DOI: 10.5592/CO/HG.2026.10

A MODEL FOR URBAN FLOOD RISK ASSESSMENT FOLLOWING DAM FAILURE

IRINA STIPANOVIĆ [1], MARTINA PEKČEC [1], LOU LERREN CURACHA[1], MARIO BAČIĆ [2], NICOLA ROSSI [2], MEHO SAŠA KOVAČEVIĆ [2]

[1] *Infra Plan consulting llc, Croatia*

[2] *Faculty of Civil Engineering, University of Zagreb, Croatia*

Abstract

This study examines flash-flood risks in steep catchments draining from Medvednica Mountain into Zagreb, focusing on three retention systems: Črnomerec, Pusti dol, and Jazbina. The analysis explores cascading multi-hazard interactions, where earthquake-induced stress and extreme precipitation may compromise retention performance, potentially triggering dam failure and downstream urban flooding. Scenarios are structured using hazard intensity levels, infrastructure fragility, and consequence indicators, enabling integration into crisis-management platforms. The CRISAFE project models these interactions using Bayesian Belief Networks (BBNs), a probabilistic framework that links initiating hazards to infrastructure response, flood propagation, and downstream impacts through conditional relationships, while accounting for uncertainty propagation. The methodology supports risk-informed decision-making for urban resilience and emergency planning.

Keywords

Risk assessment, Bayesian Belief Networks (BBN), Cascading multi-hazard scenarios, Urban flooding, Critical infrastructure, Earthquake

1 Introduction

Over the past decade, Europe has faced a rising number of urban floods, often with devastating consequences for infrastructure and public safety. Climate change, coupled with rapid urbanization, has intensified both the frequency and severity of these events, with flash floods and river floods posing significant risks to human life and critical infrastructure. Flash floods alone account for an average of 50 fatalities annually in Europe, predominantly in Mediterranean countries such as Croatia, Italy, and Spain (Pino et al., 2016). Recent catastrophic events, such as the 2020 Zagreb floods triggered by extreme precipitation and the 2021 floods in Germany, Belgium, and the Netherlands, highlight the compounded impacts of natural hazards and inadequate flood protection systems (Nimac et al., 2022; Kreienkamp et al., 2021). Additionally, cascading effects, such as earthquake-induced infrastructure damage, further increase urban vulnerability, as demonstrated by the 2020 Zagreb and Petrinja earthquake in Croatia.

The growing threat of urban flooding highlights the need for robust risk assessment methodologies, particularly in scenarios involving dam failures and multi-hazard interactions, which is the focus of the methodology developed within the CRISAFE project (Civil Protection Knowledge Network). By employing BBNs, the approach models causal relationships between hazards, infrastructure performance, and cascading impacts, while accounting for uncertainty through conditional probabilities. The methodology integrates hazard, exposure, and vulnerability data, enabling probabilistic risk assessment that supports informed decision-making for disaster risk reduction and urban resilience, including critical infrastructure exposed to both hydrological extremes and seismic events.

The retention dams located at the bottom of Medvednica mountain, constructed to protect Zagreb from heavy rainfall-induced floods, face increasing hydraulic loads due to climate-driven changes in precipitation patterns (Rossi et al. 2025). These changes characterized by more frequent and intense rainfall events, result in higher water volumes filling retention systems more rapidly, thereby heightening the risk of dam failure and downstream flooding (Nissen & Ulbrich, 2017; Hosseinzadehtalaei et al., 2020).

The study presented in this paper addresses the urgent need for methodologies that assess multi-hazard cascading risks, ensuring the resilience of urban areas and critical infrastructure against both hydrological extremes and seismic events.

2 Methodology

This paper presents a methodology for assessing risk in cascading multi-hazard scenarios in urban areas, focusing on interactions between earthquakes and floods. The methodology builds on experiences from UCPM projects oVERFLOw and CROSScade (Bacic et al., 2022; Skaric Palic et al., 2023) and is adapted in CRISAFE project for critical urban infrastructure (Gavin et al., 2025; Rossi et al., 2025; Stipanovic & Pekcec, 2026). The project addresses two major hazards, earthquakes and extreme rainfall, which can trigger flash floods in our case study area. These hazards are widespread and can lead to chains of events that severely impact infrastructure and society. Due to their complexity and uncertainty, cascading hazard scenarios require a probabilistic approach to handle incomplete and uncertain data. For this, BBNs are used for this purpose, combining available data with expert knowledge to model causal links between hazards, quantify uncertainty with conditional probabilities, identify key risk factors, and predict their impacts, supporting risk-informed decision-making even when data are limited (Chivata et al., 2012).

