Hydrol. Earth Syst. Sci. Discuss., 9, C5046–C5053, 2012
www.hydrol-earth-syst-sci-discuss.net/9/C5046/2012/

Hydrology and
Earth System
Sciences
Discussions

Interactive comment on "Streamflow allocation in arid watersheds: a case study in Northwestern China" *by* C. He et al.

C. He et al.

he@wmich.edu

Received and published: 2 November 2012

Interactive comment on "Streamflow allocation in arid watersheds: a case study in Northwestern China" by C. He et al.

Anonymous Referee #1 Received and published: 1 August 2012 9, C3452–C3453, 2012 Interactive Comment

Authors' response to comments by Anonymous Referee #1

We appreciated the Anonymous Referee #1's comments and have revised or clarified our manuscript accordingly.

RC: 1. Streamflow allocation framework.

Response: We have clearly stated that the proposed allocation framework is in its preparation stage in the revised manuscript. It would be applicable to other similar watersheds after having been tested with the in situ data.

2. Application of the DLBRM to the Heihe Watershed.

Response: We have clearly stated the applicability and limitations of the DLBRM, including their uncertainties, failures, and needed improvements in the support of the water allocation plan in the revised manuscript.

Hydrological modelling: 1) The concept of the dominant hydrological variables.

Response: Hydrogeological investigations and isotopic studies by a number of researchers in the Heihe Watershed (Chen et al. 2006; Pan and Tian, 2001; Wu et al., 2004; 2010; Zhang et al. 2005) show that frequent transformations occur between the surface and groundwater in the Heihe Watershed. Specifically, (1) in the upper reach mountain area (outlet at the Yingluoxia flow gage station), net supply from precipitation and glacial melt infiltrates to the subsurface mainly through fractures; (2) Once the river flow exits the mountain outlet, majority of it (70 to 80%) infiltrates into the deep alluvial piedmont aquifer with coarse grains as the mountain front is a large fault zone, and subsequently a portion of the infiltrated water either discharges to the river in the form of return flow or flows to the downstream aquifer that consists three layers of middle- fine sands; (3) In the oasis area zones with fine-grained soil, irrigated agriculture by both groundwater and surface water is the largest consumptive water use , and about 40% of the groundwater discharges and enters the surface water in the form of spring water ; (4) In the lower reach desert (north of the Zhengyixia flow gage station), surface water seeps into the aquifer through irrigation and large fractures as annual precipitation in the area is smaller than 50 mm.

Thus, we define the water budget in the upper reach mountain, middle reach oasis, and lower reach desert in Fig. 2, respectively. Gu represents portion of the net supply that recharges groundwater in the mountain area, Gm represents portion of the surface water that has been infiltrated to the aquifer in the middle oasis area, and Gl is the amount of surface water that is infiltrated to the aquifer in the lower reach.

2) How was the groundwater - surface water interaction modeled?

Response: The DLBRM was developed by the National Oceanic and Atmospheric Administration(NOAA) Great Lakes Environmental Research Laboratory and Western Michigan University. It represents a watershed by using 1 km2 (or other size) grid cells organized in a tree-like flow network derived from digital elevation maps. Each cell of the watershed is composed of moisture storages of the upper soil zone (USZ), lower soil zone (LSZ), groundwater zone (GZ), and surface, which are arranged as a serial and parallel cascade of “tanks” to coincide with the perceived basin storage structure (Fig. 4). Precipitation enters the snow pack, which supplies the cell surface (degree-day snowmelt). Infiltration is proportional to this supply and inversely proportional to saturation of the upper soil zone (partial-area infiltration). Excess supply is surface runoff. Within the cell, moisture moves vertically from USZ to LSZ and eventually to GZ. Flows from runoff and subsurface components contribute to the cell’s surface water storage. Except for the headwater cells (leaves), each cell of this tree receives flows from upstream cells into its surface storage and into its subsurface storages. The sum of all tributary inflows from each level determines the total input hydrographs into each of the storage zones (upper soil zone, lower soil zone, groundwater zone, and surface zone) of the cell. Flows from all tanks are proportional to their amounts (linear-reservoir cascade routing). Mass conservation applies for the snow pack and tanks; energy conservation applies to evapotranspiration (ET). The model computes potential ET from a heat balance, indexed by daily air temperature, and calculates actual ET as proportional to both the potential and storage. It allows surface and subsurface flows to interact both with each other and with adjacent-cell surface and subsurface storages. While the DLBRM models the groundwater’s contribution to surface outflow, it doesn’t

