Reply to reviewer #3

- First sentence in the section of Abstract: reword, it is too long and I did not understand it.

Reply: It is rewritten as "Pumping in a vertical well may produce a large drawdown cone near the well." (lines 2-3, page 2348)

- Pumping water next to a river may result in negative consequences, e.g. an increased infiltration rate can cause a river to become ephemeral. I would not only highlight the engineering aspects of pumping next to a river, but also add some points discussing that increased stream depletion can be a significant problem (see and cite e.g. Konikow, L. F. and Kendy, E., 2005. Groundwater depletion: A global problem. Hydrogeology Journal, 13(1): 317-320.)

Reply: Thanks for the suggestion. Regarding to this issue, the manuscript has been revised as "Consider that the water flowing to the well is significantly less than that in the stream; therefore, the effect of depletion on the stream is negligible. Otherwise, some negative impacts due to depletion of the stream had been discussed in Konikow and Kendy (2005)." (lines 2-4, page 2350)

- P. 2349, line 2: remove "the" so that it reads… "(1979), groundwater…"

Reply: The word, "the", has been deleted.

- P. 2349, line 9: Common assumptions of these solutions should be discussed because they are also made in this approach. All the cited papers here (including this one) are assuming that the interaction between the aquifer and the river remains fully saturated and therefore connected. However, pumping next to a river frequency results in a disconnection between surface water and groundwater. Under disconnected reaches, an additional drawdown does not result in a local increase of the infiltration rate. I suggest that the authors add the following text block and include the references: "These analytical solutions assume that no unsaturated zone between the river and the water table developed. However, if the streambed has a lower hydraulic conductivity than the aquifer, pumping is likely to induce unsaturated flow and disconnect the surface water from the groundwater. Once groundwater disconnects from the river, additional drawdown does not result in a local increase of the infiltration rate. The conditions under which a disconnection can occur have been discussed in detail by Brunner et al., 2009. Fox (2007) used a semi-analytical approach and showed how the length of the unsaturated zone under a river increased in time as

a result of pumping. These studies illustrate that it is important keep in mind that if a streambed has a lower conductivity than the aquifer (e.g. through streambed clogging), a disconnection between surface water and groundwater is likely to occur as a result of pumping. In this case, these solutions should no longer be applied directly as one of the main assumptions is no longer fulfilled."

Reply: Thanks for the comments and suggested discussions on the problems of low hydraulic conductivity and unsaturated flow. We had added those descriptions in the revised manuscript. (lines 1-12, page 2350)

- I think some key points should be added:
  1. Under what conditions do the authors suggest to use their solutions?
  2. What are the implications of the assumptions?

  A critical one that should be addressed is the assumption of a fully connection during pumping. Also, the available literature on horizontal wells under rivers does not seem to be explored adequately, e.g. the paper "Numerical simulation of groundwater flowing to horizontal seepage wells under a river" by Wei Wang and Ge Zhang, Hydrogeology Journal, Volume 15, Number 6 / September, 2007 is relevant for this work. Also, I suggest that the authors of this paper consult the reference within Wang and Zhang's papers, there might be interesting addition to mention.
- All the implicit assumptions should be listed and discussed.
  1. It is assumed that the river stage is not influenced by pumping.
  2. It is assumed that the system remains confined during pumping.
  3. It is further assumed that the streambed has the same conductivity as the aquifer. It is assumed that the stream and the aquifer remain hydraulically connected during pumping (as mentioned on page 2354). It is worth pointing out that this assumption is in fact a consequence of assuming the same hydraulic conductivity in the aquifer as well as in the streambed.

Reply: Thanks for the suggestion. A new paragraph is added to address the assumptions and applicability of the proposed model in the section of Method. It is shown below "

Three assumptions for the development of the mathematical model are made as follows: 1. The stream stage is not influenced by pumping. 2. The aquifer is assumed to maintain confined condition. 3. The hydraulic conductivities of the aquifer and streambed are the same. The first two assumptions imply that the proposed model is applicable if no unsaturated zone (no seepage face) occurs and the pumped water is significantly less than that in the stream." (lines 23-29, page 2350)

To address the issues in regard to the boundary condition at the stream, in the Introduction section, we have added following "Some articles also addressed the problems of pumping horizontal wells near the stream with treating the stream as the first-type (constant head) or second-type (constant flux) boundary (e.g., Kawecki, 2000; Zhan and Cao, 2000; Langseth et al., 2004). Fox (2007) used a semi-analytical approach and showed how the length of the unsaturated zone under a stream increases in time as a result of pumping. Wang and Zhang (2007) used a numerical simulation for describing the behavior of the infiltration from the stream during pumping of horizontal seepage wells. They indicated that if a streambed has a lower conductivity than the aquifer (e.g., through streambed clogging), a disconnection between surface water and groundwater is likely to occur. Under these circumstances, the use of first-type or second-type boundary condition for the stream may not be appropriate." (lines 1-12, page 2350)

- P. 2349, lines 12-13: change it to … "Installing horizontal wells has…". The next sentence ("The problems with…") is not understandable, please be more specific and detailed.

Reply: The sentence "Recently, the technique of installing the horizontal well has…" has been replaced by "Recently, installing horizontal wells has…".

The next sentence has been written as "The installation of vertical wells may not be feasible for the locations where the ground surfaces are covered with obstructions such as buildings and roads. Those problems can be overcome if adopting the horizontal well." (line 13-15, page 2349)

- P. 2349, line 24: This sentence is unclear and should be reformulated.

Reply: It is rewritten as "Joshi (2003) indicated that the use of horizontal wells reduces 50% operating costs in comparison with that of vertical wells." (line 24, page 2349)

- P. 2350, first sentence: the behavior instead of behaviors.
- P. 2351, line 2: "is the specific storage".
- P. 2351, line 10: "…are formulated as" instead of … "are respectively considered as".
- P. 2351, line 15: remove "The".
- P. 2353, line 8: "…Appendix A".
- P. 2354, line 4: … "hydraulically connected with…"
- P. 2354, line 9: Equation 23 is developed…
- P. 2354, line 11: "independent of …"

Reply: The manuscript has been revised according to these suggestions.

- P. 2354, line 15: I suggest to providing some justification on why the exponential terms are neglected.

Reply: Thanks for the suggestion. We added the following text to explain the neglect of the exponential terms.

"The drawdown due to pumping increases with time and approaches steady state after a certain period of time. This is because the exponential terms in equations (17) and (18) become small, say, less than 10^{-4}, when the time is large. A quasi-steady solution can then be obtained by applying the residue theorem when neglecting the exponential terms in equations (17) and (18)." (lines 14-17, page 2354)

References

Brunner, P., Cook, P. G., Simmons, C. T.: Hydrogeologic controls on disconnection between surface water and groundwater, Water Resour. Res., 45(1), W01422, doi: 10.1029/2008WR006953, 2009.

Fox, G. A., Gordji, L.: Consideration for unsaturated flow beneath a streambed during alluvial well depletion, J. Hydrol. Eng., 12(2), 139-145, 2007.

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Kawecki, M. W.: Transient flow to a horizontal water well, Groundwater water, 38(6), 842-850, 2000.

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Wang, W. and Zhang, G.: Numerical simulation of groundwater flowing to horizontal seepage wells under a river, Hydrogeology Journal, 15(6), 1211-1220, 2007.

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