Geophysical Research Abstracts
Vol. 15, EGU2013-3179, 2013
EGU General Assembly 2013

Dynamic Attribution of Global Water Demand to Surface Water and Groundwater Resources: Effects of Abstractions and Return Flows on River Discharge

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As human water demand is increasing worldwide, groundwater is abstracted at rates that exceed groundwater recharge in many areas, resulting in depletion of existing groundwater stocks. Most studies, that focus on human water consumption and water stress indicate a gap between water demand and availability. However, between studies very different assumptions are made on how water abstraction is divided between surface water, groundwater, and other resources. Moreover, simplified assumptions are used of the interactions between groundwater and surface water. Here, we simulate at the global scale, the dynamic attribution of total water demand to surface water and groundwater resources, based on actual water availability and accounting for return flows and surface water-groundwater interactions. The global hydrological model PCR-GLOBWB is used to simulate water storages, abstractions, and return flows for the model period 1960-2010, with a daily time step at 0.5° x 0.5° spatial resolution. Total water demand is defined as requirements for irrigation, industry, and domestic use. Water abstractions are variably taken from surface water and groundwater resources depending on availability of both resources. Return flows of non-consumed abstracted water contribute to a single source; those of irrigation recharging groundwater, those of industry and domestic use discharging to surface waters. Groundwater abstractions are taken from renewable groundwater, or when exceeding recharge from an alternative unlimited resource. This resource consists of non-renewable groundwater, or non-local water, the former being an estimate of groundwater depletion. Results show that worldwide the effect of water abstractions is evident, especially on the magnitude and frequency of low flows when the contribution of groundwater through baseflow is substantial. River regimes are minimally affected by abstractions in industrial regions because of the high return flows. In irrigated regions the effect of abstractions is clear and including return flows is important as well. It increases groundwater storage and baseflow to the river channel. Furthermore, simulated trends of water abstraction, and its attribution to surface water or groundwater, strongly depend on whether return flows are included or not. Particularly on the ratio of renewable to non-renewable and non-local water resources. Estimated total groundwater abstraction for the year 2000 is 1100 km^3y^{-1}, of which ∼35% comes from reused irrigation water. Non-renewable-, or non-local water abstraction is estimated to be ∼560 km^3y^{-1}, which corresponds well with estimates from previous studies. This term increases, mainly for intensively irrigated areas, to ∼840 km^3y^{-1} when return flows are not accounted for. The dynamic representation of abstractions and return flows makes the model a suitable tool for assessing spatial and temporal impacts of global water demand on hydrology and water resources.