We thank the reviewer, Wolfgang Gossel, for his kind and careful assessment of our work.

He raises a number of interesting and relevant issues not only for our work but also for any attempt at quantifying flow of regional, macro-scale aquifers located in areas where data are scarce. This is the case, for instance, of other transboundary aquifers such as the Nubean sandstone aquifer, which has even less data available than the Guaraní.

It is acknowledged that the conceptual model, and therefore the numerical model, was built upon the available data at the time of the PSAG project, which resulted in some model limitations. Unfortunately a follow-up, second-phase regional study that would fill the gaps and reduce the uncertainties that emanated from the PSAG project was not undertaken so far. Instead, efforts are underway in Brazil and Argentina to address particular issues on the aquifer functioning, which in turn, will allow revising the current conceptual and numerical regional models.

Having said all this, we address each of the questions pointed out by the reviewer.

1) Title: "Conceptual model and numerical modeling approach of the Guarani Aquifer System.

We agree with the suggested change.

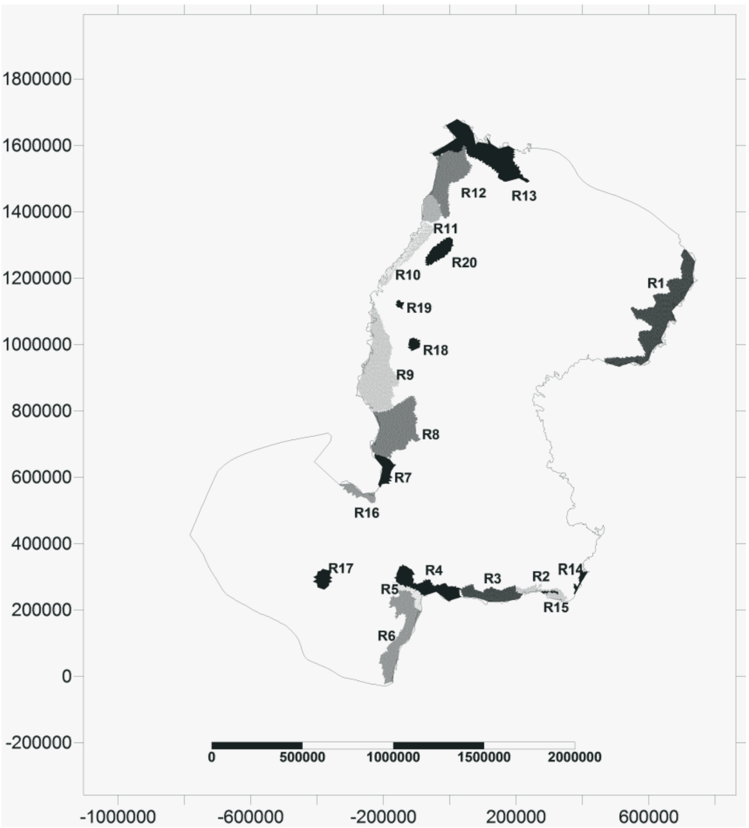
2) The introduction already shows one scientific dilemma for the reader to follow up the investigation results: The reports of the PSAG are not available, so that in the consequence some of the data should have been presented in the paper.

After completion of the PSAG, the Argentinean Water Resources Agency (Subsecretaría de Recursos Hídricos de la Nación), uploaded all technical reports resulting from that Project to its web page http://pag-ar00.minplan.gov.ar/SAG/ . We acknowledge that those reports are written either in Spanish or Portuguese, limiting somehow its accessibility. We will add new information to our manuscript to complete our description mainly regarding pumping and recharge (see items below), while at the same time keeping the text as concise as possible.

3) The groundwater recharge conditions remain quite unclear: This parameter is most important for the conceptual model and a distribution map should therefore be shown in the figures.

We have modified Figure 4 (still in a draft stage), replacing the colours of recharge zones (see item 12) by grey colours following no particular pattern, identifying each zone by a number. The figure is now accompanied by a table with the corresponding recharge rates applied to the steady state period. For the transient years, all recharge rates were multiplied by the recharge coefficient corresponding to that year (Figure 5) as explained in item 12.

