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Brief communication: The effect of resolution uncertainty in road flood-disruption modelling

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Abstract. Flood-disruption models are used to support road adaptation planning, yet the influence of flood-map resolution on disruption estimates remains unclear. We show that resolution strongly influences road exposure, which propagates into strong variations within the estimated network disruption metrics. In our case study, apparent road exposure increases when resolution coarsens beyond 5-10 m, indicating that resolutions finer than this range are preferred to limit these effects. At resolutions above 50-70 m, substantially different estimates of connectivity loss and conflicting interpretations of adaptation priorities emerge, highlighting spatial resolution as a key uncertainty in road adaptation assessments.

1 Introduction

Flood exposure estimates are known to vary with spatial resolution. Grid size affects inundation extent, water depth, and the ability to represent local features that determine how water is stored and routed across the landscape (Lee et al., 2025; Muthusamy et al., 2021; Xing et al., 2025; Yalcin, 2020). High-resolution flood maps can show detailed wet and dry patterns along roads, canals, bridges, and local terrain features, albeit at increased computational expense. Coarser maps may generalise or shift those patterns relative to the road network, creating resolution-induced artefacts, i.e. flood-road overlay effects that arise from data representation rather than the underlying flood process.

Flood models are increasingly combined with transport-network analyses to estimate disruption and support flood-risk assessment and adaptation planning (Deidda et al., 2026; van Ginkel et al., 2022). These applications rely on spatial overlays between flood-hazard data and exposed assets. Earlier large-scale studies often represented infrastructure through raster-based land-use data, whereas more recent work increasingly uses vector-based road networks to represent individual road links and their network structure (van Ginkel et al., 2021; Papilloud et al., 2020). This progression has improved the representation of exposed infrastructure, but uncertainties in the flood representation itself remain an important challenge for flood impact assessments (Bates, 2023). As such, more detailed exposure data do not eliminate uncertainty in impact estimates when combined with uncertain flood-hazard information. When used for road-network analyses, these uncertainties may affect estimates of transport disruption.

In road-network applications, resolution-induced differences in flood extent and water depth may alter which links are classified as flooded and consequently affect estimates of connectivity loss and detours. This is relevant given the wide range of flood-hazard resolutions used in transport disruption studies, ranging from metre-scale inundation maps (Kasmalkar et al., 2020) to continental-scale studies using 100 m (van Ginkel et al., 2022) and 0.5° (~55 km) hazard data (Deidda et al., 2026). Although several authors acknowledge limitations associated with coarse flood-hazard data (Deidda et al., 2026; van Ginkel et al., 2022), the implications of these limitations for transport-disruption modelling remain unclear.

Relevant research falls into two broad categories. One examines how spatial resolution and terrain representation affect flood extent, water depth, and exposure estimates (Bates, 2023; Lee et al., 2025; Muthusamy et al., 2021; Xing et al., 2025; Yalcin, 2020). The other uses flood maps to estimate road exposure and network disruption, including connectivity loss, accessibility reductions, and detour requirements (Deidda et al., 2026; van Ginkel et al., 2022; Kasmalkar et al., 2020; Papilloud and Keiler,

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2021). However, it remains unclear whether resolution-driven differences in flood representation translate into meaningful differences in disruption estimates.

This brief communication examines how the choice of flood-map resolution affects which roads are identified as flooded and how these differences propagate into network disruption estimates. The aim is to show how resolution-related uncertainty can alter interpretations of network vulnerability and adaptation priorities.

2 Methods

2.1 Flood maps and spatial resolution

This study builds on a large-scale pluvial flood case study in South Holland, the Netherlands, described in detail by (De Bruijn et al., 2022). Pluvial flooding occurs when intense rainfall exceeds drainage and storage capacity, causing water to accumulate across the landscape. In this predominantly low-lying polder system, flood patterns are strongly influenced by local topography and the distribution of excess water volumes. The resulting flood maps form the basis for analysing how spatial resolution affects estimates of road-network disruption.

The flood maps were produced from a two-step modelling chain. First, regional hydrological-hydraulic 1D SOBEK water-system models (Deltares, 2024) were used to estimate stored water volumes per drainage area given large-scale precipitation event. Then, these volumes were translated into water-depth maps using the Waterverspreider (Dutch for 'water distributor'), a post-processing tool that distributes SOBEK-derived storage volumes across each area using a digital elevation model (De Bruijn et al., 2022). This approach is appropriate for modelling pluvial flooding in our setting, as inundation patterns are primarily governed by the accumulation and spatial distribution of excess water volumes rather than detailed routing of high-velocity flows. In this study, the upstream SOBEK volumes and model settings were kept fixed. Only the grid size used to distribute these volumes into water-depth maps was changed. The finest possible water volume distribution is limited by the AHN3 elevation data, constrained to a grid size of 0.5 m.

