

SuPeRBE Training Material

Macro Area of Expertise MAE4:

Risk Assessment At Small Urban Scale

Hazard: Floods (B)

Macro Area of Expertise MAE4.2:

Urban Sector: Transport (B2)

Risk Category: Damage risk for road transport network (B2.2)

Level of competence: 3



FLOODS

Floods occur when water overflows onto normally dry land as the capacity of natural or artificial drainage systems is exceeded. They are among the most frequent and damaging climate-related hazards, increasingly affecting urban areas worldwide. Rising temperatures, sea-level rise, and changes in precipitation patterns are intensifying flood frequency, magnitude, and duration.

Main drivers:

- **Extreme precipitation:** More intense and prolonged rainfall events associated with climate change.
- **Snow and ice melt:** Rapid melting increases runoff volumes and river discharge.
- **Sea-level rise and storm surges:** Amplify coastal flooding and saltwater intrusion.
- **Urbanization:** Impermeable surfaces and inadequate drainage accelerate surface runoff.
- **Land-use change:** Deforestation and wetland loss reduce natural water retention capacity.





IMPACTS ON TRANSPORTATION NETWORKS

Direct Impacts:

- Submergence and erosion of roads, bridges, railways, and embankments.
- Structural instability due to scour, foundation washout, or prolonged submergence.
- Flooding of tunnels, stations, depots, and signaling systems, causing costly downtime.
- Blockage of routes by sediments, debris, or landslides.

Indirect Impacts:

- Disruption of mobility and logistics, causing congestion and economic losses
- Delays in emergency response and repair operations.
- Cascading failures where transport disruption affects supply chains, utilities and public services.
- Increased maintenance, rehabilitation, and insurance costs for operators and authorities.





WIDER URBAN IMPACTS

Buildings and infrastructure:

- Inundation of ground floors and basements, damaging structural elements and technical systems.
- Contamination of materials with polluted water and sediments.

Health and society:

- Injuries and fatalities from swift water, submerged hazards, or electrical accidents.
- Public health risks due to mold growth, and damp conditions.
- Displacement of residents and psychological stress in affected communities.

Urban systems:

- Overload of wastewater networks and combined sewer overflows leading to environmental pollution.
- Interruption of essential services such as power supply, telecommunications and potable water.
- Increased pressure on emergency management and recovery operations.





LOOKING AHEAD

Trend:

- Flood events are becoming more frequent and severe, particularly in densel built or low-lying areas. Compound events—where river flooding coincides with surface runoff or drainage backflow—are also increasing.
- Climate change will continue to intensify extreme rainfall and accelerate sea-level rise.
- Aging drainage systems and impermeable urban development will further increase runoff and exposure.

Strategic adaptation:

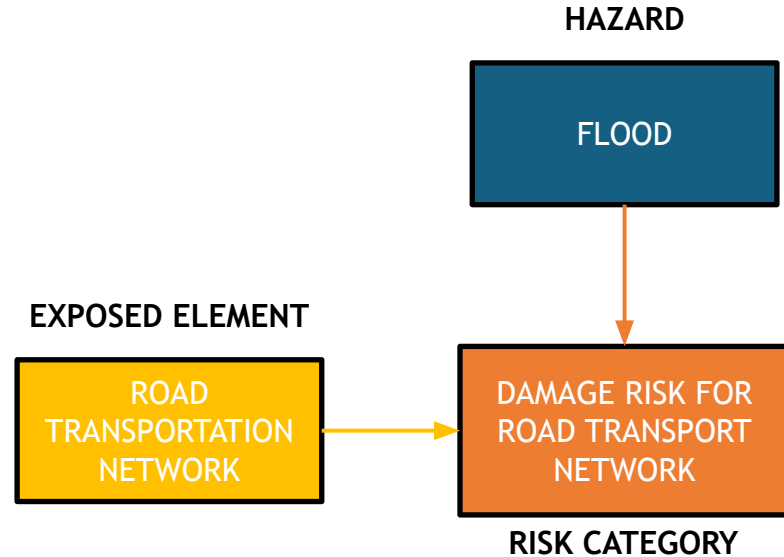
It is essential to safeguard transport networks and interconnected systems, including:

- Elevation and flood-proofing of critical transport assets.
- Restoration of natural retention areas (wetlands, green corridors, floodplains).
- Expansion of drainage capacity and use of smart monitoring systems.
- Integrated planning between mobility, housing, and environmental sectors.

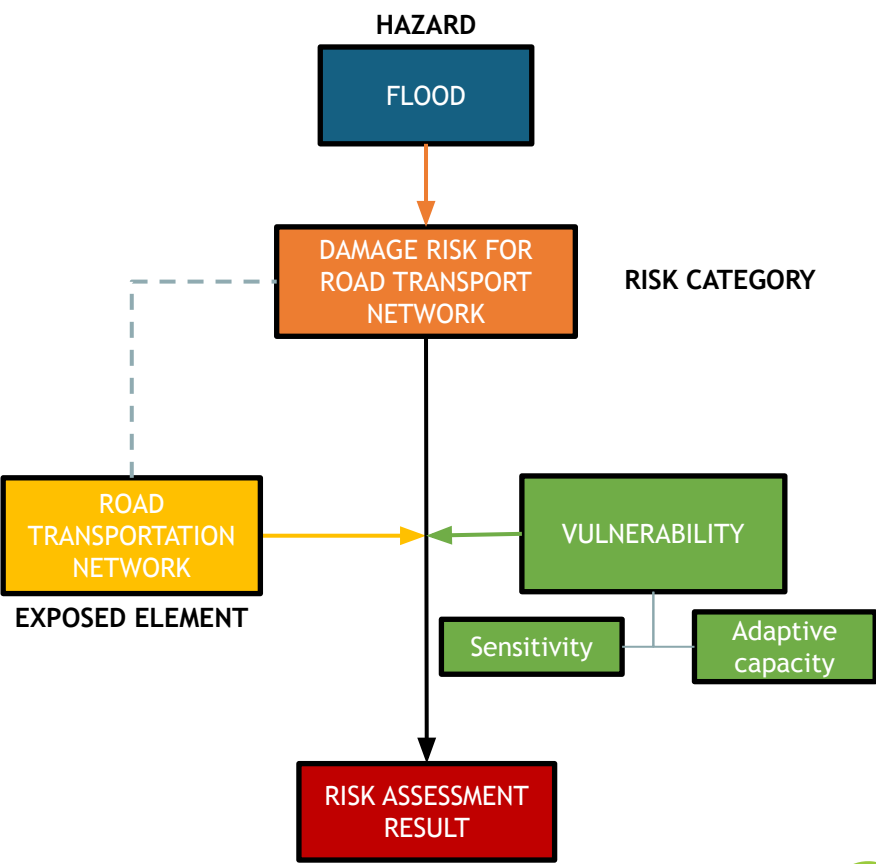
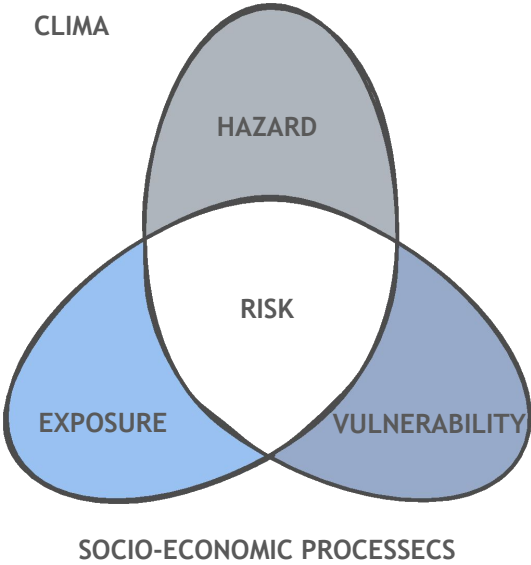