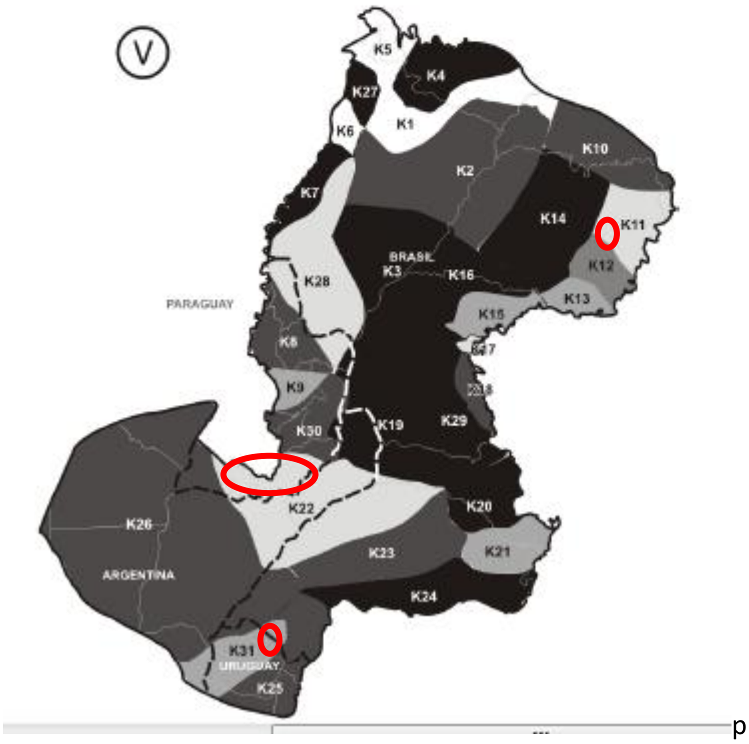
Recharge Zone	***Recharge (m/d)***	***Recharge rate (m3/d)***
1	0.1709E-03	3756840
2	0.4384E-04	128072
3	0.4384E-04	265171
4	0.4384E-04	332597
5	0.4384E-04	96241
6	0.4384E-04	549121
7	0.4384E-04	130836
8	0.4932E-04	828324
9	0.4932E-04	1051990
10	0.4932E-04	318704
11	0.5479E-04	204625
12	0.5479E-04	678069
13	0.5479E-04	952314
14	0.000	0
15	0.4384E-04	12525
16	0.4384E-04	99441
17	0.4932E-04	111825
18	0.4932E-04	51419
19	0.4932E-04	20131
20	0.4932E-04	177218



4) Why did you choose the zonation method instead of a regionalization of measured values? How does the distribution of measured values look like (map of measurements)? How do the resulting values of the zones fit to the measured values in the same zones?

At the time of the construction of the conceptual and numerical models, there were not enough point hydraulic conductivity data as to construct a regionalized distribution map for K using a tool such as kriging. We followed the definition by Carrera et al. (2005) in the sense that zonation is one of the methods to parametrize hydraulic properties to produce alternative K maps. The resulting zonations are shown in Figure 3 of the manuscript, while the text explains the criteria employed for the delineation of the zones patterns and distribution.

Whenever possible, we have compared the zones calibrated hydraulic conductivity with both, point data and K ranges reported by previous authors, seeking calibration values coherent with available data. For instance, at the Uruguayan-Brazilian border around the cities of Rivera/Santana, we relied upon 16 pumping test data (all concentrated in 150 km^2, the average finite element size of our mesh is 25 km^2) with K ranging from 0.17 to 19.92 m/d. (Gómez et al., 2010). Based on 7 pumping test in southern Paraguay, it was determined that K ranges from 1.6 to 3.8 m/d (BGR, 2008). For the best model fit scenario, K for the zones overlaying those available point data in both areas were 5-10 m/d (K22), and 2.5-5 m/d (K31), respectively.



A similar comparison was carried out in Brazil. Based upon 11 pumping tests (highly concentrated in space), hydraulic conductivity values of around 3 m/d were reported by for the Riberao Preto area in NE Brazil. Calibrated values for that area (K11) were in the range between 2.5 and 5 m/d.

Besides this point-to-zone comparison, we constructed Figure 11 of the manuscript, in an attempt to compile ranges of reported *K* values attributed to various authors that could be used to assess our model calibration. Instead of the classical representation of log *K* vs. the scale of observation, the *x* axis simply corresponds to a bibliographic reference number. On a regional scale, our best fit scenario (zonation 5) yields a calibrated K range larger than published ranges. We attributed these results in part to a possible scale effect on K and to deficiencies of the conceptual model, among other factors.