Flood maps were produced for the Bleiswijk-Bergschenhoek area at multiple spatial resolutions: 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, and 100 m. For instance, a 100 m resolution map has cells of 100 m by 100 m. Each cell stores one water-depth value. Changing the resolution changes how finely water depths are represented across the landscape. All maps used the same input data and model parameters, isolating the effect of spatial resolution. Finally, coarser maps were compared with the 1 m reference.

2.2 Road overlay and impact metrics

For each resolution, the flood map was overlaid with the road network retrieved from OpenStreetMap (OpenStreetMap contributors, 2025) using the Risk Assessment and Adaptation for Critical InfrastructurE (RA2CE) tool (Deltares, 2026). This overlay assigns flood characteristics to each road link, represented as an infinitely thin centreline (rather than the full road surface), including the maximum flood depth and the fraction of the length of the link that is flooded. These attributes determine whether each road link is classified as disrupted under each road-failure rule. In the reported results, bridges and tunnels were excluded from the disruption classification where mapped inundation did not represent the functional road surface. Results without this exclusion were used to identify bridge and tunnel artefacts. Road classes follow the OpenStreetMap hierarchy; *unclassified* roads represent local roads that do not belong to a higher functional class such as tertiary, secondary, or primary roads.

Flood exposure describes the direct overlay result before network effects are calculated. Exposure was measured as the share of road links classified as disrupted at each resolution. Three road-failure rules were applied:

- *Near-zero depth rule*: a link was classified as disrupted if any part of the link intersected water deeper than 0.01 m.
- *Depth rule*: a link was classified as disrupted if any part of the link intersected water deeper than 0.3 m.

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- *Depth-and-fraction rule*: a link was classified as disrupted if any part of the link intersected water deeper than 0.3 m and more than 30% of the link was flooded.

Next, network disruption metrics were calculated. For each rule and resolution, all links classified as disrupted were removed from the road network. To enable consistency across resolutions, a fixed reference set of origin-destination (OD) pairs was generated by drawing 100 random samples of 200 nodes from the road network graph using a fixed random seed. The same samples were used for all rules and resolutions, ensuring that any differences in network metrics reflected the effects of disruption rather than differences in the sampled OD-pairs.

Connectivity loss was calculated per sample over all OD-pairs. Each of the 200 nodes was used as an origin and paired with the other 199 nodes as possible destinations, giving 39,800 OD-pairs per sample. Connectivity loss was defined as the share of OD-pairs that became disconnected after flood-induced edge removal.

Detour ratios reflect the added route length. Route lengths were calculated for connected OD-pairs in both the undisrupted and disrupted networks. The detour ratio was the disrupted shortest-path length divided by the undisrupted shortest-path length. Within each sample, detour ratios were summarised using the median and 90th percentile. The median describes typical route degradation among connected pairs, while the 90th percentile captures more severe detour effects. Metrics are reported as means across 100 samples and as changes relative to the 1 m reference.

3 Results

3.1 Resolution influences inferred infrastructure disruption

Road exposure, connectivity loss, and detour ratios all vary with flood-map resolution (Fig. 1a). Exposure increases as resolution becomes coarser, with a marked increase between 5 and 10 m resolution followed by a more gradual rise thereafter. The response of network metrics is more complex. Connectivity loss remains relatively stable at finer resolutions, then increases sharply between approximately 50 and 70 m resolution. Median detour ratios remain close to reference values across most resolutions, whereas 90th percentile detour ratios increase progressively. At coarser resolutions, however, these extreme detours seemingly decline; this is misleading as heavily disrupted parts of the network become disconnected altogether (Fig 1b), causing the most severely affected origin–destination pairs to drop out of the detour calculation. These results suggest two characteristic resolution transition ranges, occurring around 5–10 m and 50–70 m resolution.