RISK ASSESSMENT FOR DAMAGE RISK FOR ROAD TRANSPORT NETWORK

- **Hazard:**
Flood
- **Exposed element:**
Road Transportation Network



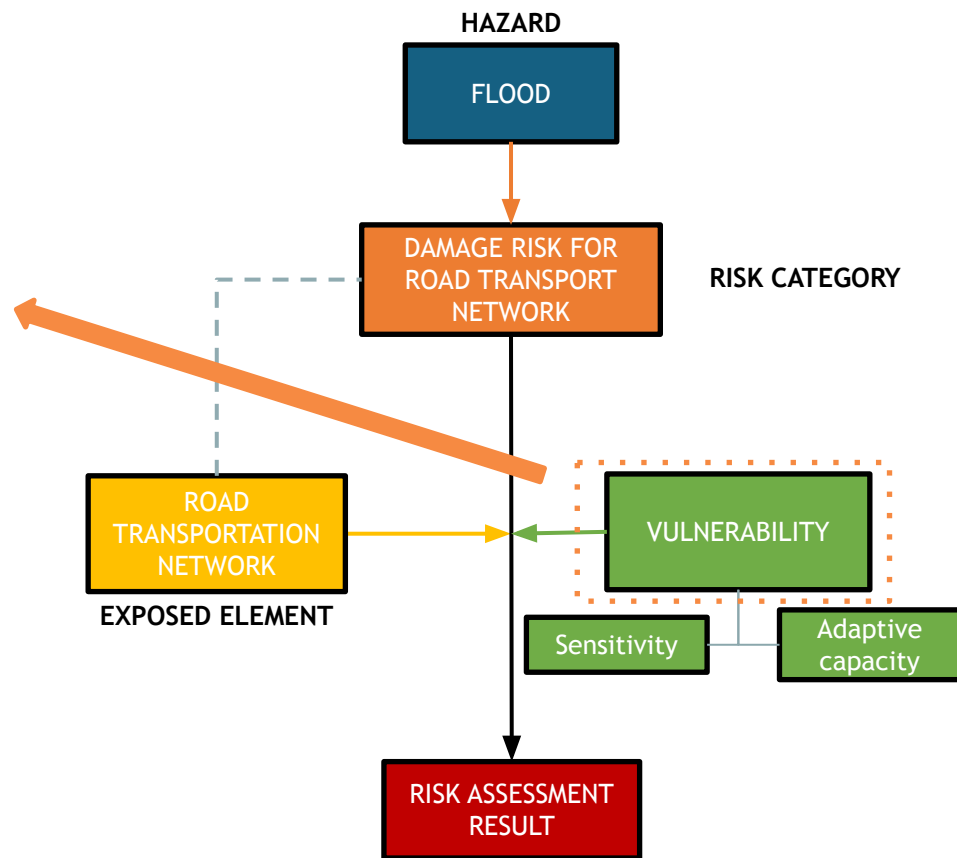
IMPACT CHAIN



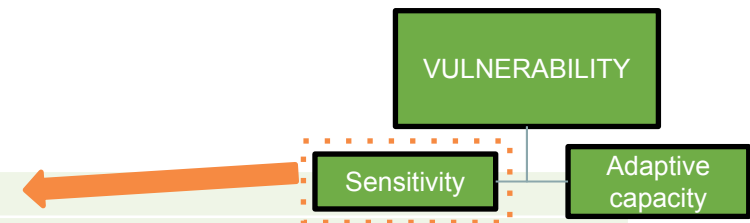
VULNERABILITY CRITERIA

CRITERION

- B2.2.1 Drainage capacity of road infrastructure
- B2.2.2 Susceptibility to Surface Flooding
- B2.2.3 Rainwater Penetration Risk
- B2.2.4 Drainage System Clogging/ Obstruction Risk
- B2.2.5 Sewer Overflow Connectivity
- B2.2.6 Subgrade Saturation Sensitivity
- B2.2.7 Pavement Material Flood Resistance
- B2.2.8 Maintenance and inspection Condition of Road Network
- B2.2.9 Road Foundation Stability
- B2.2.10 Roadside Vegetation and Buffer Zones
- B2.2.11 Elevation of Road Network
- B2.2.12 Emergency Accessibility



VULNERABILITY ASSESSMENT



CRITERION	INDICATOR
B2.2.1 Drainage capacity of road infrastructure	Drainage capacity per km of road
B2.2.2 Susceptibility to Surface Flooding	Proportion of road length below nearby terrain drainage path
B2.2.3 Rainwater Penetration Risk	Proportion of road segments with documented infiltration-related damage
B2.2.4 Drainage System Clogging/ Obstruction Risk	Frequency of drainage system blockages per km of road or percentage of drainage infrastructure reported clogged within assessment period
B2.2.5 Sewer Overflow Connectivity	Percentage of road network connected to combined sewer system
B2.2.6 Subgrade Saturation Sensitivity	Soil permeability
B2.2.7 Pavement Material Flood Resistance	Material vulnerability index
B2.2.8 Maintenance and inspection Condition of Road Network	Percentage of road segments in poor or critical condition
B2.2.9 Road Foundation Stability	Proportion of roads built on weak or water-sensitive subgrade soils
B2.2.10 Roadside Vegetation and Buffer Zones	Percentage of road length with vegetated swales, buffers, or rain gardens
B2.2.11 Elevation of Road Network	Proportion of road length located in areas with high flood or landslide susceptibility due to elevation or slope
B2.2.12 Emergency Accessibility	Share of roads in critical emergency access routes in flood zones

VULNERABILITY ASSESSMENT

This presentation includes examples of some of the most relevant criterion:

CRITERION	INDICATOR
B2.2.1 Drainage capacity of road infrastructure	Drainage capacity per km of road
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B2.2.1 DRAINAGE CAPACITY OF ROAD INFRASTRUCTURE

Description:

This criterion assesses the ability of roadside and subsurface drainage systems to evacuate stormwater and floodwater effectively, reducing surface flooding and ensuring road functionality during heavy rainfall.

Objective:

Evaluate whether the road network's drainage system provides sufficient capacity to prevent ponding, road damage, and transport disruption, and to identify critical segments requiring improvement.

Relevance:

Insufficient drainage capacity can lead to water accumulation on roads, traffic disruption, accelerated pavement deterioration, and secondary hazards. Assessing drainage performance supports resilient mobility and flood-safe urban design.



B2.2.1 DRAINAGE CAPACITY OF ROAD INFRASTRUCTURE

Indicator:

Drainage capacity per km of road [$\text{m}^3/\text{h}/\text{km}$]

Benchmarks: HIB

Optimal value (0): $\geq 500 \text{ m}^3/\text{h}/\text{km}$

Critical value (1): $\leq 50 \text{ m}^3/\text{h}/\text{km}$

Formula:

$$I = \sum Q_{i,\max} / L$$

$Q_{i,\max}$ = Maximum flow rate of each drainage element (m^3/h)

L = Length of the road segment (km)



B2.2.1 DRAINAGE CAPACITY OF ROAD INFRASTRUCTURE

CALCULATION STEP-BY-STEP

Step 1 - Identify drainage elements

List all gutters, inlets, storm drains, and culverts along the road network using GIS and infrastructure databases.

Step 2 - Determine flow capacity

Retrieve or estimate the maximum flow rate (m^3/h) of each element based on technical specifications or hydraulic formulas.

Step 3 - Compute indicator value

Sum all flow rates per road segment and divide by its length (km).

Step 4 - Evaluate performance

Compare the resulting value with benchmark thresholds and classify segments as adequate, moderate, or critical.



B2.2.1 DRAINAGE CAPACITY OF ROAD INFRASTRUCTURE

Data sources:

- Road and drainage asset databases
- Hydraulic design reports or stormwater models
- GIS data on road and drainage networks
- Field inspections and condition reports

EXAMPLE

A 2 km road segment with drainage elements totaling 750 m³/h

$$I = \sum Q_{i,\max} / L$$

$$I = 750 / 2 = \boxed{375 \text{ m}^3/\text{h}/\text{km}} \Rightarrow \text{Optimal performance (0)}$$

B2.2.2 SUSCEPTIBILITY TO SURFACE FLOODING

Description:

This criterion evaluates the likelihood of road surfaces flooding due to low points, poor grading, or insufficient runoff paths. Identifying flood-prone road segments helps prioritize interventions to maintain mobility, reduce infrastructure damage, and improve urban drainage.

Objective:

Determine areas of the road network most vulnerable to surface flooding and support urban planning and maintenance strategies to reduce flood risk and enhance transport resilience.

Relevance:

Surface flooding on roads can lead to:

- Obstructed transportation and reduced accessibility
- Increased risk of accidents and vehicle damage
- Localized property and infrastructure damage
- Impaired emergency response and mobility during storms



B2.2.2 SUSCEPTIBILITY TO SURFACE FLOODING

Indicator:

Proportion of road length below nearby terrain drainage path
[%]

Benchmarks: LIB

Optimal value (0): no roads below drainage paths

Critical value (1): 100% of roads below drainage paths

Formula:

$$I = (L_{\text{below}} / L_{\text{total}}) \times 100$$

L_{below} = total length of road segments lower than adjacent drainage path

L_{total} = total road length in the assessed area (m)



B2.2.2 SUSCEPTIBILITY TO SURFACE FLOODING

CALCULATION STEP-BY-STEP

Step 1 - Collect spatial data

Obtain DEM, GIS road network shapefiles with elevations, and drainage/flow path models.

Step 2 - Identify drainage paths

Map natural runoff paths near the road network using DEM or hydrological models.

Step 3 - Assess road elevation

Compare each road segment's elevation to the nearest drainage path. Classify as “below drainage path” if lower.

