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Hydrology and Earth System Sciences Discussions

Interactive comment on "Impact of climate change on groundwater point discharge: backflooding of karstic springs (Loiret, France)" *by* E. Joigneaux et al.

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As said by the two Referees, the study must be completed in order to meet the objectives. Please find below our responses to the specific comments of Referee 2 and how they were taken into account to revise our article.

- The description of the study area is not entirely clear for someone who does not know the area. It is necessary to inspect Figure 1 several times to understand it well enough to be able to understand the paper. I suggest the use of colors to enhance it.

More information about the study area was added to the text: Tracer studies (both

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Interactive Discussion

Discussion Paper

artificial and natural) have shown that the Loire river waters infiltrates the aquifer mainly at Jargeau and reaches within a few days (3 to 4 days for the nearest ones) many temporary springs (Fig. 1) (Albéric and Lepiller, 1998; Lepiller, 2006). Most of them are located in the Loiret river which starts at the Bouillon Spring. Its mean flow is nearly 1m3/s and it mainly depends on the Loire river flow. However, under specific hydrological and meteorological condition, the first and major springs of the Loiret river, the Bouillon and Abîme springs, can behave as sinks. This happens when the Loire is at a low level and when heavy local precipitation occur in the Dhuy watershed (216 km^2), this river being an affluent of the Loiret river (confluence 1 km downstream of the Bouillon Spring). Surface waters of the Dhuy river backflow along the Loiret river and disappears into the Abîme and Bouillon resurgences which become sinkholes (Albéric, 2004). Fig. 1 has also been modified with a more detailed legend and more colors used. Please find Fig.1 at the end of this document and the new legend here: Figure 1. Geological and hydrological setting of the study area (modified from Albéric, 2004). The Loire river, going through the Val d'Orléans, loses water into sinkholes at Jargeau; the infiltrated surface waters reach several karst springs in the Loiret river. The Bouillon and Abîme springs are the major springs feeding the Loiret river. These resurgences can become sinkholes if the Dhuy river flows back in the Loiret river at the confluence, and the infiltration of Dhuy waters into the aquifer can threaten the drinking water wells near the springs.

- In section 2 it is mentioned that there are observations of backflooding events from 1997 to 2001, but in the next section (data and methodology) this is not remembered. This is confusing because, at first, the reader does not know whether the authors have this data or just are citing the paper of Albéric (2004). This should be mentioned somewhere within section 3.

These details have been added on the beginning of the section 3.1: Backflooding events were observed and studied from 1997 to 2001 mainly; the observation is still active today but since 2002 only a small number of events were recorded. Thus the

HESSD

8, C1830–C1836, 2011

period 1997-2001 can be called the backflooding reference period. However, this time period is too short to study efficiently the impact of climate change on the study area, consequently the reconstruction of potential past events is needed.

- In section 4.2 the flow of the Dhuy is reconstructed using a lumped hydrological model, but not much is said on how the model was calibrated, over which period, etc. The correlation and the quadratic deviation are mentioned, but the Nash-Suttclife efficiency (NSE) is not used. I suggest using the NSE, which is related to the quadratic deviation, because, being normalized, it gives a better idea of the performance of the simulation. This section should be improved.

The only objective of the use of the Gardenia model was the reconstruction of the missing daily flow from 1971 to 1974 and from 1977 to 1978. The Gardenia model simulates the water cycle using a system with several consecutive reservoirs. In this study three reservoirs are simulated: the first is a superficial reservoir which corresponds to the first centimeters of soil, fed by precipitation. The second is an intermediate reservoir representing the unsatured zone, recharged by surpluses occurring above the capacity of the superficial reservoir. This intermediate reservoir is drained by two ways: percolation in another reservoir and fast runoff outside. The third is a ground reservoir recharged by the intermediate one, and drained by percolation or slow runoff outside. The two hydrological parameters which control these reservoirs are WRC and RUNPER: WRC represents the Water Retention Capacity of the superficial reservoir, and RUNPER the water level in the intermediate reservoir when fast RUNoff and PERcolation are in equilibrium. Several simulations were tested with different values of WRC and RUNPER. When WRC or RUNPER are too high (more than 300mm for WRC and 25mm for RUNPER), the high Dhuy river flows are too much underestimated and backflooding events are less frequent. When these two parameters are too low (less than 100mm for WRC and 10mm for RUNPER), the high Dhuy river flow are too much overestimated, and there are too many backflooding events obtained from calculation. Consequently, the best values kept for this study were 205mm for WRC and 15mm for RUNPER. The