simulate the seepage from the channel to groundwater storage.

Simulating the river-aquifer interactions in fractured bedrock mountain regions and discharge basin like the Heihe Watershed by hydrological models has been a challenge . Isotopic and hydrogeological field methods are needed to help reveal the river-aquifer interactions in such watersheds (We et al. 2004; 2010). We have revised the manuscript to clearly describe the simulation of the river-aquifer interaction by the DLBRM and the applicability and limitations of the model to arid watersheds like the Heihe. 3) Calibration and validation results for the four stream gauges.

Response: We have added the calibration and validation results including the statistic summary and hydrographs to discuss the performance of the DLRBM at the four flow gauge stations with different scales and dominant processes.

4) Uncertainty analysis.

Response: We have addressed the simulation uncertainties by conducting a sensitivity analysis of the variables and statistical analysis. The results are shown in the revised manuscript.

Interactive comment on “Streamflow allocation in arid watersheds: a case study in Northwestern China” by C. He et al. Anonymous Referee #2 Received and published: 2 August 2012

Authors’ response to comments by Anonymous Referee #2

We appreciated the Anonymous Referee #2’s comments and have revised or clarified our manuscript accordingly.

RC: Validation of the streamflow allocation framework. Response: We have clearly stated that the proposed allocation framework is in its preparation stage in the revised manuscript. It would be applicable to other similar watersheds after having been tested with the in situ data.

RC: Hydrological analysis. 1. Description of the flood routing component of DLBRM.

Response: We have added a brief description of the routing of the DLBRM in the revised manuscript. "Cells in a watershed are organized in a tree-like flow network derived from digital elevation maps. Within each cell, flows from runoff and subsurface components contribute to its surface water storage. Except for the headwater cells (leaves), each cell of this tree receives flows from upstream cells into its surface storage and into its subsurface storages. The sum of all tributary inflows from each level determines the total input hydrographs into each of the storage zones (upper soil zone, lower soil zone, groundwater zone, and surface zone) of the cell. The output of each cell storage to a downstream cell is determined by a linear cascade-type routing (Croley et al. 2006)."

2. Analysis of the upper soil zone evaporation (USZE) .

Response: we have experimented in the DLBRM by setting three higher levels of the upper soil zone evaporation partial linear reservoir coefficient (0.2E-7; 0.5E-7; and 0.5E-6; with 0.1E-9 the current value) and recalibrated the model. The values of the new RMSE are respectively 0.00723, 0.00725, 0.00747 (the present RMSE is 0.00724), showing a deterioration in model performance with higher USZ evaporation and lower LSZ evaporation.

This phenomenon is attributable to several factors. First, the USZ is a conceptual storage layer with a simulated capacity of a few cm to up to 100 cm. Second, between the mountain outlet (Yingluoxia) and middle reach outlet (Zhengyixia), soil is quite coarse and sandy, and thus water from the USZ infiltrates to the LSZ quickly (Cheng et al., 1999;Wu et al., 2010) (Figs. 5, 6, and 7). Third, consumption of groundwater is mainly through evaporation in the middle reach of the watershed. Since the LSZ is several hundred meters deep and could be mixed with groundwater zone, loss of soil water and groundwater was simulated through the form of evaporation to the atmosphere in this study (Cheng et al., 1999; Jia et al., 2005; Pan and Tian, 2001; and Wu et

al., 2010). Fourth, during summer monsoon, a significant quantity of water is stored in reservoirs for irrigation purposes. This withdraw is not explicitly modeled by this version of the model and results in higher LSZ storage and evaporation losses.