Step 4 - Compute indicator

Sum lengths of road segments below drainage paths (L_{below}).
Divide by total road length (L_{total}) and multiply by 100



B2.2.2 SUSCEPTIBILITY TO SURFACE FLOODING

Data sources:

- High-resolution Digital Elevation Models (DEM)
- GIS road network shapefiles with accurate elevation attributes
- Hydrological flow path models or watershed analyses

EXAMPLE

Given:

Road segments below drainage paths: 1.2 km

Total road length in the area: 5 km

$$I = (L_{\text{below}} / L_{\text{total}}) \times 100$$

$$I = (1.2 / 5) \times 100\% = 24\% \Rightarrow$$

Closer to optimal performance (0)



B2.2.4 DRAINAGE SYSTEM CLOGGING/ OBSTRUCTION RISK

Description:

Likelihood that drainage or sewer systems become obstructed by debris or sediment, reducing runoff capacity and causing water accumulation on roads.

Objective:

Identify critical sections of the drainage network prone to blockages and assess their impact on flood risk.

Relevance:

Blocked drainage systems can lead to urban flooding, road damage, and safety hazards. Monitoring obstruction risk supports preventive maintenance and resilient urban water management.



B2.2.4 DRAINAGE SYSTEM CLOGGING/ OBSTRUCTION RISK

Indicator:

Frequency of drainage system blockages per km of road or percentage of drainage infrastructure reported clogged within assessment period [clog events/km or %]

Benchmarks: LIB

Optimal value (0): 0 clog events/km or 0% components clogged

Critical value (1): ≥ 5 clog events/km

or $\geq 20\%$ components clogged

Formula:

Clog events per km:

$I = \text{Total clog events reported} / \text{Total km of drainage system}$

or

Percentage clogged:

$I = (\text{Total clogged components} / \text{Total components assessed}) \times 100$



B2.2.4 DRAINAGE SYSTEM CLOGGING/ OBSTRUCTION RISK CALCULATION STEP-BY-STEP

Step 1 - Collect data

Gather records of reported drainage blockages and total length/number of drainage components.

Step 2 - Compute indicator

Divide total clog events by total km of drainage system, or calculate the percentage of clogged components.

Step 3 - Interpret results

Compare indicator with benchmark values to identify areas requiring maintenance or intervention.



B2.2.4 DRAINAGE SYSTEM CLOGGING/ OBSTRUCTION RISK

Data sources:

- Municipal/regional maintenance records,
- Drainage and road asset inventories,
- Field inspections, sensor monitoring (if available).

EXAMPLE

Given:

Total clog events reported = 12

Total km of drainage system = 6 km

$I = \text{Total clog events reported} / \text{Total km of drainage system}$

$I = 12 / 6 = \boxed{2 \text{ clog events/km}} \Rightarrow \text{closer to optimal performance (0)}$

B2.2.6 SUBGRADE SATURATION SENSITIVITY

Description:

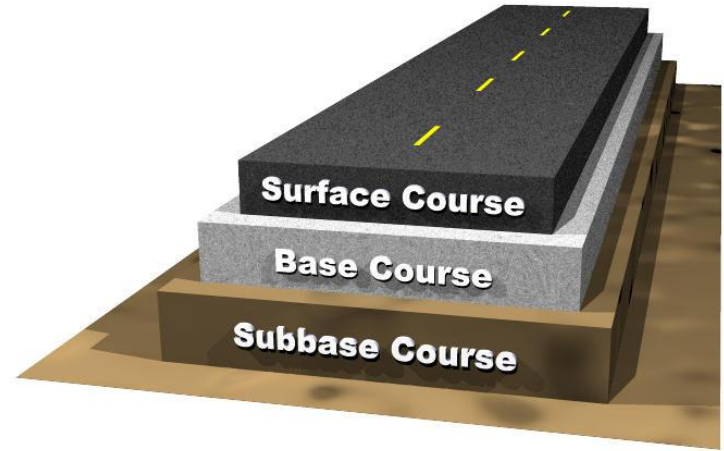
This criterion assesses the sensitivity of road substructures to prolonged water saturation and water ingress. Roads built over low-permeability soils are more vulnerable to structural damage, deformation, and accelerated deterioration during and after heavy rainfall events.

Objective:

Identify road sections at risk due to poor drainage and soil saturation.

Relevance:

Critical for flood resilience, as saturated subgrades can cause pavement deformation, potholes, and increased maintenance needs.



B2.2.6 SUBGRADE SATURATION SENSITIVITY

Indicator:

Average soil permeability beneath the road subgrade [mm/h]

Benchmarks: HIB

Optimal value (0): ≥ 30 mm/h (high permeability, low saturation risk)

Critical value (1): ≤ 1 mm/h (very low permeability, high saturation risk)

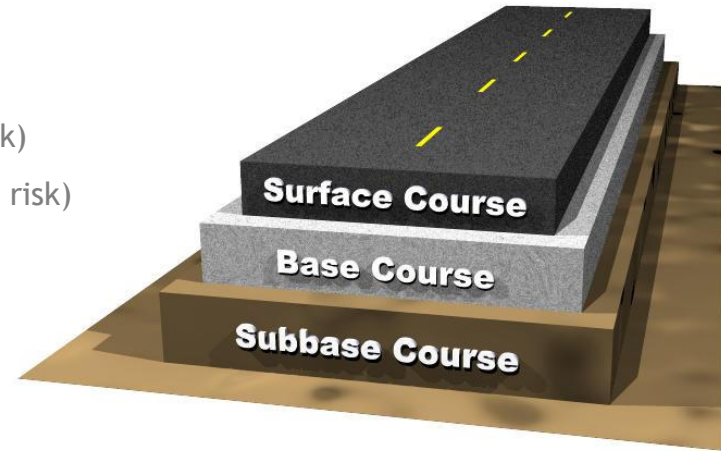
Formula:

$$I = ((k_1 \times A_1) + (k_2 \times A_2) + \dots + (k_n \times A_n)) / A_{\text{total}}$$

k_n = permeability of soil type n (mm/h)

A_n = area of soil type n under the road (m²)

A_{total} = total subgrade area (m²).



B2.2.6 SUBGRADE SATURATION SENSITIVITY CALCULATION STEP-BY-STEP

Step 1 - Gather spatial data on soil types beneath the road

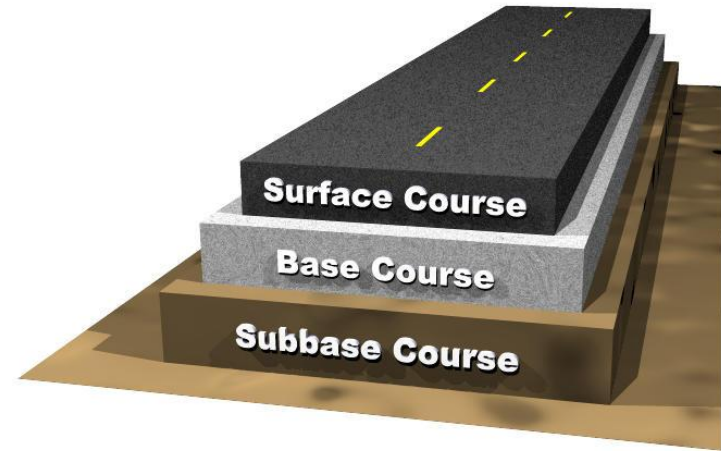
Collect soil maps and datasets from national/regional geotechnical surveys, ES DAC datasets, and local investigations. Include both the road subgrade and adjacent soils that may influence water flow.

Step 2 - Assign soil permeability values

Use published values from hydrological databases or laboratory tests and ensure consistent units.

Step 3 - Calculate area-weighted average permeability

For each soil type under the road, multiply its permeability by the area it occupies. Sum all products and divide by the total subgrade area.



B2.2.6 SUBGRADE SATURATION SENSITIVITY

Data sources:

- National/regional soil maps and databases
- Local geotechnical investigations
- ESDAC soil permeability datasets
- Engineering soil property reports and hydrological studies

EXAMPLE

Assume a 5000 m² road section with three soil types underneath:

$$I = ((k_1 \times A_1) + (k_2 \times A_2) + \dots + (k_n \times A_n)) / A_{\text{total}}$$

$$I = ((40 \times 2000) + (15 \times 1500) + (2 \times 1500)) / 5000 = \boxed{21.1 \text{ mm/h}} \Rightarrow \text{moderate performance}$$

Soil Type	Area (m ²)	Permeability (mm/h)	Contribution (k × A)
Sandy soil	2000	40	80000
Loamy soil	1500	15	22500
Clay	1500	2	3000
Total	5000	-	105500

B2.2.7 PAVEMENT MATERIAL FLOOD RESISTANCE

Description:

This criterion assesses the ability of pavement surfaces and subsurfaces to withstand prolonged water exposure.