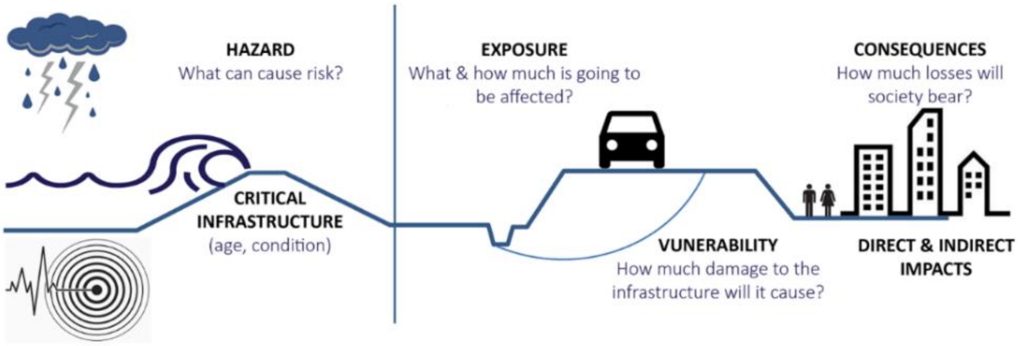

Figure 1. Interaction of key risk factors - hazard, exposure, vulnerability and consequence analysis (Pekcec&Stipanovic, 2025)

Risk is defined as the potential for negative consequences when something of value is at stake and the outcome is uncertain (UNDRR, 2017). It arises from the combination of hazard, exposure, and vulnerability. In this work, flood protection systems (e.g., dams and retention basins) are analysed as critical infrastructure, with a focus on their capacity to resist damage and ensure urban defence, as presented in Figure 1.

In order to perform risk analysis, it is necessary to collect data about the exposure. Exposure refers to the presence of people, buildings, infrastructure, and other valuable assets in areas that are at risk from natural or man-made hazards. It is measured by the number and type of elements located in these hazard-prone areas. Considering that the CRISSAFE project addresses hazards that impact the urban environment, the focus was on the data acquisition related to the population within the affected areas during different periods in the week, data about different types of buildings and data concerning the presence of land use, infrastructure, property, economic activities within the case study area.

3 Case study – City of Zagreb

3.1 Case Study Area Description

The study focuses on the City of Zagreb, Croatia, located between the southern slopes of Medvednica Mountain and the Sava River plain. This geographical setting strongly influences both hydrological processes and urban development. While the Sava River is the main watercourse, flash floods are mainly caused by short, torrential streams descending from Medvednica. Due to their steep gradients and rapid runoff, these streams generate fast flows that move from mountainous catchments through urban lowlands before discharging into the Sava River (Management Plan for Medvednica Nature Park (2010)). To mitigate the risk of torrential flooding, a network of 19 retention dams was constructed on Medvednica's southern slopes, upstream of Zagreb's densely urbanized core. Built primarily from the mid-1970s onward in less developed areas, these structures are designed to regulate runoff from the mountain's steep catchments. By temporarily detaining stormwater and reducing peak flows before they reach the city, the dams play a critical role in reducing downstream flood risk (Gjetvaj et al., 2013).

For the purposes of this study, three retention dams were selected as representative case studies: Črnomerec Dam (western part of Zagreb), Pusti Dol Dam (central part), and Jazbina Dam (eastern part) as it can be seen in Figure 2.