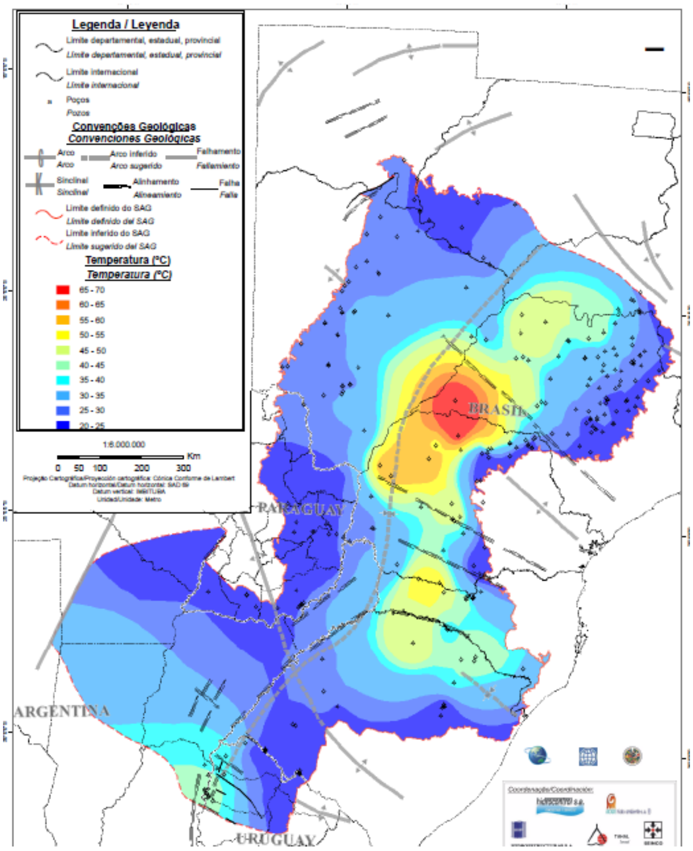
- BGR, 2008. SAG-PY. Uso sostenible del Sistema Acuífero Guaraní en la Región Oriental del Paraguay. Volúmen 4. Modelo de Aguas Subterráneas. Project for Environmental Protection and Sustainable Development of the Guaraní Aquifer System.
- Gómez, A. A., Rodríguez, L., and Vives, L.: The Guaraní Aquifer System: estimation of recharge along the Uruguay–Brazil border, Hydrogeol. J., 18, 1667–1684, 2010.
- SNC Lavalin International. 2008. Modelo numérico hidrogeológico del área piloto Ribeira˜o Preto, Sistema Acuífero Guaraní, Contrato No. LPI/03/05 Servicios de Inventario, Muestreo, Geología, Geofísica, Hidrogeoquímica, Isótopos e Hidrogeología Localizada de las Areas Operativas Norte y Sur del Sistema Acuífero Guaraní, Project for Environmental Protection and Sustainable Development of the Guarani Aquifer System, Global Environment Facility (GEF), Technical report prepared by Henri Sangam, Jonathan Hunt y David Charlesworth, Montevideo, Uruguay.

5) The correction of hydraulic conductivities according to the temperature is quite good and helpful, but what is the result of it? Is the correction overcompensated by the rough zonation of the hydraulic conductivities/ transmissivities?

We really appreciate this comment thanks to which we gave a second look to calibrated K results.

We resorted to the temperature distribution map estimated by LEBAC (2008), based on a previously pushed map by Araujo et al. (1999) shown below to correct the initial estimates of hydraulic conductivity.

Certainly, hydraulic conductivity zonations I and II do not bring too much detail. However, a close look at calibrated K for zonations Z3, Z4 and Z5 shows that, in general terms, high calibrated conductivity areas overlap the highest temperature region of the GAS, an elongated region located to the east of the central axis of the sedimentary following a NE-SW direction in Brazilian territory. This result would indicate that alternative zonations do not overcompensate the temperature correction, preserving its effect on K values.



Araújo, L. M., Franca, A. B., and Poter, P. E.: Hydrogeology of the Mercosul Aquifer System in the Paran´a and Chaco-Paran´a Basins, South America, and comparison with the Navajo-Nugget Aquifer System, USA, Hydrogeol. J., 7, 317–336, 1999.

LEBAC (2008). *Informe Final de Hidrogeologia do Projeto Aquífero Guarani*. Coord.: Gastmans, D. y Chang, H.K. Equipe: Paula e Silva, F., Correa, S.F., Informe Técnico – Consórcio Guarani. Rio Claro, 172 p.

6) The mesh and the pumping areas are to a certain extent connected to each other, therefore a map of pumping wells or at least the mentioned pumping zones (if possible with extraction rates) would be helpful.