Objective:

Identify road segments vulnerable to flood-induced damage and support resilient road network design.

Relevance:

Flood-susceptible pavements can lead to road failures, traffic disruptions, and higher maintenance costs. Evaluating material resistance informs selection of durable surfaces and maintenance planning.



B2.2.7 PAVEMENT MATERIAL FLOOD RESISTANCE

Indicator:

Material Vulnerability Index (MVI) [index]

Benchmarks: LIB

Optimal value (0): Low vulnerability

Critical value (1): High vulnerability

Formula:

$$I = (\sum (V_i \times A_i)) / A_{\text{total}}$$

V_i = vulnerability score of material i (0-1)

A_i = area or length covered by material i

A_{total} = total pavement area or length



B2.2.7 PAVEMENT MATERIAL FLOOD RESISTANCE CALCULATION STEP-BY-STEP

Step 1 - List pavement materials

Include surface (asphalt, concrete, gravel) and subsurface (base, sub-base) layers.

Step 2 - Assign vulnerability scores

0 = no vulnerability, 1 = maximum vulnerability based on material flood resistance standards.

Step 3 - Compute weighted vulnerabilities

Multiply each material score by its area/length.

Step 4 - Aggregate and normalize

Sum all weighted vulnerabilities and divide by total pavement area/length to obtain the MVI.



B2.2.7 PAVEMENT MATERIAL FLOOD RESISTANCE

Data sources:

- Road authority asset databases
- GIS pavement maps, laboratory or standard-based material flood resistance data (e.g., CEN EN 1991-1-7 Eurocode 1)

EXAMPLE

Asphalt ($V = 0.2$), Area = 5000 m²

Concrete ($V = 0.1$), Area = 3000 m²

Gravel ($V = 0.5$), Area = 2000 m²

Total Area = 10,000 m²

$$I = (\sum (V_i \times A_i)) / A_{\text{total}}$$

$$I = ((0.2 \times 5000) + (0.1 \times 3000) + (0.5 \times 2000)) / 10,000 = (1000 + 300 + 1000) / 10,000 = \boxed{0.23} \Rightarrow \text{rather an optimal value}$$

B2.2.10 ROADSIDE VEGETATION AND BUFFER ZONES

Description:

This criterion evaluates the presence of green infrastructure along roads that mitigates runoff, promotes infiltration, and reduces erosion.

Objective:

Assess the effectiveness of roadside vegetation and buffer zones in managing surface water and protecting infrastructure.

Relevance:

Vegetated buffers and swales reduce runoff volume, improve water quality, and enhance urban resilience against flooding.



B2.2.10 ROADSIDE VEGETATION AND BUFFER ZONES

Indicator:

Percentage of road length with vegetated swales, buffers, or rain gardens [%]

Benchmarks: HIB

Optimal value (0): 100 %

Critical value (1): 0 %

Formula:

$$I = (L_{\text{vegetated}} / L_{\text{total}}) \times 100$$

$L_{\text{vegetated}}$ = length of roads with vegetated swales, buffers, or rain gardens (m)

L_{total} = total road length (m)



B2.2.10 ROADSIDE VEGETATION AND BUFFER ZONES CALCULATION STEP-BY-STEP

Step 1 - Map road network

Collect GIS data of all road segments within the study area. Validate with recent satellite imagery or municipal maps.

Step 2 - Identify vegetated infrastructure

Determine which road segments have adjacent vegetated swales, buffer zones, or rain gardens through GIS, field surveys, or remote sensing.

Step 3 - Measure and calculate indicator

Measure total length of roads with vegetated infrastructure. Compute the indicator as the percentage of total road length using the formula.



B2.2.10 ROADSIDE VEGETATION AND BUFFER ZONES

Data sources:

- Local GIS road and green infrastructure data,
- Field surveys and EEA reports
- Municipal SUDS/green infrastructure plans

EXAMPLE

Given:

Total road length $L_{\text{total}} = 10,000 \text{ m}$

Roads with vegetated buffers $L_{\text{vegetated}} = 6,500 \text{ m}$

$$I = (L_{\text{vegetated}} / L_{\text{total}}) \times 100$$

$$I = (6,500 / 10,000) \times 100 = \boxed{65\%} \Rightarrow \text{moderately optimal}$$



B2.2.11 ELEVATION OF ROAD NETWORK

Description:

Road elevation and slope affect their exposure to flooding and landslides. Low-lying or steep roads are more likely to accumulate water or be damaged by runoff, impacting accessibility and safety.

Objective:

Assess road vulnerability to floods and landslides.

Relevance:

Identifying at-risk roads helps prioritize protection and adaptation measures.



B2.2.11 ELEVATION OF ROAD NETWORK

Indicator:

Proportion of road length in high flood or landslide susceptibility zones [%]

Benchmarks: LIB

Optimal value (0): 0 %

Critical value (1): 100 %

Formula:

$$I = (L_{\text{hazard}} / L_{\text{total}}) \times 100\%$$

L_{hazard} = road length in hazard zones (m)

L_{total} = total road length (m)



B2.2.11 ELEVATION OF ROAD NETWORK CALCULATION STEP-BY-STEP

Step 1 - Map hazard zones

Identify flood- and landslide-prone areas using DEM, slope, and hazard maps.

Step 2 - Overlay road network

Use GIS to intersect roads with high-susceptibility zones.

Step 3 - Compute road length in hazard zones and calculate indicator

Measure total road length in high-risk zones and divide by total road length. Apply formula.



B2.2.11 ELEVATION OF ROAD NETWORK

Data sources:

- Digital Elevation Models (DEM) and slope maps from regional GIS,
- Flood hazard maps and landslide susceptibility maps from local or national environmental agencies
- Road network GIS data from transportation authorities

EXAMPLE

Given:

Total road length: 25,000 m

Roads in high flood/landslide zones: 3,500 m

$$I = (L_{\text{hazard}} / L_{\text{total}}) \times 100\%$$

$$I = (3,500 / 25,000) \times 100 = \boxed{14\%} \Rightarrow \text{rather an optimal value}$$

B2.2.12 EMERGENCY ACCESSIBILITY

Description:

This criterion assesses the ability of roads to provide safe and reliable emergency access for evacuation and emergency services during flood events.

Objective:

Identify critical road segments at risk to ensure reliable evacuation and emergency response.

Relevance:

Flooded access routes can delay emergency services and evacuation, increasing risk to residents and property. Maintaining accessible routes is essential for resilient urban planning.



B2.2.12 EMERGENCY ACCESSIBILITY

Indicator:

Share of critical emergency access routes located in flood hazard zones [%]

Benchmarks: LIB

Optimal value (0): 0 %

Critical value (1): 100 %

Formula:

$$I = (L_{\text{flood}} / L_{\text{total}}) \times 100\%$$

L_{flood} = length of critical emergency routes within flood zones (m)

L_{total} = total length of critical emergency routes (m)



B2.2.12 EMERGENCY ACCESSIBILITY CALCULATION STEP-BY-STEP

Step 1 - Map critical emergency routes

Identify main roads, evacuation routes, and access roads for emergency services.

Step 2 - Overlay flood zones

Use GIS to intersect flood hazard maps with emergency route maps.

Step 3 - Compute indicator

Measure the length of routes within flood zones and calculate the percentage of at-risk routes.



B2.2.12 EMERGENCY ACCESSIBILITY

Data sources:

- Official road and emergency route maps,
- Flood hazard maps from hydrological studies or national agencies,
- GIS software for spatial analysis.