3. How was the groundwater - surface water interaction modeled?

Response: The DLBRM was developed by the National Oceanic and Atmospheric Administration(NOAA) Great Lakes Environmental Research Laboratory and Western Michigan University. It represents a watershed by using 1 km2 (or other size) grid cells organized in a tree-like flow network derived from digital elevation maps. Each cell of the watershed is composed of moisture storages of the upper soil zone (USZ), lower soil zone (LSZ), groundwater zone (GZ), and surface, which are arranged as a serial and parallel cascade of “tanks” to coincide with the perceived basin storage structure (Fig. 4). Precipitation enters the snow pack, which supplies the cell surface (degree-day snowmelt). Infiltration is proportional to this supply and inversely proportional to saturation of the upper soil zone (partial-area infiltration). Excess supply is surface runoff. Within the cell, moisture moves vertically from USZ to LSZ and eventually to GZ. Flows from runoff and subsurface components contribute to the cell’s surface water storage. Except for the headwater cells (leaves), each cell of this tree receives flows from upstream cells into its surface storage and into its subsurface storages. The sum of all tributary inflows from each level determines the total input hydrographs into each of the storage zones (upper soil zone, lower soil zone, groundwater zone, and surface zone) of the cell. Flows from all tanks are proportional to their amounts (linear-reservoir cascade routing). Mass conservation applies for the snow pack and tanks; energy conservation applies to evapotranspiration (ET). The model computes potential ET from a heat balance, indexed by daily air temperature, and calculates actual ET as proportional to both the potential and storage. It allows surface and subsurface flows to interact both with each other and with adjacent-cell surface and subsurface storages. However, while the DLBRM models the groundwater’s contribution to surface outflow, it doesn’t simulate the seepage from the channel to groundwater storage.

Simulating the river-aquifer interactions in fractured bedrock mountain regions and discharge basin like the Heihe Watershed by hydrological models has been a challenge . Isotopic and hydrogeological field methods are needed to help reveal the river-aquifer interactions in such watersheds (We et al. 2004; 2010). We have revised the manuscript to clearly describe the simulations of the river-aquifer interaction by the DLBRM and the applicability and limitations of the model to arid watersheds like the Heihe.

4. Calibration and validation.

Response: We have added the calibration and validation results including the statistic summary and hydrographs to discuss the performance of the DLRBM at the four flow gauge stations with different scales and dominant processes.

5. Uncertainty analysis.

Response: We have addressed the simulation uncertainties by conducting a sensitivity analysis of the variables and statistical analysis. The results are shown in the revised manuscript.

RC:IWRM review in arid regions.

Response: While there are many research projects addressing water management in arid regions, a framework like the proposed is timely needed to comprehensively address multiple factors and processes involved in water allocation and to facilitate the implementation of IWRM at the watershed level, particularly in the water stressed inland rivers of China. We appreciate the suggestion and will consider a comprehensive review of IWRM in arid regions in a separate paper. Sincerely,

C. He et al. Additional References Cited Chen, Z.Y., Wan, L., Nie, Z.L., Shen, J.M. and Chen, J.S.: Identification of groundwater recahrge in the Heihe Basin using environmental isotopes. Hydrogeology and Engineering Geology 6:9-14, 2006 (in Chinese). Wu, Y., Wen, X. and Zhang, Y.: Analysis of the exchange of groundwater and river water by using Radon-222 in the middle Heihe Basin of northwestern China. Environmental Geology 45:647-653, 2004. Zhang, G., Nie, Z., Wang, J. and Cheng, Xu.: Isotopic characteristic and recharge effect of groundwater in the water circulation of Heihe River Basin. Advances in Earth Science 20:511-519, 2005 (in Chinese).

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 8941, 2012.