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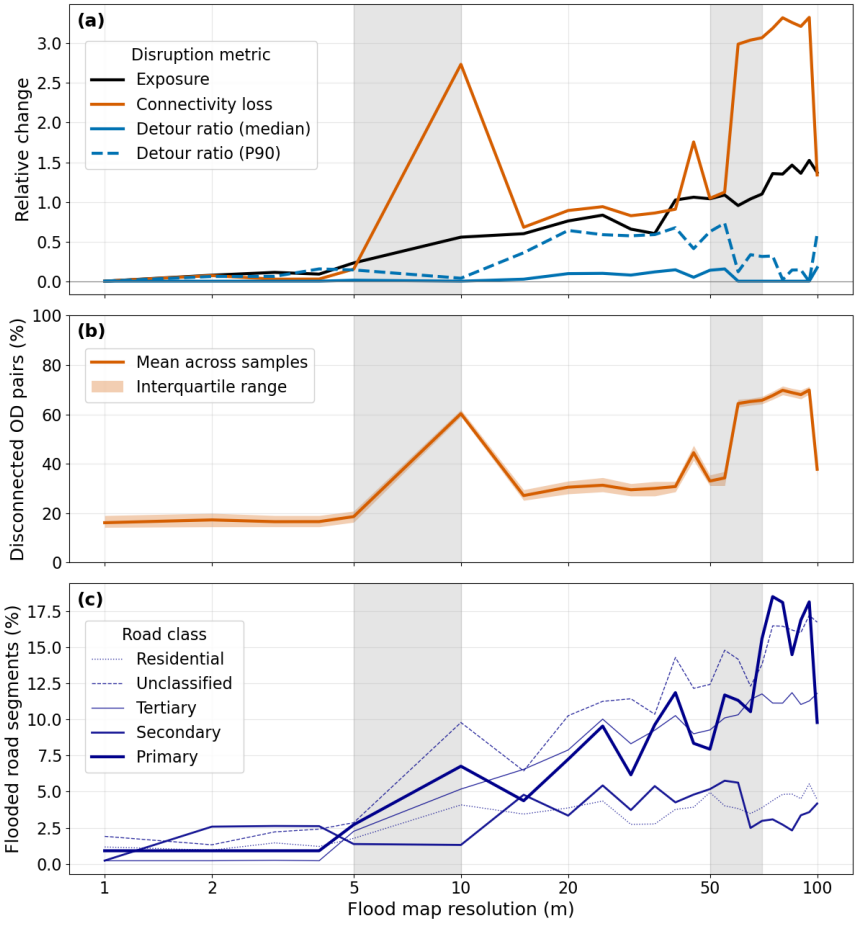


Figure 1. Resolution effects on network disruption and flooded road classes. (a) Relative change in road exposure, mean connectivity loss, median detour ratio, and 90th percentile detour ratio compared with the 1 m reference resolution under the 0.3 m *'depth-rule'*. (b) Percentage of disconnected origin-destination pairs. (c) Percentage of exposed road length disaggregated by road class.

While the overall pattern is consistent across road-failure rules (Table S1), the magnitude of the two transitions differs (Fig. S1). Under the near-zero depth rule, very shallow flooding can classify roads as disrupted even where only a small part of the link is affected or where water depths may still allow vehicle passage. This can occasionally disconnect major parts of the network, leading to a pronounced increase in connectivity loss. Depth and flooded-fraction criteria reduce the influence of these shallow and localised artefacts by requiring more substantial flooding before a link is removed, producing more stable connectivity estimates. Exposure follows a different pattern: it continues to increase with coarsening resolution because the flood-road overlay remains sensitive to grid size. These results indicate that road-failure assumptions reduce the influence of shallow and localised artefacts on connectivity metrics, while exposure estimates remain affected by spatial resolution.

3.2 Resolution coarsening changes exposure across the road hierarchy

The differences in network disruption correspond to changes in the classes of roads identified as flooded (Fig. 1c), which in turn arise from the resolution-induced artefacts described below. While exposure increases across most road classes as resolution coarsens, the increase is not distributed evenly across the network. The increase in exposure is accompanied by a shift across the road hierarchy. At finer resolutions, additional exposure mostly occurs on local roads, whereas at coarser resolutions an increasing share is assigned to higher-order roads, particularly primary roads. Consequently, the composition of

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flooded road classes changes with resolution, with exposure becoming increasingly represented on roads that support movement across larger parts of the network. As a result, the interpretation of disruption shifts from predominantly local accessibility impacts towards impacts affecting broader network connectivity. An exception is the motorway class, which exhibits relatively high exposure across all resolutions. This is associated with a temporal mismatch between the digital elevation model, which does not reflect a newly built interchange, and the road data, which include the interchange, rather than with the resolution effects discussed below (Table S2, Fig. S2).

The shift across the road hierarchy is associated with a progression of resolution-induced artefacts visible in Fig. 2. *Grade-separation* and *road-adjacency* artefacts primarily affect local roads, whereas *terrain-smoothing* artefacts increasingly affect higher-order roads.