We uploaded a draft figure with this information including extraction rates for each zone. This new figure will be incorporated in the final version of the manuscript after the discussion period ends.

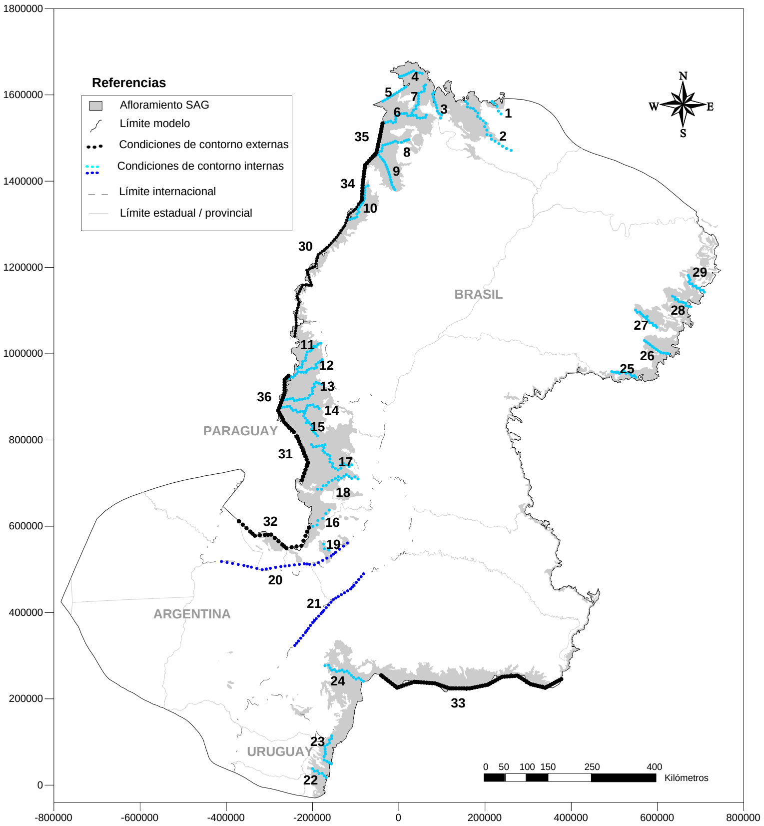
7) A map of observation points would be helpful, too (or does fig. 7 show the observation points?).

Yes, Figure 7 shows calibration errors at observation points. In Page 9901- Lines 16-17, the text reads “The geographic distribution of errors, with their corresponding sign and magnitude, not only highlights the location and density of calibration data …” .

8) For the rivers, even for the conceptual model it would be helpful to differentiate between parts where effluent and where influent conditions are observed or can be assumed.

For their quick location, all simulated rivers have been given a number. In the final version of the manuscript we will replace Figure 4 (without including the table).

Number	**Stream name**	**Number**	**Stream name**	**Number**	**Stream name**	**Number**	**Stream name**
1	Claro	9	Coxim	17	Yguazú	25	Jurumirím
2	Verde	10	Aquidauana	18	Capiibary I	26	Tieté
3	Araguaia	11	Ypané	19	Capiibary II	27	Jacaré Pepina
4	Itiquira	12	Guazú	20	Paraná	28	Moji Guazú
5	Correntes	13	Aguarey Guazú	21	Uruguay	29	Pardo
6	Tacuarí	14	Jejui Guazú	22	Tacuarembó Chico		
7	Ariranha	15	Curuguaty Correntes	23	Tacuarembó		
8	Jaurú	16	Tebicuary	24	Ibicui		



Analysing the results of scenario 5 (Z5) in detail, all streams but numbers 1,3,5,11,19 and 23 resulted influent.

For the rivers Jacaré Pepira (number 27), Ypané (number 11), Tacuarembó (number 23) and Paraná (number 20) (Figure 9) we evaluated stream/aquifer fluxes for steady state, year 4 (maximum recharge year, minimum pumping), year 30 (minimum recharge year, average pumping), and last simulated year (close to average recharge, maximum pumping), comparing them with the stream mean flow. Percentages given in the table below express stream leakage relative to mean flow.