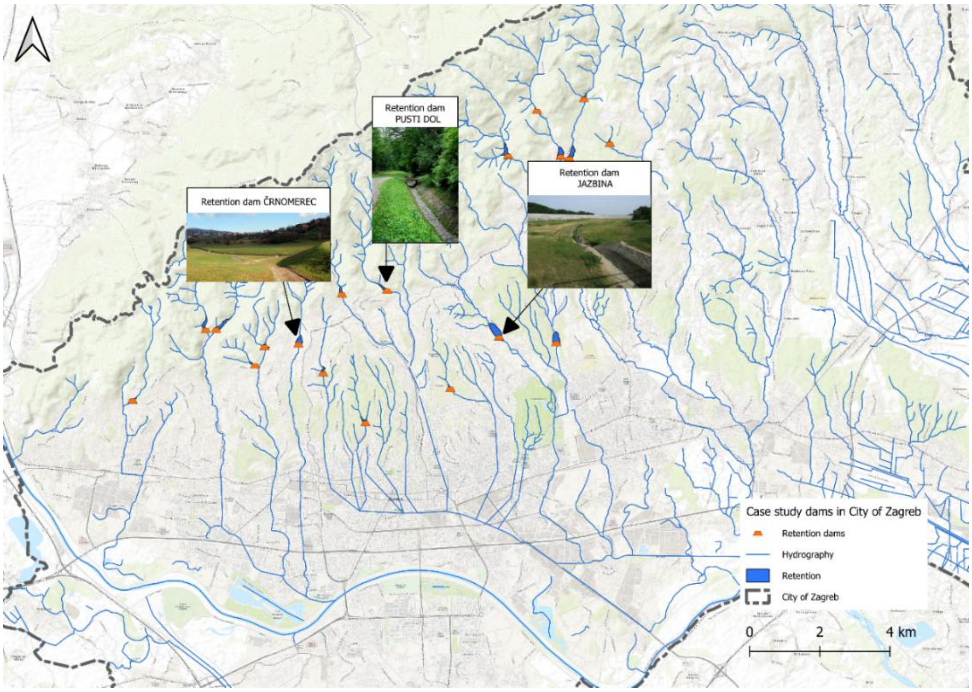

Figure 2. Locations of retention basins in Zagreb, highlighting the three sites analyzed in this study

In addition to hydrological hazards, Zagreb is exposed to significant seismic risk. According to the national seismic hazard map for a 475-year return period, the city is in a zone of pronounced seismic activity. The 1880 Great Zagreb Earthquake, with a magnitude of 6.3, which represents the baseline and most significant historical event, as well as the more recent earthquakes in March 2020 (Zagreb) and December 2020 (Petrinja), confirmed the city's ongoing exposure to seismic hazards and revealed vulnerabilities in buildings and critical infrastructure (Markušić et al., 2020). These events highlight the importance of integrating potential earthquake impacts into multi-hazard risk assessments for flood protection infrastructure, such as retention dams.

3.2 Defined Scenarios

This study outlines a multi-hazard scenario for the retention dams on Medvednica Mountain, where an earthquake-induced structural compromise of a dam is followed by intense upstream rainfall before repairs can be implemented.

3.2.1 Earthquake

To assess the impact of earthquakes on dam stability, Rossi (2025) described how both dynamic finite element analyses and pseudo-static slope stability analyses were conducted. For dynamic analyses, full seismic records were applied at the model's base, while pseudo-static analyses relied on peak ground acceleration (PGA), the maximum acceleration during an earthquake. To account for variability in seismic loading and derive failure probabilities, 30 artificial seismic records were generated, each conforming to the design spectral acceleration diagram for a 475-year RP. These records were based on source parameters from the 1880 Medvednica earthquake, as previously described.

3.2.2 Rainfall Events as Drivers of Flood Scenarios

When examining rainfall as a key driver of flood scenarios, Rossi et al. (2025) highlights the importance of integrating hydrological and morphometric data to assess flood risks in dam systems. Basin delineation and morphometric characteristics were derived through GIS analysis of a digital elevation model for the three dam basins under study, with maximum retention volumes calculated for each individual reservoir.

To estimate water flow and volume during heavy rainfall, the Rational Method (Žugaj, 2010) was applied. Among the observed streams, only the Črnomerec stream has an upstream hydrological station, enabling direct correlation between precipitation and flow data for retention filling analysis. Hourly flow measurements were analyzed for extreme rainfall events, and the hydrograph method was used to calculate water volumes entering the retention areas. For assessing the effect of the outlet structure on water wave height and duration, three key inputs are required: the rainfall-vs-time curve, the volume-vs-height relationship, and the outlet-discharge curve. This integrated approach ensures a comprehensive evaluation of flood dynamics in response to extreme rainfall events.

3.2.3 Cascading hazards – Earthquake and Extreme Rainfall

The methodology for assessing the joint occurrence of high water and seismic events (Rossi et al., 2025; based on Hynes-Griffin, 1980) aligns earthquake return periods with rainfall duration. For this analysis, extreme rainfall is approximated as one-hour events, while Croatia's 475-year return period (RP) for seismic events is adopted per standard practice. Given the water-wave duration distributions, shorter for Črnomerec and Pusti Dol, longer for Jazbina, Rossi et al. (2025) finds the probability of a design-level earthquake coinciding with high-water conditions to be negligible, even before considering extreme rainfall return periods. Over the dams' operational lifespan and plausible rainfall frequencies, the likelihood of such overlap remains insignificant. Thus, rainfall- and earthquake-induced loads are treated as independent cases in stability and vulnerability assessments (Rossi et al., 2025).