At the finest resolutions (Fig. 2a-c), artefacts are dominated by grade-separated crossings, where bridges and tunnels above or below flooded areas can be classified as flooded. Most exposure assigned to features labelled as bridges or tunnels was filtered out. However, where flooded cells extend beyond the labelled feature, adjoining road sections may still be classified as disrupted. Filtering these features also removes genuine bridge and tunnel flooding. This choice reflects a trade-off between two imperfect interpretations: retaining bridges and tunnels would classify most of them as disrupted, often producing extensive network fragmentation from grade-separation artefacts alone; filtering out these features may omit some genuine tunnel flooding, particularly where drainage systems are overwhelmed or fail (De Bruijn et al., 2022). We consider the latter interpretation preferable because it avoids systematically overstating disruption.

At slightly coarser resolutions, above 5-10 m (Fig. 2d-e), road-adjacency artefacts become more prominent. These arise when flooded cells overlap roads immediately adjacent to flooded features, even though little or no flooding occurs on the road itself. Flooded-fraction criteria reduce their influence but cannot eliminate them entirely.

At coarser resolutions, above 50-70 m (Fig. 2f-h), local effects remain, but terrain-smoothing artefacts become increasingly evident. The loss of local topographic controls, such as the shape, orientation, and layout of buildings, streets, and canal slopes, alters where water accumulates and can result in flooding being assigned to roads that are unaffected in finer-resolution maps. As resolution coarsens, apparent exposure shifts from predominantly local roads towards roads that support movement across larger parts of the network.

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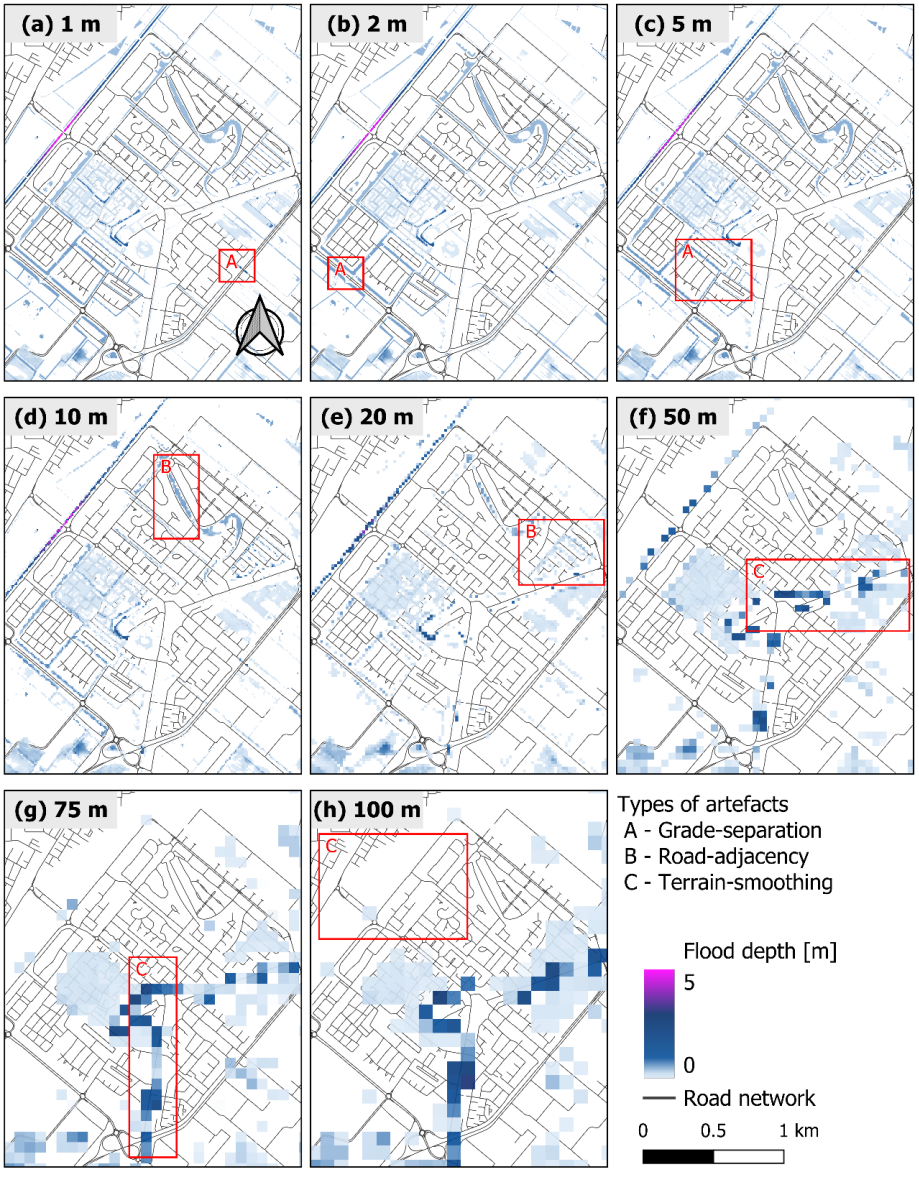