Stream	Observed Mean flow (m^3/s)	Simulated Condition	Steady state (%)	Year 4 (%)	Year 30 (%)	Last year (%)
Jacaré Pepira (27)	29	Effluent	-10.3	-14.2	-2.7	-2.4
Ypané (11)	94	Influent	3.3	2.5	3.7	3.3
Tacuarembó (23)	40.3	Effluent/influent	-0.4	-1.7	1.4	0.8
Paraná (20)	12406	Efluent	0.0	0.0	-0.01	-0.01

Leakage from the aquifer to the river decreases in the Jacaré Pepira stream due to increasing pumping. Leakage from the stream to the aquifer in the Ypané river increases slightly with time caused by increasing pumping, however that change is no so drastic due to relatively low pumping rates in the area. The simulated condition for the Tacuarembó river changes from effluent to influent though the leakage magnitude is small. There is no pumping in the area as to justify this behavior. Finally, the interaction between the aquifer and the simulated reach of the Paraná is negligible compared to the river mean discharge.

9) Fig. 8 only roughly summarizes the values for certain model parts. It would be also helpful for the conceptual model if a differentiation for the pumping is made for areas, where the extraction leads to bank filtration.

Pumping distribution will be included in a new figure where areas and rates can be identified.

10) Is it really a good idea to have a factor for the precipitation to get the recharge value? In most parts of the world it is better to subtract a certain value for the evapotranspiration and the surface discharge. Perhaps a mixture of both would be more helpful in your area?

De Vries and Simmers (2002) reported that regional recharge can be reasonably estimated applying methods including regional-flux determination by isotope dating, Darcian flow modeling, chloride mass-balance calculations, and direct measurement of spring discharge or base flow, among others.

Choosing an appropriate technique depends on the study objectives, the precision of the sought results, the working time/space scales and background information on recharge (Scanlon et al., 2002). Data availability in the GAS and the aquifer extent were determinant for selecting applicable methods.

Subtracting evapotranspiration and surface discharge from precipitation would be equivalent to perform a water balance to estimate recharge. Evapotranspiration could be relatively easy to estimate resorting to global data bases on a regional scale, however, streamflow data for the numerous streams that cut across outcropping areas is not available. Stream discharges are available for Brazilian streams, however not readily available within Paraguay and Uruguay. We followed this approach in a smaller area of the GAS along the Uruguayan-Brazilian border, implementing several methods to bracket recharge rates (Gómez et al., 2010).

During the preliminary stages of the model development (Vives et al., 2008), we performed a sensitivity analysis of model results to recharge rates, using values between 1 and 10 % of mean annual precipitation. Those extreme values were not arbitrarily chosen. In our previous work we had compiled recharge rates from several authors and aquifer locations (see Gómez et al., 2010). That sensitivity analysis was also performed in order to reduce the number of calibration parameters during the inverse simulation runs and, with that, help convergence and diminish simulation times.

De Vries J, Simmers I (2002) Groundwater recharge: an overview of processes and challenges. Hydrogeol J 10(1):5–17.
Gómez, A. A., Rodríguez, L., and Vives, L.: The Guaraní Aquifer System: estimation of recharge along the Uruguay–Brazil border, Hydrogeol. J., 18, 1667–1684, 2010.
Scanlon BR, Healy RW, Cook PG (2002) Choosing appropriate techniques for quantifying groundwater recharge. Hydrogeol J 10(1):18–39.
Vives, L. S., Rodríguez, L. B., Gómez, A. A., and Cota, S. D. S.: Modelación numérica regional del Sistema Acuífero Guaraní (Regional numerical modeling of the Guaraní Aquifer System), Project for Environmental Protection and Sustainable Development of the Guaraní Aquifer System, Global Environment Facility (GEF), Technical Report, Montevideo, Uruguay, 144 pp., 2008.

11) It would be better to have chapter 6.4 (Hydraulic conductivity) before chapter 6.3 (Model structure) so that the range of the values for the zones can be assessed better by the reader.

We will switch the order of sections 6.4 and 6.3 for clarity, as suggested by the reviewer. This change will be done on the final edition of the article.

12) To the figures: Fig. 4: What do the colors in the left part of the figure mean? Fig. 5: The figure needs more explanation: It should be made clear, that ratios between a steady state and the transient state of the new modeling approach are meant.

Colours had the only purpose of delineating different zones which were distinguished as being recharge-only zones and recharge/discharge zones. Figure 4 was reworked to clarify the point (see item 3).

The time function shown in Figure 5 represents anomalies with respect to the mean annual precipitation, i.e. a value of the time function equal to 1.2 for a particular year means that the annual precipitation for that year is 20 % higher than the mean annual precipitation. The precipitation series corresponding to the station Rivera-Santana, on the border between Uruguay and Brazil, was used to construct Figure 5, which were considered indicative of the precipitation temporal variability.