EXAMPLE

Given:

Total critical route length: 12,000 m

Length within flood zones: 3,600 m

$$I = (L_{\text{flood}} / L_{\text{total}}) \times 100\%$$

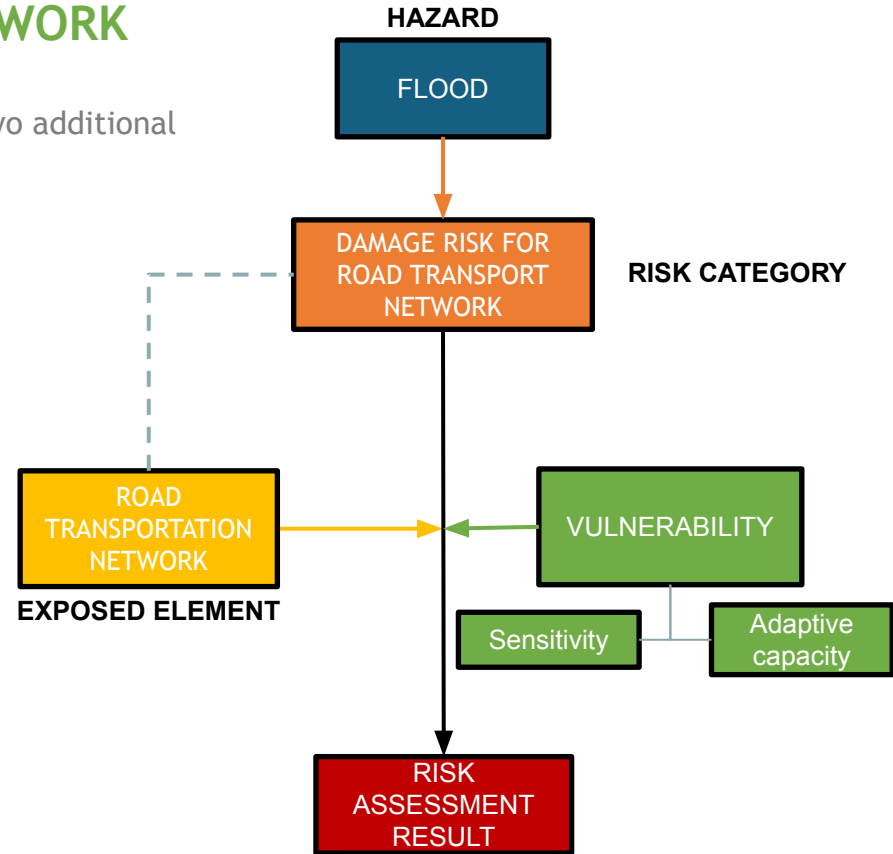
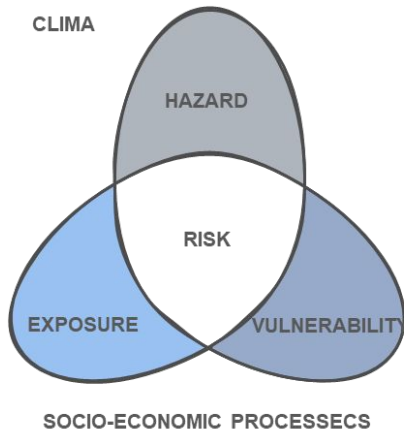
$$I = (3,600 / 12,000) \times 100 = \boxed{30\%} \Rightarrow \text{moderate risk}$$



EXPOSURE OF ROAD TRANSPORT NETWORK

After assessing vulnerability, it is necessary to quantify two additional factors to determine the level of risk:

- **HAZARD**
- **EXPOSURE**



HAZARD LIKELIHOOD

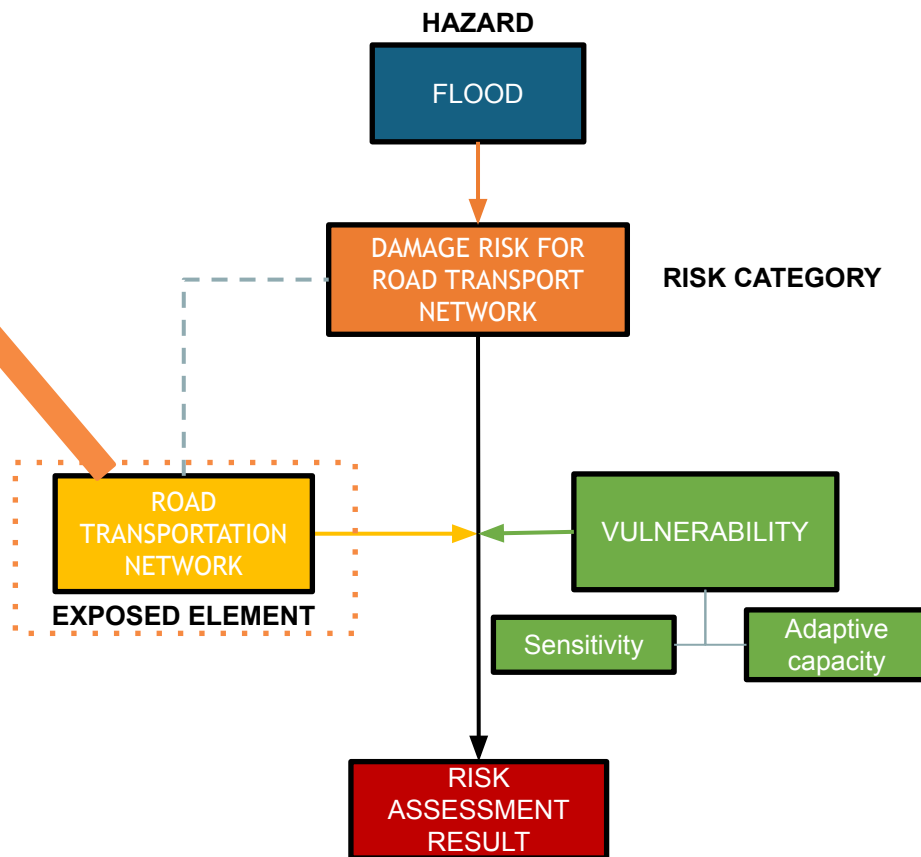
Hazardous event		Slow-on set process		Hazard Value (HV)
Frequent	Likely to occur often in a life time (every 10 years)	Very likely	Very likely to occur in the next 10 years	1 - 0,9
Probable	Likely to occur several times in a lifetime (every 25 years)	Likely	Likely to occur in the next 10 years	0,89 - 0,66
Occasional	Likely to occur some times in a lifetime (every 50 years)	As likely as not	As likely as not to occur in the next 10 years	0,65 - 0,33
Remote	Unlikely but still possible to occur in a lifetime (every 100 years)	Unlikely	Unlikely to occur in the next 10 years	0,32 - 0

Hazard Value (HV) = This information is provided by SECAPs or by experts' judgment

For example, Hazard Value (HV) = **0.8 (Probable)**

EXPOSURE CRITERIA

CRITERION
B2.2-E.1 Road Network in Flood Zones
B2.2-E.2 Traffic Volume on Flood-Prone Roads
B2.2-E.3 Density of Critical Roads
B2.2-E.4 Number of Critical road infrastructures Exposed
B2.2-E.5 Presence of Underground Parking in Risk Zones
B2.2-E.6 Proximity to River or Coastal Flood Sources
B2.2-E.7 Historical Flood Impacts on Roads
B2.2-E.8 Urbanization and Impervious Surfaces Nearby
B2.2-E.9 Land Use Around Road Network
B2.2-E.10 Social Dependence on Exposed Roads
B2.2-E.11 Protective Flood Infrastructure Presence



EXPOSURE CRITERIA

CRITERION	INDICATOR
B2.2-E.1 Road Network in Flood Zones	Total length of roads in flood-prone zones (km)
B2.2-E.2 Traffic Volume on Flood-Prone Roads	Average daily traffic on at-risk segments
B2.2-E.3 Density of Critical Roads	km of primary roads per km ² in flood zones
B2.2-E.4 Number of Critical road infrastructures Exposed	Number of critical assets in flood zones
B2.2-E.5 Presence of Underground Parking in Risk Zones	Total area of parking in hazard zones
B2.2-E.6 Proximity to River or Coastal Flood Sources	Percentage of road network within 100m of flood source
B2.2-E.7 Historical Flood Impacts on Roads	Number of flood events with road closures in past 10 years
B2.2-E.8 Urbanization and Impervious Surfaces Nearby	Percentage of impervious surface near road segments
B2.2-E.9 Land Use Around Road Network	Percentage of high-runoff land uses within 50 m of road
B2.2-E.10 Social Dependence on Exposed Roads	Population dependent on each exposed km of road
B2.2-E.11 Protective Flood Infrastructure Presence	Percentage of road length protected by flood mitigation structures

EXPOSURE CRITERIA

This presentation includes examples of some of the most relevant criterion:

CRITERION	INDICATOR
B2.2-E.1 Road Network in Flood Zones	Total length of roads in flood-prone zones (km)
B2.2-E.2 Traffic Volume on Flood-Prone Roads	Average daily traffic on at-risk segments
B2.2-E.3 Density of Critical Roads	km of primary roads per km ² in flood zones
B2.2-E.4 Number of Critical road infrastructures Exposed	Number of critical assets in flood zones
B2.2-E.5 Presence of Underground Parking in Risk Zones	Total area of parking in hazard zones
B2.2-E.6 Proximity to River or Coastal Flood Sources	Percentage of road network within 100m of flood source
B2.2-E.7 Historical Flood Impacts on Roads	Number of flood events with road closures in past 10 years
B2.2-E.8 Urbanization and Impervious Surfaces Nearby	Percentage of impervious surface near road segments
B2.2-E.9 Land Use Around Road Network	Percentage of high-runoff land uses within 50 m of road
B2.2-E.10 Social Dependence on Exposed Roads	Population dependent on each exposed km of road
B2.2-E.11 Protective Flood Infrastructure Presence	Percentage of road length protected by flood mitigation structures

B2.2-E.1 ROAD NETWORK IN FLOOD ZONES

Description:

This criterion assesses the proportion of the road network exposed to flood-prone zones, indicating the vulnerability of urban mobility and emergency access during flood events.

