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Hydrodynamic modelling of floods and developing an emulator for long term inundation predictions

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Abstract: Flood inundation modelling is a critical component of river basin management, supporting engineering, ecological, and environmental decision-making. By simulating the extent, depth, and duration of floodwaters across landscapes, hydrodynamic models enable effective risk assessment, emergency planning, and resilient infrastructure design. They are essential tools for informing land-use planning, insurance assessments, and policy development, particularly in the face of increasing flood risks driven by climate change and urban expansion. Moreover, accurate flood modelling helps safeguard lives and livelihoods by enabling timely warnings and targeted mitigation strategies.

Despite their utility, hydrodynamic models are often limited by complex configuration and long simulation runtimes. To address this, we developed a flood inundation emulator capable of rapidly estimating daily inundation area based on daily river flow. This study presents flood inundation modelling results for the Victoria River catchment in northern Australia, using a two-dimensional flexible mesh hydrodynamic model (MIKE21 FM). The model domain spans 16,730 km^2, covering major river floodplains and tidal flats of the catchment. A high-resolution 5 m LiDAR Digital Elevation Model – LiDAR DEM (±0.3 m horizontal and ±0.1 m vertical accuracy) was used, supplemented with a 30 m Forest And Buildings removed Copernicus digital elevation model (FABDEM) beyond the LiDAR extent. Hydraulic roughness coefficients for the land surface were derived from Geoscience Australia's dynamic land cover map.

Model calibration employed inundation maps derived from MODIS and Landsat imagery, along with water level data from river gauges. Five flood events, with magnitudes ranging from an Annual Exceedance Probability (AEP) of 1 in 2 to 1 in 18, were simulated. Each simulation was conducted for 30 days irrespective of flood magnitude. The calibrated hydrodynamic models were then used to investigate flood characteristics under future climate and hypothetical development scenarios.

Simulated inundation areas were related to river inflows using a regression-based emulator. Among potential covariates (flood volume and peak flow), peak flow during flood events proved to be the most reliable predictor of inundation extent and was chosen as the measure for use in the regression model. The emulator was applied to a 133-year discharge time series (1890-2022) to estimate the annual mean flooded area under various climate and hypothetical development scenarios. Under current climate and development conditions, the mean annual maximum flooded area was 417 km^2. This was reduced to 302 km^2 with the addition of three dams of 1367 GL total storage, and to 408 km^2 under a 680 GL water harvesting scenario. The effects of instream dams on inundation extent, depth, and duration are relatively high, since dams reduce and delay peak flows by storing water during the high flows, depending upon the antecedent storage capacity of the dam.

Keywords: *LiDAR, MIKE21, MODIS, Northern Australia, Victoria Catchment*

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