – 350	8.6	8 - 9	34	30 – 45
Alfalfa	782	750 – 850	12.1	11.5 – 12.5	12	10 – 30

L 727-729: What is the real message of these diagrams?

They intend to represent the evolution of the climatic variable across the 21st century by plotting the 10-year moving average. The diagrams were explained jointly with Fig 2 in section 2.2: there is an increase in both the maximum and the minimum temperatures (all scenarios agree), with a likely decrease in precipitation, specially by the end of the 21st century (the ECHAM5 and the CNRM agree while the HADCM3 shows no decrease).

L730-732: The figures must be increased, nothing can be read

The figures' size has been increase and the figure corresponding to the middle year (2000), has been deleted.

Fig7: use individual scales and enlarge comparisons of time series. The comparison has been enlarged by reducing the number of piezometers plotted. The same scale has been used.

Fig8+10: enlarge and use same scales. The figures have been updated to satisfy both the editor and the reviewer's comments. Now they are figures 9 and 11.

Fig11: enlarge time series comparisons for readability. Did you use new codes for combinations of cc and luc scenarios? From what I can read only in one observation well groundwater nitrate concentrations exceed 40 mg/l – is this correct? The comparison series have been enlarged by reducing the amount of piezometers plotted. The new codes requested by the editor and the reviewer have been used, explanation about land use codes can be found in section 2.3. Regarding the entire set of 24 piezometers, only in 3 of them concentrations rise above 40 mg/l: in 2 of them to reach a top around 60 mg/l and in the other 1 up to 140 mg/l.