HESSD

8, C1830–C1836, 2011

Interactive Comment

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Nash-Sutcliffe Efficiency NSE has been calculated: for the whole period, the NSE is about 0.78, because the model trends to underestimate high flows and to overestimate low flows.

- In section 4.4 the authors find a relationship between WT and backflooding events. To achieve this, it is considered that a given WT affects the flow of the river of the following 3 days, with different weights. But nowhere in the study it is explained why these assumptions were made. As the paper is written, this looks very arbitrary and should be justified.

Several methods have been tested to evaluate the best relationship between daily WT and backflooding events. Indeed, we first linked each daily WT with a weighted moving average of Dhuy flow over the three days following the appearance of the WT, because we noticed that heavy precipitation related to one specific WT would be able to influence the Dhuy flow during a maximum of three days after the heavy rain. However, we also linked WT with the Dhuy flow of the next day, and the results are the same in both cases. So for the revised manuscript we choose to take into account the last calculation, which is the simplest.

- Previously, the authors mention that: although the appearance of backflooding is, on the daily scale, linked to the local river flows, its frequency is associated with the rainfall sequences of the order of several years. Later, analyzing two different short periods, they suggest that it is important how the sequences of different WT are. Therefore, I understand that the occurrence of a backflooding events not only depends on the WT of the day, but also on the previous days and months. This is expected, as the Dhuy and the Loire are non linear and the karstic system is non linear too, therefore, the resulting system might hide a complexity that the method used is not able to comprehend. As a result, Fig. 7 shows that the abilities of the different WT to produce backflooding events is very low. For example, JJA4 and IJA5, which are considered that trigger these events, have a ability between 5 and 10.

HESSD

8, C1830–C1836, 2011

Interactive Comment

At the pluri-annual scale, we noticed that according to precipitation, the Dhuy flow could vary from several consecutive years with generally low flows to years with high flows. Consequently, the years with Dhuy flows generally low are years with very few backflow events. However, at the daily scale, backfooding appearance depends on the respective flows of the Loire and Dhuy rivers. Indeed, as remembered in the Referee comment, previous days or weeks (maximum 3 weeks, but not months) may be important to control the hydrological state of the Loire river before precipitation event on the study area.

- As it is mentioned that the Loire must be low to have an event, then, it might be interesting to study the probability of a WT triggering an event conditioned to the level of the Loire. This might improve the results.

Yes, this is a really relevant comment. Indeed, backflow events cannot occur when the Loire river flow is higher than 320m3/s. To work in that direction, we calculated new abilities for each WT: the ability corresponds to the aptitude of a WT to cause backflooding, but weighted in relation with the seasonal occurrence of the WT. So we took into account for the calculation of this seasonal occurrence only days when the Loire flow was lower than 350m3/s. The new abilities recorded were significantly higher than the former ones. Moreover, we found two new triggering WTs (DJF5, DJF6) and one WT (JJA4) was removed because it has now a lower aptitude compared to the others.

- Finally, section 4.5 inherits the previous problems. From the results of the previous section, it is difficult to really discriminate backflooding events from WT information, therefore, the conclusions drawn from the analysis of the climate simulations is not very solid. Furthermore, there is not much agreement between climate model runs, as Figure 9 shows. Therefore, the uncertainty inherent to climate simulations severely increases the uncertainty of the whole study.

