Response to reviews

Title: Coupling global models for hydrology and nutrient loading to simulate nitrogen and phosphorus retention in surface water. Description of IMAGE-GNM and analysis of performance

Authors: A.H.W. Beusen, L.P.H. Van Beek, A.F. Bouwman, J.M. Mogollón, J.J. Middelburg

We are very grateful to the two reviewers for their constructive feedback. The suggestions for better-input data from reviewer 2 will definitely lead to significant improvement of next versions of the model. Reviewer 1 had a concern about the validation data used for the Mississippi, which we will address below and in the revised manuscript. Below are the **reviewer comments in bold**, our response is in regular text, *new text that will be included in the revision of our paper is in italics*.

REVIEWER 2

The manuscript "Coupling global models for hydrology and nutrient loading to simulate nitrogen and phosphorus retention in surface water – description of IMAGE-GNM and analysis of performance" by Beusen et al. describes the functionality and performance of their new addition to the IMAGE model complex. The paper is well written and clearly describes the model, which is a promising addition to existing lumped models, given its spatially explicit nature. Apart from two things, I have only minor aspects to comment and thus recommend minor revisions before the manuscript should be published in GMD.

My first comment regards the used input data, most of which are outdated. Newer datasets are available for - Soil data: http://www.isric.org/content/soilgrids - Lithology: Hartmann, J., Moosdorf, N., 2012. The new global lithological map database GLiM: A representation of rock properties at the Earth surface. Geochemistry Geophysics Geosystems, 13(12): Q12004 - Hydrology: Hydrosheds, SRTM water bodies The used data are not only of coarser spatial resolution, but also include sometimes substantial thematic shortages. Please discuss the effect of adding up-to-date datasets as model inputs, and please consider updating your input data in the future.

Response: We thank reviewer 2 for pointing to updates in the gridded input data for soils, lithology and water bodies. These are all quite recent data that were not (all) available when we selected the data for our model development. The suggested data also has a much higher spatial resolution, which will fit in our plans for the next model version. It is however, difficult to discuss what the effect of this will be on model results, as the reviewer asks.

In the revision in section 3.3 on future improvements we will discuss this issue in the first paragraph as follows:

We recognize that updates of the data used in this paper are now available. For example, soil data (http://www.isric.org/content/soilgrids), hydrographic information (http://hydrosheds.cr.usgs.gov/index.php) and lithology (Hartmann and Moosdorf, 2012) and associated porosity and permeability data (Gleeson et al., 2014). With these updates we will also have a finer resolution, allowing more specific calculation of surface characteristics (bare rock, more detailed soil texture classes, etc.). Hence, these updates and additional *datasets will be considered for future improved versions of the model, and tested with new sensitivity analyses.*

The second main comment aims at the calibration examples. The model aspires to represent global fluxes to be used at global scale, yet only three temperate rivers were used to evaluate the performance. I urge the authors to include datasets from rivers of different climates and regions.
Response: The second concern of reviewer 2 is the validation data used, i.e. the bias towards temperate rivers. Unfortunately the data for tropical rivers is quite scarce. The only data we could find that included tropical rivers are the GEMS-GLORI data, which are snap shots for a large number of rivers. Nevertheless, this dataset contains very few rivers with information for total N or total P. The few nutrient data for tropical rivers that were available have been compared with model results for total N. One additional measurement for the Amazon is included in the analysis. We agree that data for tropical rivers are scarce, and in future we hope to find more measurements.

Minor comments: P7480L28-P7481L21: That section already dives deep into the methodology – perhaps move it there.
Response: The comment that text on page 7480-L28 to 7481 L21 dives deep into the model is correct, but we maintain it in the introduction because it is meant to explain why this model development is a next step after the lumped regression models available until recently, as discussed at the bottom of page 7481. In that sense, it belongs in the introduction. The actual model description is a much more detailed description of the equations.

P7486L17: Why do you use the slope/runoff classification only of unconsolidated sediment – should that not be different for other lithological classes?
Response: We thank the reviewer for his/her concern about surface runoff in areas with bare rock.

We will add the following text to the relevant section 2.2.1 below equation (4):

The soil map used shows dominant soil texture, and has no bare rock class. In areas with bare rock such as in mountainous regions, slopes are generally steep, and equation (4) yields high values for f_{qsro}(slope) and thus for f_{qsro}. With the above suggested updated soil map and lithology map we will improve this calculation in a more elegant way.

P7506L121: Check model performance not just against individual rivers but against the weighted mean of all rivers in the EEA database
Response: We actually did, in figure 9e-f. See Line 7506 line 23-25.

Table 1: What is the reference of the porosity values? How do they compare to those provided in Gleeson, T., Moosdorf, N., Hartmann, J., van Beek, L.P.H., 2014. A glimpse beneath earth's surface: GLobal HYdrogeology MaPS (GLHYMPS) of permeability and porosity. Geophysical Research Letters, 41(11): 3891-3898. ?
Response: The reference for the porosity values is de Wit et al. (1999). We have added the reference to Table 1. The values are comparable to Gleeson et al. As the Gleeson et al. data is linked to the updated lithology map of Hartmann et al., this will be part of future improvements of our model, and the following text will be included in section 3.3 (future improvements):

We recognize that updates of the data used in this paper are now available. For example, soil data (http://www.isric.org/content/soilgrids), hydrographic information (http://hydrosheds.cr.usgs.gov/index.php) and lithology (Hartmann and Moosdorf, 2012) and associated porosity and permeability data (Gleeson et al., 2014). With these updates we will also have a finer resolution, allowing more specific calculation of surface characteristics (bare rock, more detailed soil texture classes, etc.). Hence, these updates and additional datasets will be considered for future improved versions of the model, and tested with new sensitivity analyses.

The following references will be added to the reference list:

de Wit, M.: Nutrient fluxes in the Rhine and Elbe basins, Faculteit Ruimtelijke Wetenschappen, Utrecht University, Utrecht, 163 pp., 1999.

Gleeson, T., Smith, L., Moosdorf, N., Hartmann, J., Dürr, H. H., Manning, A. H., Van Beek, L. P. H., and Jellinek, A. M.: Mapping permeability over the surface of the Earth, Geophysical Research Letters, 38, 2011.

Hartmann, J., and Moosdorf, N.: The new global lithological map database GLiM: A representation of rock properties at the Earth surface, Geochemistry, Geophysics, Geosystems, 13, 2012.