Objective:

Identify critical road segments affected by flooding to support risk mitigation, resilient design, and improved evacuation planning.

Relevance:

Flood-exposed road networks can disrupt transportation, hinder emergency response, and cause infrastructural damage. Understanding exposure supports better infrastructure planning and prioritization of flood protection measures.



B2.2-E.1 ROAD NETWORK IN FLOOD ZONES

Indicator:

Total length of roads within flood-prone zones [km]

Benchmarks: LIB

Optimal value (0): 0 km

Critical value (1): $\geq$ total road network length

Formula:

$$I = L_{\text{flood}}$$

where L_{flood} = total length of road segments located within flood-prone zones (km)



B2.2-E.1 ROAD NETWORK IN FLOOD ZONES CALCULATION STEP-BY-STEP

Step 1 - Collect spatial datasets

Obtain GIS layers for the road network and flood hazard zones.

Step 2 - Identify intersecting segments

Overlay the flood hazard layer with the road network to detect intersections and extract road segments within flood-prone zones.

Step 3 - Compute indicator

Measure the total length (in km) of road segments within the flood-prone areas. Compare the result with benchmarks to assess exposure level.



B2.2-E.1 ROAD NETWORK IN FLOOD ZONES

Data sources:

- Local or national transport authorities,
- Hydrological model outputs,
- Flood hazard maps from hydrological studies or national agencies,
- The European Flood Awareness System (EFAS)

EXAMPLE

Given:

Total road network length (L_{total}) = 20 km

Roads within flood-prone zones (L_{flood}) = 2.4 km

$$I = 2.4 \text{ km}$$

(It is also possible to express the result as a %).



B2.2-E.2 TRAFFIC VOLUME ON FLOOD-PRONE ROADS

Description:

This criterion evaluates exposure to flooding based on vehicle flow on roads located within high flood-risk areas.

Objective:

Assess the potential impact of floods on transportation and mobility to inform risk mitigation measures.

Relevance:

High traffic on flood-prone roads increases the likelihood of disruptions, accidents, and economic losses during flood events. Understanding traffic exposure supports resilient urban mobility planning.



Prague map: flood hazard map

Source: <https://iprpraha.cz/stranka/59/zaplavova-uzemi>

B2.2-E.2 TRAFFIC VOLUME ON FLOOD-PRONE ROADS

Indicator:

Average daily traffic on flood-prone segments
[vehicles/day]

Benchmarks: LIB

Optimal value (0): 0 vehicles/day

Critical value (1): maximum observed traffic volume
on flood-prone segments

Formula:

$$I = (\sum T_i) / n$$

T_i = average daily traffic on flood-prone segment i

n = number of flood-prone segments



Prague map: flood hazard map

Source: <https://iprpraha.cz/stranka/59/zaplavova-uzemi>

B2.2-E.2 TRAFFIC VOLUME ON FLOOD-PRONE ROADS CALCULATION STEP-BY-STEP

Step 1 - Identify flood-prone road segments

Map all road sections within high flood-risk zones using flood hazard maps and GIS layers.

Step 2 - Collect traffic data

Obtain or estimate average daily traffic for each at-risk segment from transport departments, traffic sensors, or surveys.

Step 3 - Compute indicator

Calculate the mean traffic of all flood-prone segments using the formula.



Prague map: flood hazard map

Source: <https://iprpraha.cz/stranka/59/zaplavova-uzemi>

B2.2-E.2 TRAFFIC VOLUME ON FLOOD-PRONE ROADS

Data sources:

- National/regional flood hazard maps
- Traffic volume data from transport authorities or road sensors
- GIS road network and flood zone layers
- European Flood Awareness System (EFAS) datasets.

EXAMPLE

Given flood-prone segments with average daily traffic:

Segment 1: 5,000 vehicles/day

Segment 2: 3,000 vehicles/day

Segment 3: 2,000 vehicles/day

$n=3$

$$I = (\sum T_i) / n$$

$$I = (5000 + 3000 + 2000) / 3 = \boxed{3,333 \text{ vehicles/day}}$$



B2.2-E.4 NUMBER OF CRITICAL ROAD INFRASTRUCTURES EXPOSED

Description:

This criterion assesses the exposure of critical road infrastructures, such as bridges and tunnels, to flood hazards.

Objective:

Identify key transport assets at risk of flooding to support risk mitigation and emergency planning.

Relevance:

Flooded or damaged road infrastructures can disrupt mobility, emergency response, and urban connectivity. Assessing exposure helps prioritize protective measures and resilient transport planning.



B2.2-E.4 NUMBER OF CRITICAL ROAD INFRASTRUCTURES EXPOSED

Indicator:

Number of critical assets located within flood zones [n]

Benchmarks: LIB

Optimal value (0): 0

Critical value (1): Total number of critical infrastructures located in flood hazard zones

Formula:

I = Number of critical road infrastructures within flood zones



B2.2-E.4 NUMBER OF CRITICAL ROAD INFRASTRUCTURES EXPOSED

CALCULATION STEP-BY-STEP

Step 1 - Identify critical infrastructures

Compile a list of bridges, tunnels, and other key road nodes from transportation authority databases.

Step 2 - Map flood hazard zones

Obtain GIS layers of flood hazard areas from hydrological agencies or environmental authorities.

Step 3 - Overlay and count

Overlay critical infrastructures on flood zones in GIS to identify which assets are exposed. Count the total number of exposed assets to determine the indicator value.



B2.2-E.4 NUMBER OF CRITICAL ROAD INFRASTRUCTURES EXPOSED

Data sources:

- GIS layers of transport infrastructure,
- Transportation authority databases,
- Flood hazard maps from hydrological or environmental agencies.

EXAMPLE

Total critical infrastructures in the study area:

Bridges: 6

Tunnels: 3

Key junctions: 4

Located within flood zones: 3 bridges and 1 tunnel

$I = 4$ units



B2.2-E.6 PROXIMITY TO RIVER OR COASTAL FLOOD SOURCES

Description:

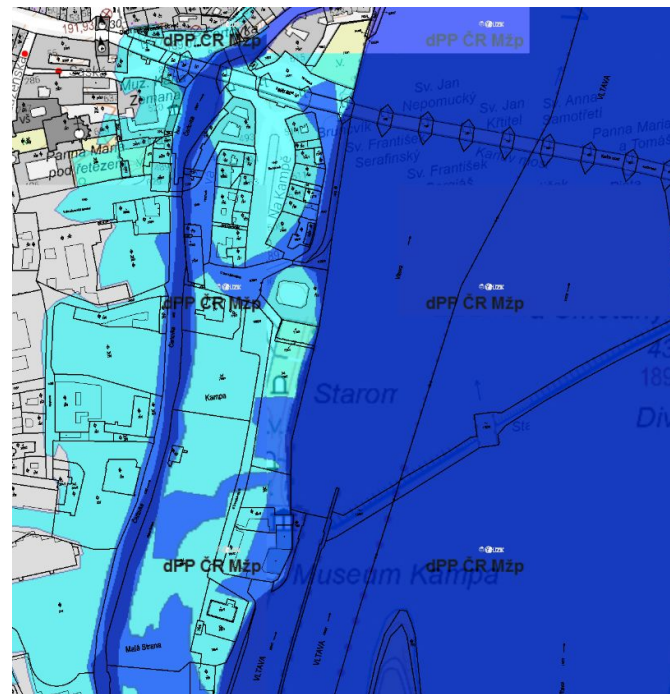
This criterion evaluates the exposure of the road network to nearby rivers, coasts, or major flood retention areas.

Objective:

Identify roads at higher risk of flooding to inform mitigation and emergency planning.

Relevance:

Roads close to flood sources are more vulnerable to inundation, affecting accessibility, emergency response, and infrastructure resilience. Monitoring proximity helps prioritize flood protection measures.