Precipitation data were obtained from the State Hydrometeorological Institute (DHMZ), covering a 25-year time series (1998–2023). The dataset included measurements from rain gauge stations with daily records (Mikulići, Puntijarka, Šestine) and automatic stations with hourly data (Puntijarka, Maksimir). Extreme precipitation events were defined as ≥30 mm/h, with analysis revealing a distinctly local pattern in the occurrence of intense rainfall across Medvednica's monitoring stations (Rossi, 2025).

3.3 Vulnerability assessment

Vulnerability of flood-protection infrastructure is quantified through fragility relationships that define the probability of reaching a specified performance state, such as damage, instability or failure, conditional on a hazard intensity measure. In CRISAFE project, fragility curves translate hazard loading into probabilistic infrastructure performance in a form that can be directly integrated into the probabilistic risk model (Stipanović & Pekčec, 2025).

In the Zagreb case study, retention-system vulnerability is evaluated under both seismic loading and rainfall-driven hydraulic loading. Earthquake loading represents inertial effects and potential degradation of stability, while extreme precipitation influences reservoir levels, seepage and overflow conditions that may lead to dam failure. The methodology is evaluating the dam stability under static (post-rainfall) and dynamic (seismic) conditions, excluding overlapping events due to negligible (Gavin et al. 2025). Numerical modelling combined Plaxis2D (FEM) for flow and dynamic analyses and PlaxisLE (LEM) for stability assessments (peak water levels, rapid drawdown, and pseudostatic seismic analyses). Key outputs included failure probabilities (derived from factor of safety) and permanent crown displacement distributions for dynamic scenarios. Soil parameters were treated deterministically, with uncertainties arising from variable external actions. Input data, sourced from seismic refraction profiles, boreholes, lab tests, and technical cross-sections, were supplemented by new CPT investigations and LiDAR-derived geometry as part of the CRISAFE project, addressing gaps in original design documentation. The corresponding conditional failure probabilities are introduced into the Bayesian network model as separate nodes for rainfall-driven and earthquake-driven instability or failure, enabling evaluation of cascading pathways.

3.4 Consequence analysis

Consequence analysis for cascading hazard scenario was performed using flood model simulates dam-failure-induced flooding based on CRISAFE dam-breach scenarios, where the failure of Medvednica retention dams generates a flood wave propagating downstream into urban areas after the earthquake. (Stipanovic et al. 2026). For Zagreb case study population data from the 2021 Census served as a key input for defining the study area and estimating evacuation needs. However, since official Croatian statistics are aggregated at the municipal district level, insufficient for emergency planning, in this study we have applied a weighted allocation method to disaggregate population figures to census blocks (enumeration areas) and further refine them to individual buildings (Stipanovic et al. (2026). This approach improves spatial precision while acknowledging residual uncertainty. Population counts were assigned only to residential, mixed-use, and housing structures, while occupancy in non-residential buildings was estimated separately (see Stipanovic et al., 2026 for methodological details). Transport infrastructure (roads, train, and tram networks) was obtained from Geofabrik's OpenStreetMap-based download server, providing a detailed road network database. Land use and land cover (LULC) data were derived from the Urban Atlas (Copernicus Program) but reclassified into 20 urban classes to better align with the study's requirements.

Damge assessment and consequence analysis follow the methodology outlined by Stipanovic et al. (2026), integrating hazard intensity with the vulnerability of buildings and infrastructure to quantify impacts. For flooding, flood depth is linked to depth-damage functions, while for earthquakes, seismic intensity (475-year RP) is tied to building fragility. Buildings are categorized by usage, with maximum market values representing potential repair costs. Transport infrastructure (roads, railways, tram tracks) is assessed in 1-meter segments, with damage estimated via depth-damage curves. Indirect losses (e.g., business interruption) are quantified by estimating affected employees, recovery times, and economic parameters per building. Land-use impacts are assessed using polygon-based LULC datasets, with damage calculated from maximum market values, depth-dependent factors, and affected area. For the earthquake scenario, building damage estimates are based on the seismic-risk assessment performed for City of Zagreb and reported in Atalić et al. (2024), downscaled to individual buildings using gross building area to align with committee-level monetary losses. Results are computed for two occupancy scenarios (working/non-working day) to account for temporal population variability. Outputs, such as affected population and economic loss, are then fed into the risk model for cross-hazard comparison and decision support.

