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Adapting communities to traffic disruption induced by flooding

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Abstract

Flooding is among the most frequent and disruptive natural hazards affecting transport systems, and its impacts are expected to intensify due to climate change, urban growth, and aging infrastructure. Bridges are particularly vulnerable because they serve as key network nodes, concentrate traffic flows, and often provide limited redundancy. When a bridge is overtopped and closed, even temporarily, the consequences can extend far beyond the local site, causing network disruptions, delays to emergency services, and significant social and economic losses (Bakhtyari et al., 2025). Bridge flooding should therefore be addressed not only as a structural or hydraulic issue, but also in terms of mobility. In this context, effective adaptation requires tools capable of identifying the most critical crossings, estimating the transportation consequences of failure, and communicating risks to support planning and decision-making.

This study proposes a multi-scale framework that integrates GIS analysis, hydrologic-hydraulic and traffic modelling, and Web-GIS communication to support community adaptation (Figure 1). The methodology follows a risk-based structure, linking bridge overtopping as the hazard source, road infrastructure as exposed element, and traffic impacts as the vulnerability.

At the large-catchment scale ($\geq 10^3$ km^2), a GIS-based screening is used to estimate bridge overtopping potential based on the sole geometric characteristics of the crossing (Amaddii et al., 2026). This information is combined with macroscopic traffic modelling to quantify network disruption from bridge closures using two indices: one capturing absolute disruption and the other relative travel-cost increases. The two components are integrated into a bridge risk index that captures both bridge

overtopping potential and traffic relevance. The findings are presented through a Web-GIS interface, allowing users to interactively explore critical bridges, disrupted routes, and alternative paths. At the local scale (< 10^3 km^2), the framework is refined using Rain-on-Grid (RoG) simulations within a two-dimensional hydrodynamic model, enabling explicit representation of bridge–flow interactions. Bridge geometries are incorporated into the computational domain to assess overtopping and local flood impacts. A sub-basin is selected for detailed analysis, where a calibrated model is applied to both a documented rainfall event and a set of design storms with varying return periods and durations. These simulations enable the evaluation of bridge overtopping, flood depths, and road impassability, providing a comprehensive representation of local impacts on transport continuity. Microscopic traffic simulations were therefore performed within a smaller study area nested inside the regional network. The traffic demand for this local model is derived by extracting the trips crossing the sub-area from the macroscopic traffic assignment results to quantify the traffic impacts associated with designed rainfall events that cause bridge closures and road segments to operate at reduced speeds due to flooding. The results are provided via the dedicated web-GIS platform, including flood maps and information on closed bridges and affected road edges for the various scenarios, as well as the suggested alternative routes. The multi-scale approach is applied to the Magra River Basin in north-western Tuscany, Italy, a flood-prone area with a history of intense rainfall events and severe transport disruption. The large-scale screening method is applied to the entire Magra River Basin (~1000 km^2), while local scale analyses were conducted on a critical sub-basin (120 km^2). The Web-GIS component further enhances risk communication by transforming complex modelling outputs into accessible information for planners, operators, and citizens. Overall, the framework demonstrates how multi-scale modelling can reconcile computational efficiency with hydraulic and network-level detail, providing a practical basis for flood adaptation planning in transport systems.

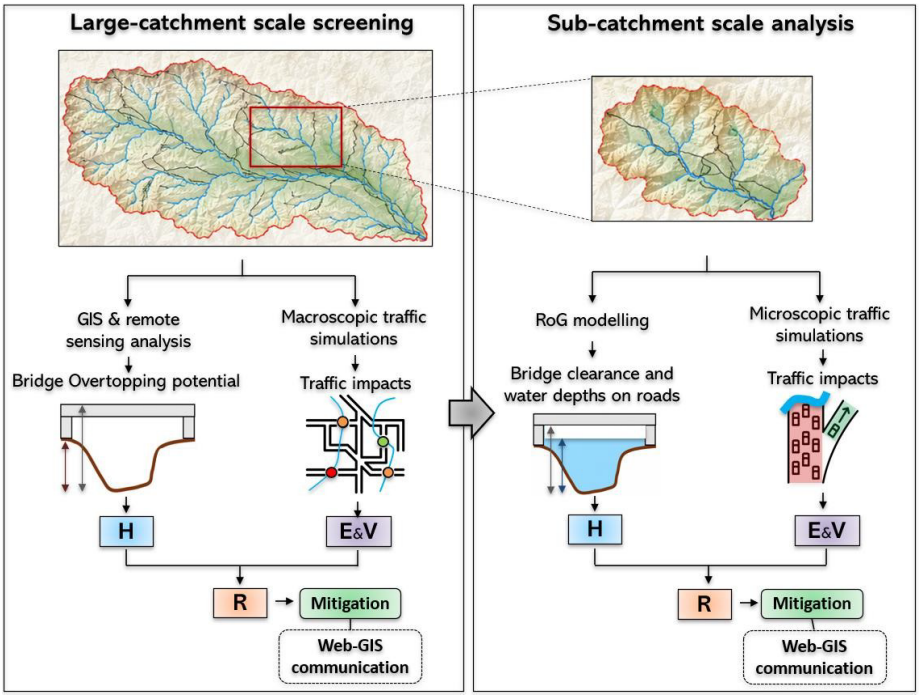

Figure 1 - Workflow of the multi-scale assessment of bridge risk derived from overtopping hazard and traffic impacts.

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