Prague: Flood map

Source:

<https://ikatastr.cz/#kde=50.085208,14.408322,17&mapa=geograficka&vrstvy=zaplavy100,zaplavy20,zaplavy5,parcelybudovy,cislabudov>

B2.2-E.6 PROXIMITY TO RIVER OR COASTAL FLOOD SOURCES

Indicator:

Percentage of road network within 100 m of flood sources [%]

Benchmarks: LIB

Optimal value (0): 0%

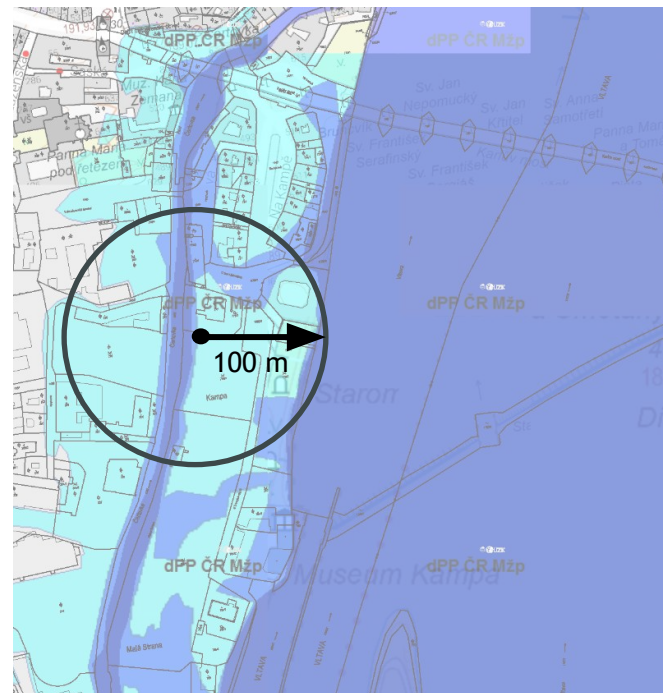
Critical value (1): $\geq 30\%$

Formula:

$$I = (L_{\text{flood}} / L_{\text{total}}) \times 100\%$$

L_{flood} = length of road segments within 100 m of flood sources (m)

L_{total} = total length of road network (m)



Prague: Flood map

Source:

<https://ikatastr.cz/#kde=50.085208,14.408322,17&mapa=geograficka&vrstvy=zaplavy100,zaplavy20,zaplavy5,parcelybudovy,cislabudov>

B2.2-E.6 PROXIMITY TO RIVER OR COASTAL FLOOD SOURCES CALCULATION STEP-BY-STEP

Step 1 - Map roads and flood sources

Compile GIS data for all roads and identify flood sources (riverbanks, coastlines, major retention areas).

Step 2 - Apply buffer

Generate a 100 m buffer around all flood sources.

Step 3 - Measure exposure

Calculate the total length of roads intersecting the buffer (L_{flood}) and the total road length in the study area (L_{total}).

Step 4 - Compute indicator

Apply the formula $I = (L_{\text{flood}} / L_{\text{total}}) \times 100\%$ to obtain the percentage of roads at risk.



B2.2-E.6 PROXIMITY TO RIVER OR COASTAL FLOOD SOURCES

Data sources:

- GIS road network data and hydrological maps,
- Floodplain and retention area maps from national or regional environmental authorities.

EXAMPLE

Given:

Total road network: 25,000 m

Road segments within 100 m of flood sources: 4,500 m

$$I = (L_{\text{flood}} / L_{\text{total}}) \times 100\%$$

$$I = (4,500 / 25,000) \times 100 = \boxed{18\%}$$



B2.2-E.7 HISTORICAL FLOOD IMPACTS ON ROADS

Description:

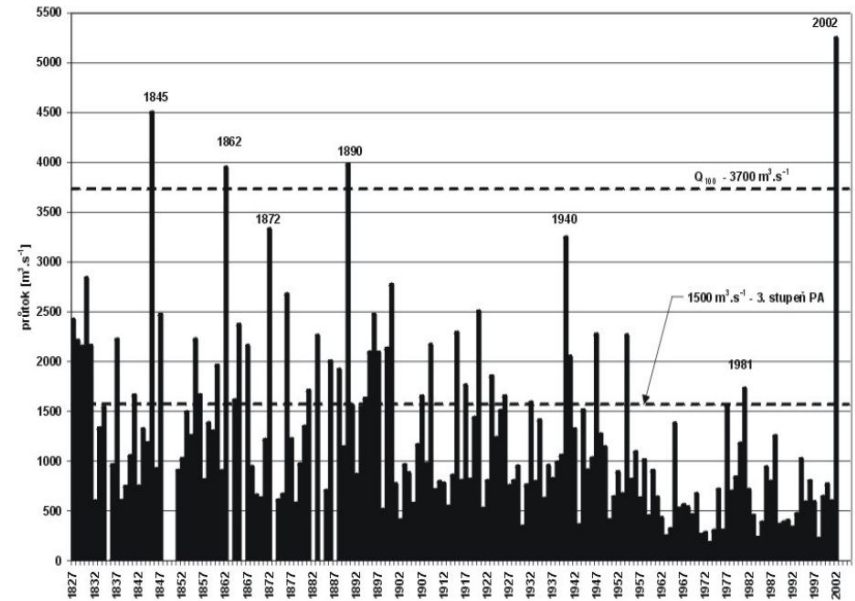
This criterion assesses the frequency and severity of past flood events affecting road infrastructure in the neighborhood.

Objective:

Identify critical road segments vulnerable to flooding and inform strategies to improve accessibility and resilience.

Relevance:

Flood-related road closures can disrupt emergency access, mobility, and essential services.



Prague: Major Floods between 1827-2002

Source: <https://bezpecnost.praha.eu/clanky/povodne>

B2.2-E.7 HISTORICAL FLOOD IMPACTS ON ROADS

Indicator:

Number of flood events causing partial or complete road closures in the past 10 years [n]

Benchmarks: LIB

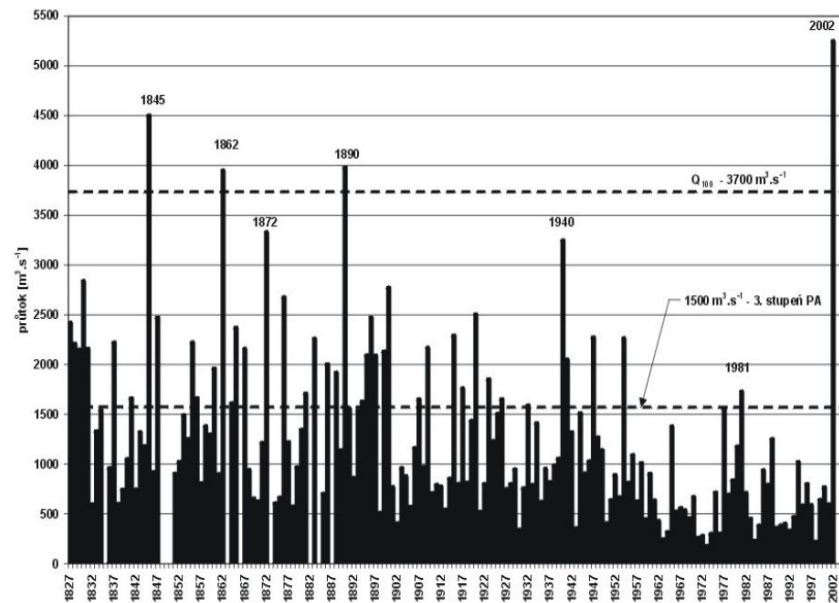
Optimal value (0): 0

Critical value (1): ≥ 10

Formula:

$$I = N_{\text{closures}}$$

Where N_{closures} = total number of flood events leading to road closures in the past 10 years



Prague: Major Floods between 1827-2002

Source: <https://bezpecnost.praha.eu/clanky/povodne>

B2.2-E.7 HISTORICAL FLOOD IMPACTS ON ROADS CALCULATION STEP-BY-STEP

Step 1 - Collect historical flood records

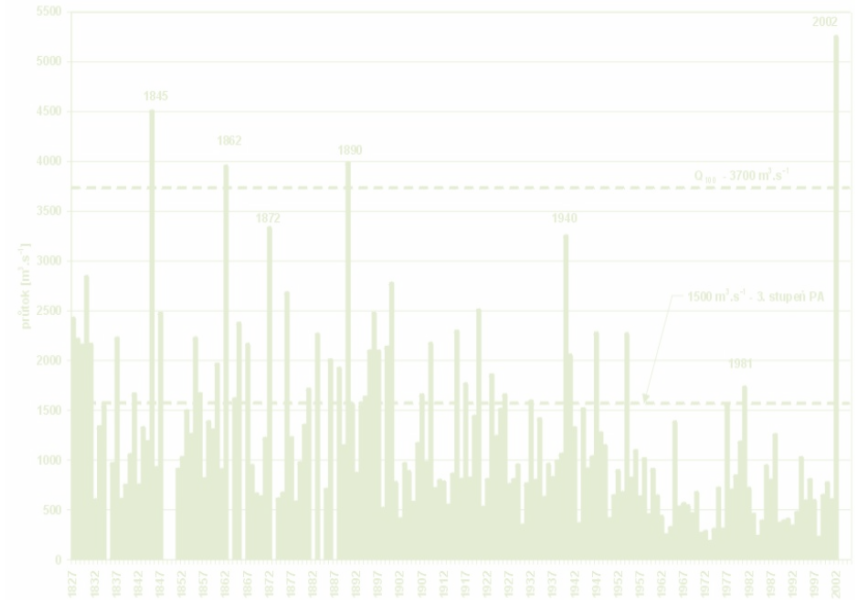
Gather data from local and regional flood archives, road authority incident logs, and reliable media reports. Focus on events affecting the study area within the last 10 years.