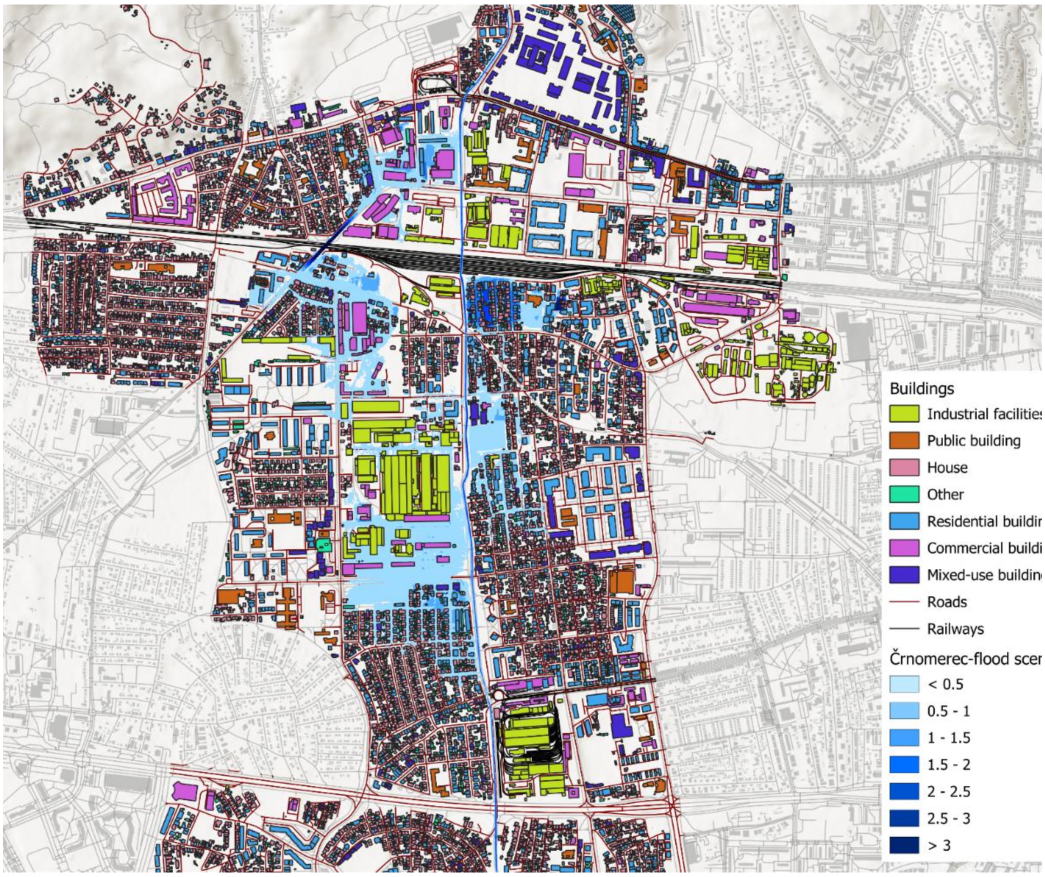

Figure 3. Exposure data for city of Zagreb, area affected by the cascading hazard on Črnomerec dam

3.5 Risk model using Bayesian Belief Networks

Cascading hazard interactions and uncertainty propagation are modelled in CRISAFE using Bayesian Belief Network (BBN), implemented as a probabilistic causal model that links initiating hazards to infrastructure performance, flood generation and downstream impacts through conditional relationships (Stipanovic et al, 2026). A BBN model is a directed acyclic graph in which nodes represent variables (e.g., hazard states, infrastructure performance states and consequence indicators) and edges encode conditional dependencies (Wang et al., 2025); in CRISAFE, these conditional relationships are organized using fragility-derived probabilities and scenario assumptions, enabling uncertainty to be propagated consistently from initiating event(s) to risk and impact outputs (Stipanovic et al., 2026).

In our model, BBN is implemented as an operational decision-support model in which selected nodes can be updated using live or near-real-time inputs (e.g., observed rainfall intensity). Vulnerability is represented through fragility relationships embedded in the network: within the relevant infrastructure-performance nodes, the user can select the applicable fragility curve and its parameters, after which the model assigns the corresponding failure probabilities and automatically propagates them to compute flood likelihood, impacts and overall risk. Consequences are evaluated for different exposure conditions, namely working-day and non-working-day scenarios, in order to account for temporal variations in population distribution and their influence on impacts and evacuation needs.

4 Results

4.1 Quantification of consequences

Quantification of multi-hazard cascading scenario included the estimation of the earthquake and flood impacts using exposure data, as presented in Figure 3. The earthquake-specific loss estimates (direct monetary building damage in million euros) were downscaled from local community-level data (Atalić et al., 2024) to individual buildings using gross building area for proportional distribution. Population exposure was assessed under two occupancy scenarios (working/non-working day), ensuring comparability with flood risk estimates through consistent exposure data and temporal variability assumptions. Črnomerec shows total building damage of about €195.0 million and an affected population of about 141,600 and 81,100 in Scenario 1 and Scenario 2 respectively. Overall the earthquake scenario produces significant building losses and population exposure across all three catchments with Jazbina and Črnomerec accounting for the largest shares of total damage and affected people. For detailed impact please refer to Stipanovic et al, 2026.

