Geophysical Research Abstracts
Vol. 17, EGU2015-3687-3, 2015
EGU General Assembly 2015

Optimizing conjunctive use of surface water and groundwater for irrigation in arid and semi-arid areas: an integrated modeling approach

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In arid and semi-arid agricultural areas, groundwater (GW) is an important water source of irrigation, in addition to surface water (SW). Groundwater pumping would significantly alter the regional hydrological regime, and therefore complicate the water resources management process. This study explored how to optimize the conjunctive use of SW and GW for agricultural irrigation at a basin scale, based on integrated SW-GW modeling and global optimization methods. The improved GSFLOW model was applied to the Heihe River Basin, the second largest inland river basin in China. Two surrogate-based global optimization approaches were implemented and compared, including the well-established DYCORS algorithm and a new approach we proposed named as SOIM, which takes radial basis function (RBF) and support vector machine (SVM) as the surrogate model, respectively. Both temporal and spatial optimizations were performed, aiming at maximizing saturated storage change of midstream part conditioned on non-reduction of irrigation demand, constrained by certain annual discharge for the downstream part. Several scenarios for different irrigation demand and discharge flow are designed. The main study results include the following. First, the integrated modeling not only provides sufficient flexibility to formulation of optimization problems, but also makes the optimization results more physically interpretable and managerially meaningful. Second, the surrogate-based optimization approach was proved to be effective and efficient for the complex, time-consuming modeling, and is quite promising for decision-making. Third, the strong and complicated SW-GW interactions in the study area allow significant water resources conservation, even if neither irrigation demand nor discharge for the downstream part decreases. Under the optimal strategy, considerable part of surface water division is replaced by 'Stream leakage-Pump' process to avoid non-beneficial evaporation via canals. Spatially, the optimization suggests increase of pumping percentage in areas with significant GW recharge and shallow water table and adjacent to the main river channel. Temporally, the optimization suggests increase of pumping percentage during dry seasons, and decrease during flooding seasons. The groundwater storage zone could work as inartificial reservoirs because of the fierce interactions between SW and GW to help achieve spatial and temporal reallocation without loss from evaporation. Moreover, the results of different scenarios reveal that, sustainability of saturated zone for the midstream part could be promoted dramatically by cutting down irrigation demand. The study results are of significant importance to the water resources management in arid and semi-arid agricultural areas.