Step 2 - Identify flood-related road closures

Review records to identify instances where floods caused partial or full closures of streets or access roads.

Step 3 - Compute the indicator value

Count the total number of closure events. Compare against benchmarks: 0 = optimal, ≥ 10 = critical.



B2.2-E.7 HISTORICAL FLOOD IMPACTS ON ROADS

Data sources:

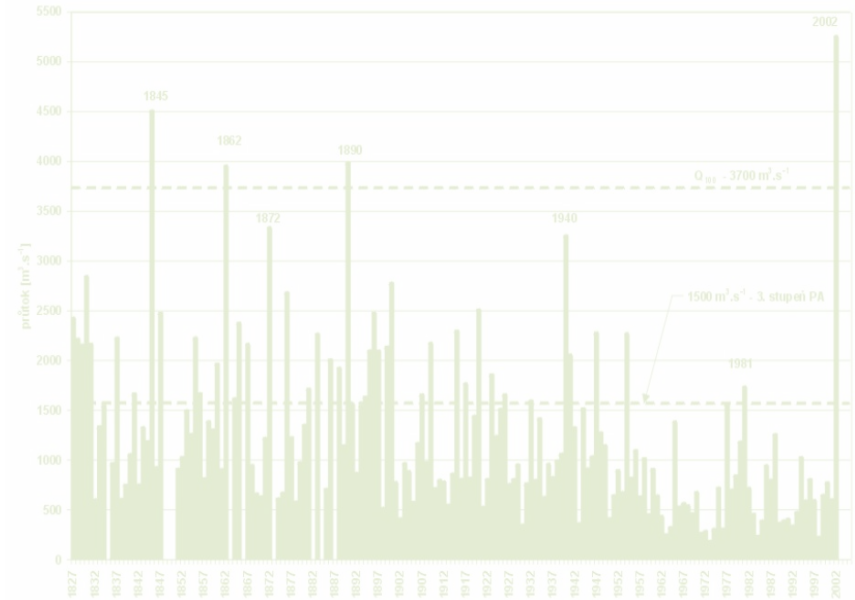
- Local and regional flood event archives,
- Road transport authorities' incident and closure logs,
- Historical weather and flood databases,
- Media reports documenting flood-related transport disruptions.

EXAMPLE

Flood event records in the past 10 years:

- 2016: Minor flooding, no closures
- 2018: Road closure on Main Street (1 event)
- 2021: Flooding on 3 roads causing closures (3 events)
- 2023: Flood on secondary roads causing 2 closures (2 events)

Total: **6 closures**



B2.2-E.10 SOCIAL DEPENDENCE ON EXPOSED ROADS

Description:

This criterion assesses the degree to which local communities rely on flood-exposed road segments for daily mobility.

Objective:

Identify vulnerable populations and critical road segments to support resilient urban mobility planning.

Relevance:

High dependence on exposed roads increases social vulnerability during flood events, potentially isolating communities and disrupting access to services.



B2.2-E.10 SOCIAL DEPENDENCE ON EXPOSED ROADS

Indicator:

Population dependent on each exposed km of road
[Population/km]

Benchmarks: LIB

Optimal value (0): 0 Population/km

Critical value (1): 1500 Population/km

Formula:

$$I = P_{\text{dep}} / L_{\text{exp}}$$

P_{dep} = total population dependent on the road segment,

L_{exp} = length of exposed road segment (km)



B2.2-E.10 SOCIAL DEPENDENCE ON EXPOSED ROADS CALCULATION STEP-BY-STEP

Step 1 - Identify exposed road segments

Use flood hazard maps to locate roads at risk of flooding.

Step 2 - Delineate dependent population

Determine the catchment area for each exposed segment to estimate the population relying on it for daily mobility.

Step 3 - Compute indicator

Divide the dependent population by the length of the exposed road segment to obtain Population/km.



B2.2-E.10 SOCIAL DEPENDENCE ON EXPOSED ROADS

Data sources:

- Flood hazard maps (local/national hydrological agencies, European Flood Awareness System)
- Road network GIS data (transport databases)
- Population distribution datasets (census, official statistics)

EXAMPLE

Given:

Exposed road segment length: 2 km

Dependent population: 2500 people

$$I = P_{\text{dep}} / L_{\text{exp}}$$

$$I = 2500 / 2 = \boxed{1250 \text{ Population/km}}$$



NORMALISATION

Once all indicator values for the selected criterion are calculated, normalization converts them to a common 0-1 scale. This ensures each indicator contributes proportionately to the overall resilience score, regardless of its original unit. Normalization enables meaningful data synthesis, cross-context benchmarking, and more transparent, objective decision-making in resilience assessments..

EXAMPLE:

For B2.2.1 vulnerability criterion „Drainage capacity of road infrastructure“ with an indicator value of **375 m³/h/km**:

$$X_{norm} = \frac{x_{max} - x_i}{x_{max} - x_{min}}$$

Where:

$X_i = 375 \text{ m}^3/\text{h}/\text{km}$

$X_{max} = 500 \text{ m}^3/\text{h}/\text{km}$ (optimal, value 0)

$X_{min} = 50 \text{ m}^3/\text{h}/\text{km}$ (critical, value 1)

$X_{norm} = 125 / 450 = 0,278 = \mathbf{0,28}$ (This means the drainage capacity is better than moderate, but still below optimal)

NORMALISATION INTERVAL

Normalisation values	Description
0.0-0.2	Optimal (no improvement necessary)
>0.2-0.4	Rather positive
>0.4-0.6	Neutral
>0.6-0.8	Rather negative
>0.8-1.0	Critical (could lead to severe consequences)

OVERALL VULNERABILITY (VULNERABILITY VALUE - VV)

CRITERION	Normalised Value	Weight
B2.2.1 Drainage capacity of road infrastructure	0,28	0,125
B2.2.2 Susceptibility to Surface Flooding	0,24	0,10
B2.2.4 Drainage System Clogging/Obstruction Risk	0,4	0,20
B2.2.6 Subgrade Saturation Sensitivity	0,31	0,10
B2.2.7 Pavement Material Flood Resistance	0,23	0,125
B2.2.10 Roadside Vegetation and Buffer Zones	0,35	0,07
B2.2.11 Elevation of Road Network	0,15	0,125
B2.2.12 Emergency Accessibility	0,3	0,155

Normalised score Weight

$$VV = \sum_{i=1}^n (I_i \times W_i)$$

$$VV = 0,28 \times 0,125 + 0,24 \times 0,10 + 0,40 \times 0,20 + 0,31 \times 0,10 + 0,23 \times 0,125 + 0,35 \times 0,07 + 0,15 \times 0,125 + 0,30 \times 0,155 = 0,288 = 0,29$$

Vulnerability Value (VV) = 0,29

Vulnerability Level =
RATHER POSITIVE

OVERALL EXPOSURE (EXPOSURE VALUE - EV)

CRITERION	Normalised Value	Weight
B2.2-E.1 Road Network in Flood Zones	0,12	0,2
B2.2-E.2 Traffic Volume on Flood-Prone Roads	0,66	0,15
B2.2-E.4 Number of Critical road infrastructures Exposed	0,31	0,15
B2.2-E.6 Proximity to River or Coastal Flood Sources	0,6	0,2
B2.2-E.7 Historical Flood Impacts on Roads	0,6	0,2
B2.2-E.10 Social Dependence on Exposed Roads	0,83	0,1

Normalised score Weight

$$VV = \sum_{i=1}^n (I_i \times W_i)$$

$$VV = 0,12 \times 0,20 + 0,66 \times 0,15 + 0,31 \times 0,15 + 0,60 \times 0,20 + 0,60 \times 0,20 + 0,83 \times 0,10 = 0,49$$

Exposure Value (EV) = 0,49

Exposure Level =
NEUTRAL

DAMAGE RISK FOR ROAD TRANSPORT NETWORK

- Hazard Value = 0,8
- Exposure Value = 0,49
- Vulnerability Value = 0,29

- W_{HV} weight of HV  0,25
- W_{EV} weight of EV  0,35
- W_{V} weight of VVA  0,40

$$HV^{w_{HV}} + EV^{w_{EV}} + VV^{w_V}$$



RISK LEVEL =
0,487 = 0,49
RATHER MODERATE