Under the flood model 1 (Rossi et al., 2025), the most severe consequences are observed in the Črnomerec retention system, which experiences significantly higher impacts compared to the other two basins. In Črnomerec, the affected population reaches 20,858 in Scenario 1 and 5,363 in Scenario 2, with total estimated losses amounting to approximately €135.5 million. The results of consequence calculations are provided in Table 1.

Table 1. Consequences within the flood footprint for Flood Model 1 (CRISAFE flood scenario) across the combined influence area of all three dams

Consequences (in €)	Črnomerec	Jazbina	Pusti dol
Total Damage in Buildings	5,204,143.05	4,173,632.69	163,000.35
Total Damage in Transport Infrastructure	1,078,887.25	250,678.35	63,713.90
Loss of Business	118,594,456.12	74,428,380.04	654,929.24
LULC: Agricultural	125,200.72	341,410.94	4,716.98
LULC: Industrial	2,498,750.45	2,106,705.17	-
LULC: Buildings Land	7,968,196.21	890,423.21	510,226.54
Total:	135,469,633.80	82,191,230.40	1,396,587.01
Population Affected:			
Scenario 1 - Working Day	20,858	9,830	124
Scenario 2 - Non-Working Day	5,363	368	124

4.2 BBN Model for Cascading Hazards

Cascading scenario modelled within CRISAFE project captures the explicitly cascading hazard chain "earthquake / extreme rainfall → dam instability → dam failure → downstream flooding". In this event, both triggering hazards (extreme rainfall and earthquake) and both associated failure mechanisms ("dam failure due to rainfall" and "dam failure due to earthquake") are represented by separate nodes whose conditional probabilities are taken from the vulnerability analyses performed for Zagreb flood protection system (Rossi et al., 2025; Gavin et al., 2025; Hynes-Griffin, 1980). For the rainfall-induced mechanism, the corresponding BBN node is defined to reflect both hydraulic loading and the influence of maintenance and operation, recognising that shortcomings in routine inspection, the functioning or handling of gates and doors, or other maintenance procedures could increase the likelihood of failure under intense rainfall. When either failure mechanism is activated in cascading event, the BBN routes the consequences through a "flooding" node parameterised using Flood Model 1, i.e. dam-break outflows and downstream flooding patterns from the 2D hydraulic simulations for the Črnomerec, Bliznec and Pustodol streams, as described in Rossi et al. (2025). Although the strict temporal coincidence of an extreme rainfall event and a 475-year return-period earthquake is negligible (Hynes-Griffin, 1980; Rossi et al., 2025), representing both rainfall-induced and earthquake-induced dam failure in the BBN makes it possible to quantify their combined contribution to overall flooding risk over the working life of the dams, and to examine how changes in maintenance and operational conditions could alter the probability of failure under rainfall.

Zagreb BBN links the two hazard scenarios to the exposure and consequence models and represents them as cascading events for each retention system, with consequences reported as economic losses and affected population for Scenario 1 and Scenario 2 (working/non-working day). BBN model presented in Figure 4 represents rainfall and/or earthquake-driven dam failure causing flooding and damages to the city urban environment and potential impacts to population. The BBN includes a real-time node linked to dam monitoring data, which provides threshold-based alerts and supports manual updating of hazard and failure probabilities to reflect current conditions, and it is implemented in a software tool developed that allows evidence assignment and computation of posterior probabilities and risk indicators for buildings, transport, loss of business and affected population.