Figure 2. Resolution-induced artefacts in the flood-road overlay. Flood maps for a section of the study area centred on Bergschenhoek, South Holland, at selected spatial resolutions. Maps show how changes in grid size affect the assignment of flooding to road links. Boxes highlight examples of (a-c) grade-separation, (d-e) road-adjacency, and (f-h) terrain-smoothing artefacts.

The two transition ranges identified in Fig. 1 correspond to this progression. The first increase in exposure, between approximately 5 and 10 m resolution, coincides with the emergence of road-adjacency effects. The second transition, between roughly 50 and 70 m resolution, coincides with exposure increasing for primary roads, producing substantially larger connectivity impacts. The reduction in exposure and connectivity loss between 95 and 100 m is mainly driven by a decline in primary-road exposure. In these cases, coarsening the resolution either reduces assigned depths below the road-failure threshold or shifts flooded areas away from the affected links (Table S3).

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3.3 Implications for adaptation prioritisation

The main implication for adaptation planning is that flood-map resolution can influence which roads emerge as priorities for intervention. As resolution coarsens, exposure increasingly shifts from local roads towards roads that support movement across larger parts of the network. Because these roads are generally associated with higher construction costs, greater direct damage potential, and wider network consequences when disrupted (van Ginkel et al., 2021; Nirandjan et al., 2024), adaptation measures targeting them may appear to deliver substantial benefits through avoided damages and avoided network disruption. Whether these adaptation priorities are justified depends on whether the identified exposure reflects the underlying flood pattern. At the coarsest resolutions, this is not always the case. Coarser resolutions do not simply exaggerate impacts, but can produce adaptation priorities that are absent in finer-resolution analyses. This is illustrated in Fig. 2g, where a major north-south road appears severely flooded and could be interpreted as a priority for adaptation. In the finer-resolution maps, however, the same road is unaffected. Resolution therefore influences the estimated magnitude of adaptation benefits and the interventions that appear most valuable.

Not all resolution-induced artefacts have the same implications. Grade-separation artefacts can often be identified and removed from the analysis, as done here, resulting in limited implications for adaptation priorities. Road-adjacency artefacts are more difficult to filter and can inflate estimates of exposure, damage, disruption, and adaptation benefits. For example, roads only marginally affected through adjacency to a flooded feature (Fig. 2d) may be classified as flooded under the near-zero-depth and depth rules, but remain operational when a flooded-fraction criterion is applied. However, because these artefacts generally expand exposure around already-flooded locations, they are less likely to alter which roads emerge as priorities for intervention. Instead, they primarily affect the estimated magnitude of impacts and adaptation benefits. The effects that emerge at the coarsest resolutions are different because they can alter adaptation priorities altogether.

4 Conclusion

Flood-map resolution influences which roads are identified as flooded and how disruption propagates through the network. In this case study, exposure associated with resolution-induced artefacts increases when resolution coarsens beyond approximately 5-10 m. A second transition occurs around 50-70 m resolution, where exposure increasingly affects higher-order roads, producing substantially different estimates of connectivity loss.

Coarse-resolution analyses can support large-scale screening by indicating where potential disruption hotspots may occur. However, these results should not be used directly to identify individual roads or prioritise adaptation investments. Potential hotspots should be examined through high-resolution local analysis that can establish which roads are affected and to what extent. Without this refinement, coarse maps may overstate impacts or redirect adaptation towards roads that are unaffected in finer-resolution analyses.

Code and data availability

An animation of the coarsening resolution progression, the model code and supporting data are available at https://doi.org/10.5281/zenodo.23101731.

Supplement link

Supplement – Supplementary results

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Author contributions

EDPG and KCHvG developed the initial idea for this manuscript. EDPG designed and carried out the analysis, created the figures, and wrote the original draft of the manuscript. KCHvG, MJEvM, and EEK contributed to the framing of the study and interpretation of the results, supervised the study, and reviewed and edited the manuscript. All authors approved the final version.

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Competing interests

The authors declare no competing interests.

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