In the revised manuscript, the section 4.5 will be divided into 2 sections: (i) the results of the ARPEGE model alone, and the conclusions that can be drawn, and then (ii) the results corresponding to the other models used. Indeed, we first studied future occurrence of triggering and non-triggering WTs only with ARPEGE. This simulation originates from the French CNRM (National Centre for Meteorological Research) and is currently used for climate impact studies (e.g. Boé et al., 2006; Boé and Terray, 2008a; Boé et al., 2009a; Quintana Segui et al., 2010; Royer et al., 2002; Planton et al., 2008). Results show that occurrences of eight triggering WTs would decrease in the future, two would stay constant and only one would increase in frequency. Consequently, the occurrence of backflooding events in the future, according to this climate scenario, would decrease too. However, the use of other simulations from IPCC is needed to illustrate the variability and uncertainties of different models on the same study area. Indeed, the selected simulations have been chosen because each one is representative of a specific future climatic state: MIROC 3.2 MEDRES represents a much warmer and wetter climate in the future than in the present. GISS ER is a feature of a warmer and wetter climate in the future, GISS AOM a warmer and drier, and MIUB ECHO G a much warmer and drier climate.

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HESSD

8, C1830–C1836, 2011

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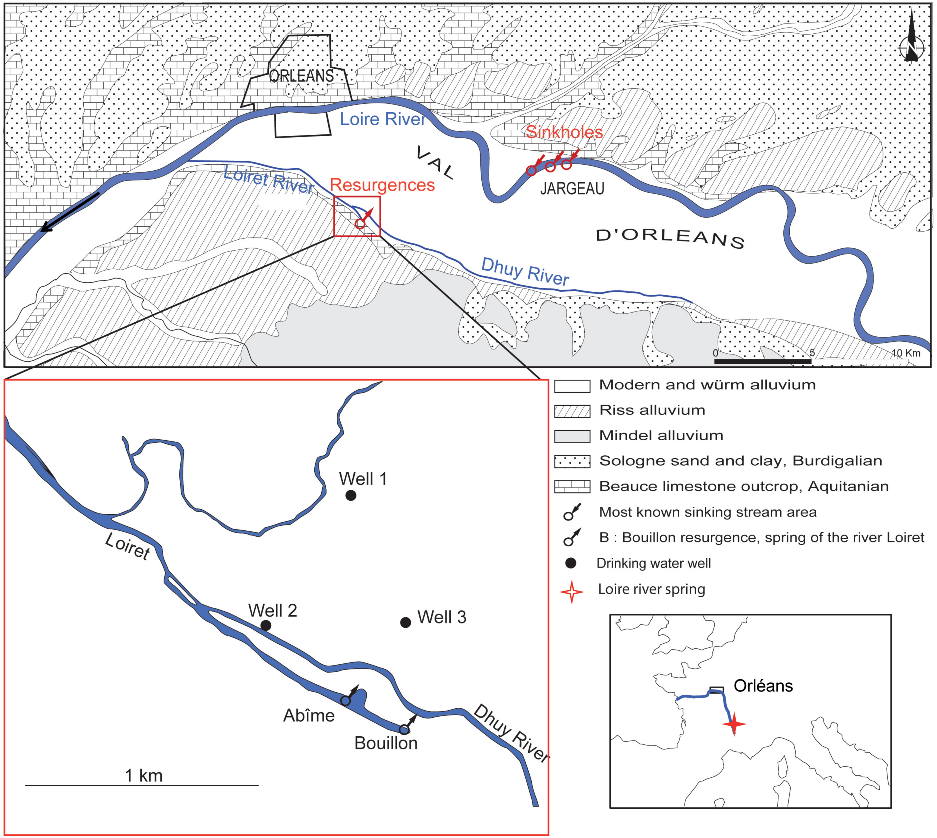

Fig. 1. Geological and hydrological setting of the study area (modified from Albéric, 2004)