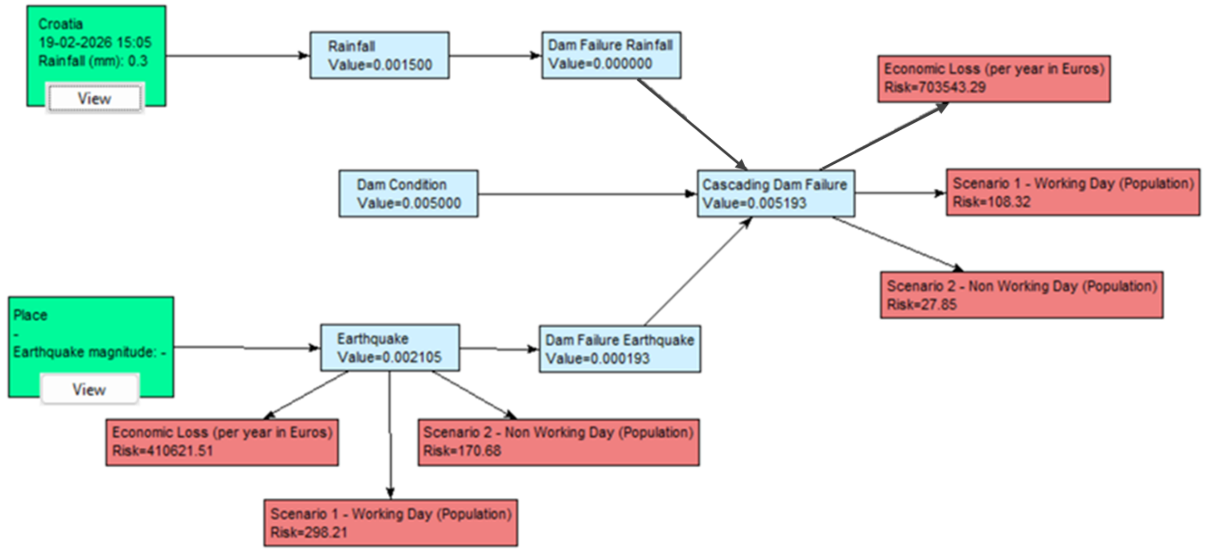

Figure 4. BBN Model for Zagreb case study area around Črnomerec dam

For illustration, BBN model and quantification of consequences in Figure 4 show the event tree and computed outputs for the Črnomerec retention system only; probabilities, risks, and consequence estimates differ across Črnomerec, Jazbina (Bliznec), and Pusti dol because hazard loading, infrastructure response, and exposure vary by study area.

4 Conclusion

Urban areas are increasingly exposed to cascading risks, where initial failures can trigger chain reactions, threatening infrastructure, public safety, and socioeconomic stability. This study introduces a quantitative, probabilistic model for assessing cascading flood risks in cities, designed to evaluate both primary dam-failure impacts and secondary effects. Its adaptability allows application to diverse urban contexts, provided high-resolution data and cross-sectoral collaboration are available. A defining feature of the model is its integration with Critical Infrastructure Management systems, enabling real-time monitoring and targeted protection of essential infrastructure. Urban environments, with their dense populations and interconnected systems, are particularly vulnerable to cascading failures. By embedding this model into infrastructure management frameworks, authorities can systematically identify vulnerabilities, prioritize critical interventions, and deploy protective measures, thereby reducing the risk of large-scale disasters.

The model leverages probabilistic risk model with integrated Bayesian Belief Network to address uncertainties and data gaps, capturing complex interactions between hazards and quantifying both direct impacts (e.g., structural damage) and indirect consequences (e.g., economic losses, service disruptions). It provides actionable insights for infrastructure managers and supports civil protection agencies in optimizing evacuation strategies and resource allocation. Exposure data, including population distribution, infrastructure networks, and land use, further refines risk assessments, ensuring a comprehensive, multi-hazard evaluation. By fostering interdisciplinary collaboration and data-driven decision-making, this model strengthens urban resilience against cascading risks. Future advancements should focus on enhancing data precision, expanding applicability to other hazard scenarios, and deepening stakeholder engagement to maintain its effectiveness in dynamic urban risk management. Its integration into existing critical infrastructure management and emergency response systems offers a proactive pathway to safeguarding critical infrastructure and community well-being.

Acknowledgement

All authors acknowledge the funding of CRISAFE project, Critical infrastructure early warning systems and population awareness for multi hazard cascading events, which received funding from the EU Civil Protection Mechanism UCPM-2023-KAPP-PREV; GA Number 101140336.

References

Atalić, J., Baniček, M., Cerić, A., Damjanović, D., Ivić, I., Kovačević, M. S., Lazarević, D., Šavor Novak, M., Uroš, M. (2024) Procjena potresnog rizika za Grad Zagreb – Aktivnost 1: Metodologija za procjenu potresnog rizika. Sveučilište u Zagrebu, Građevinski fakultet.

Chivatá Cárdenas, I., Al-Jibouri, S., Halman, J. (2012) A Bayesian belief networks approach to risk control in construction projects. Nonlinear Processes in Geophysics - NONLINEAR PROCESS GEOPHYS.

EEA (2024) European Climate Risk Assessment, EEA Report No 01/2024, European Environment Agency (https://www.eea.europa.eu/en/analysis/publications/european-climate-riskassessment) (10 July 2025).

