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Controls on the Impact of Large Reservoirs on Flood Peaks and Population Exposure at the National Scale in Italy

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In recent decades, floods have been the most frequent and impactful disasters worldwide, prompting renewed interest in the role of existing hydraulic infrastructures as adaptation measures. Large reservoirs can locally attenuate flood peaks by temporarily storing excess water, but their effectiveness at broader spatial scales remains poorly quantified. Here, we assess the national scale impact of large reservoirs on flood peak attenuation and population exposure in Italy by accounting for both the spatial variability of their effects and the combined influence of multiple reservoirs. We analyze large reservoirs in Italy using a physically based, spatially distributed index that quantifies flood peak reduction along the entire river network. The method represents the combined effect of multiple reservoirs through an equivalent reservoir concept, accounting for travel times, downstream unregulated contributions, and reservoir flood storage capacity. We compute discharge-weighted and population-weighted indices of flood peak reduction under current conditions and under hypothetical retrofit scenarios with increased flood storage capacity. Results show that, while reservoirs can strongly attenuate flood peaks locally (up to 70-80% immediately downstream), their average impact at the national scale is limited. Furthermore, increasing reservoir flood storage capacity only marginally improves this effect. The limited effectiveness is primarily controlled by the spatial configuration of reservoirs within the Italian river network and the location of population centers relative to regulated reaches. These findings indicate that existing reservoirs alone are insufficient as a systemic flood adaptation strategy in Italy, and that effective risk reduction requires spatially coordinated, catchment scale combinations of measures.