THE IMPACT OF MANMADE RESERVOIRS ON LARGE-SCALE HYDROLOGY AND WATER RESOURCES USING HIGH-RESOLUTION MODELING

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Abstract:

Manmade reservoirs are important components of the terrestrial hydrologic system. Dam installments fragment river systems, and reservoir operations alter flow regimes. The total storage capacity of existing global reservoirs is large enough to hold one sixth of annual continental discharge to ocean. Due to growing energy demands, hundreds of large dams are being built and planned around the world, especially in the developing countries. Therefore, there is an urgent need to develop a better understanding of the impact of those dams on hydrology and water resources. Owing to increasing computational power and needs to understand and simulate processes in small-scale, hydrological models are advancing towards hyper-resolutions global hydrological models. One of benefits from increasing modeling resolutions is that the dynamics of surface water inundation over natural river-floodplain systems and manmade reservoirs can be explicitly represented; however, the existing global models are not capable of simulating the river-floodplain-reservoir inundation dynamics in an integrated manner. This dissertation addresses this important standing issue by developing a high-resolution, continental-scale model to simulate the spatial and temporal dynamics of reservoir storage and release, thus paving pathways toward hyper-resolution surface water modeling in continental- to global-scale hydrological and climate models. The newly developed model is applied to simulate reservoirs within the contiguous United States (CONUS) and the Mekong River Basin (MRB) in Southeast Asia. With respect to the model development, the following advances are made over the previous global reservoir operation studies: (1) an existing algorithm for reservoir operation is improved by conducting analytical analysis and numerical experiments and by introducing new calibration features for reservoir operation; (2) the spatial extent and its seasonal dynamics of reservoirs are explicitly simulated and reservoirs are treated as an integral part of river-floodplain routing, thus reservoir storage is no longer isolated from river and floodplain storages; and (3) a novel approach for processing and integrating high-resolution digital elevation models (DEMs) in river-floodplain-reservoir routing is introduced. The newly developed reservoir scheme is integrated within the river-floodplain routing scheme of a continental hydrological model, LEAF-Hydro-Flood, which is set for the CONUS, where abundant data are available for model validation. Then, the reservoir scheme is integrated into a global hydrodynamics model, CaMa-Flood, to investigate the historical impact of manmade reservoirs in the MRB that is undergoing an unprecedented boom in hydropower dam construction. Using the new scheme, the role of flood dynamics in modulating the hydrology of the MRB and the potential impact of flow regulation by the dams on the inundation dynamics are investigated. The significance of hydrologic effect of increasing dams is compared with that of climate variability. The fully coupled river-reservoir-floodplain storage simulation approach presented in this dissertation provides an advancement in hydrological modeling in terms of representation of surface water dynamics, which is indispensable to for better attribution of the observed changes in the water cycle, prediction of changes in water resources, and the understanding of the continually changing environmental and ecological systems.