Gavin, K., Reale, C., Rossi, N., Bacic, M., Kovacevic, M.S. (2025) CRISAFE Deliverable 2.2: Vulnerability Assessment of the Infrastructure Subjected to Multi-Hazards.

Gjetvaj, G., Lončar, G., Paladin, M., & Mostečak, H. (2013) Mathematical model of flood wave propagation due to dam failure at Dubravica, Kunišćak and Fučkov jarek retentions, Zagreb (in Croatian) [Technical report].

Hosseinzadehtalaei, P., Tabari, T., Willems, P. (2020) ‘Climate change impact on short-duration extreme precipitation and intensity–duration–frequency curves over Europe’, Journal of Hydrology, Volume 590, 2020, 125249, ISSN 0022-1694, https://doi.org/10.1016/j.jhydrol.2020.125249.

Hynes-Griffin, M.E. (1980) The Joint Occurrence of Earthquakes and Floods (Final Report No. GL-80-10). U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Kreienkamp, F., Philip, S.Y., Tradowsky, J.S., Kew, S.F., Lorenz, P., Arrighi, J., Belleflamme, A., Bettmann, T., Caluwaerts, S., Chan, S.C., Ciavarella, A., De Cruz, L., de Vries, H., Demuth, N., Ferrone, A., Fischer, E.M., Fowler, H.J., Goergen, K., Heinrich, D., Henrichs, Y., Lenderink, G., Kaspar, F., Nilson, E., Otto, F.E.L., Ragone, F., Seneviratne, S.I., Singh, R.K., Skålevåg, A., Termonia, P., Thalheimer, L., van Aalst, M., Van den Bergh, J., Van de Vyver, H., Vannitsem, S., van Oldenborgh, G.J., Van Schaeybroeck, B., Vautard, R., Vonk, D., Wanders, N. (2021) ‘Rapid attribution of heavy rainfall events leading to the severe flooding in Western Europe during July 2021’, Report, World Weather Attribution. https://www.worldweatherattribution.org/wp-content/uploads/Scientific-r eport-Western-Europe-floods-2021-attribution.pdf

Markušić, S., Stanko, D., Korbar, T., Belić, N., Penava, D., Kordić B. (2020) ‘The Zagreb (Croatia) M5.5 Earthquake on 22 March 2020’, Geosciences, 10(7):252, https://doi.org/10.3390/geosciences10070252.

Nimac, I., Cindrić Kalin, K., Renko, T., Vujnović, T., Horvath, K. (2022) ‘The analysis of summer 2020 urban flood in Zagreb (Croatia) from hydro-meteorological point of view', Natural Hazards 11, pp. 873–897.

Nissen, K. & Ulbrich, U. (2017) 'Increasing frequencies and changing characteristics of heavy precipitation events threatening infrastructure in Europe under climate change', Natural Hazards and Earth System Sciences, 17, pp. 1177-1190. 10.5194/nhess-17-1177-2017.

Pekcec, M., Stipanovic, I. (2025) CRISAFE Deliverable 3.1: Cascading multi - hazard risk

assessment methodology

Medvednica Nature Park (2010) The Management Plan https://www.pp-medvednica.hr/wp-content/uploads/2019/05/Plan-upravljanja-Parka-prirode-Medvednica.pdf (3. 2. 2026.)

Stipanovic, I., Pekcec, M., Curacha, L.L. (2026) CRISAFE Deliverable 3.2: Case study cascading multi - hazard risk assessment

Pino, D., Ruiz-Bellet, J. L., Balasch, J. C., Romero-León, L., Tuset, J., Barriendos, M., Castelltort, X. (2016) 'Meteorological and hydrological analysis of major floods in NE Iberian Peninsula', Journal of Hydrology, 541, pp. 63–89. doi:10.1016/j.jhydrol.2016.02.008

Rossi, N., Bacic, M., Gavin, K., Kovacevic, M.S., (2025) CRISAFE Deliverable 2.1: Current and future cascading multi - hazard scenarios

United Nations Office for Disaster Risk Reduction (UNDRR) (2017) The Sendai Framework Terminology on Disaster Risk Reduction. "Disaster risk", (13 February 2026). https://www.undrr.org/terminology/disaster-risk.

Žugaj, R. (2010) Velike vode malih slivova, Rudarsko-geološko-naftni fakultet i Hrvatska komora arhitekata i inženjera u graditeljstvu, Zagreb.

Wang, Q., Lu, A., Ni, Y., Wang, J., & Ma, Z. (2025) 'Bayesian Network in Structural Health Monitoring: Theoretical Background and Applications review', Sensors, 25(12), 3577. https://doi.org/10.3390/s25123577