Assessment of the risk of destabilization of vehicles at crossing points between streams and roads

By:

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Introduction

- Several studies indicate that a large number of people have lost their lives when trying to cross flooded areas with their vehicles (Drobot et al., 2007, Fitzgerald et al., 2010)

- Floods are the main cause of disruption of public and private transport systems (Pregnolato et al., 2017). The affectation of these systems generates a cascade effect that can have serious repercussions (Suárez et al., 2005)

- There are few studies aimed at determining the risk of vehicle instability at intersections sites between roads and streams

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Objectives

1. To develop a methodology to calculate the risk of vehicle instability at intersection sites between streams and roads

2. To implement the developed methodology in a case study

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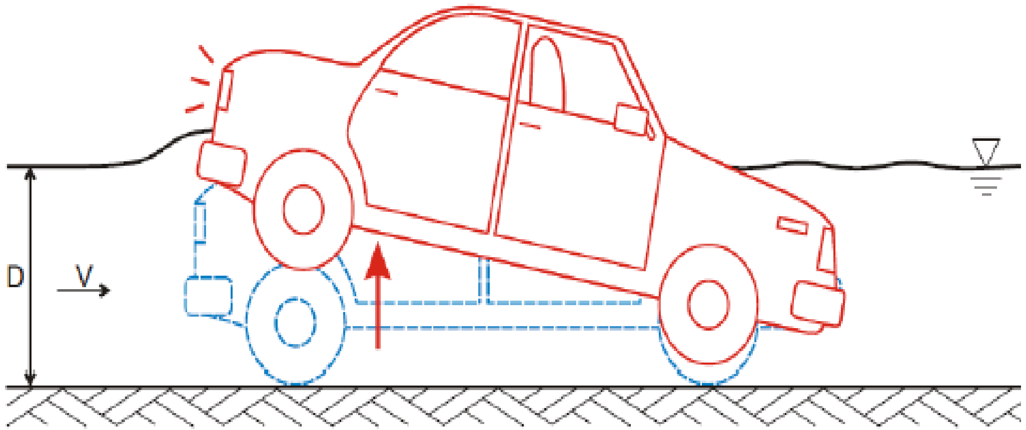
Vehicle stability failure mechanisms

Floating

Buoyancy and lift forces exceed the weight of the vehicle. This instability is dominant in low velocity and high depth flow



Source: Shand et al. (2011)

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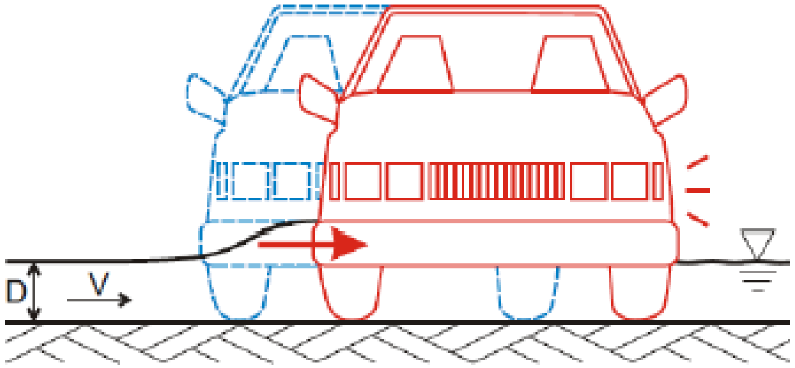
Vehicle stability failure mechanisms

Sliding

Drag force exceeds the frictional force produced between tires and ground



Source: Shand et al. (2011)

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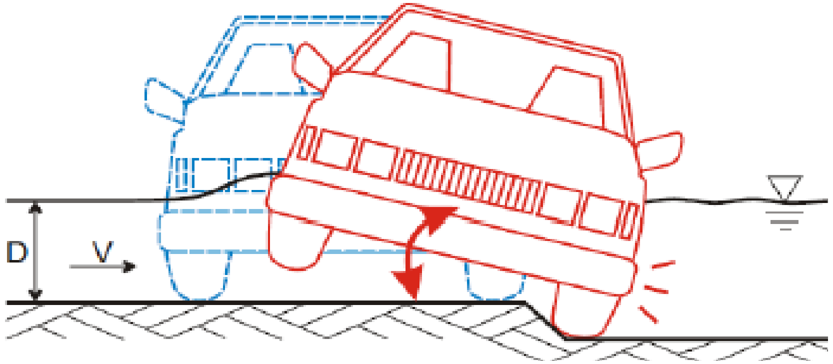
Vehicle stability failure mechanisms

Toppling

It seems to occur only when the vehicles have already been washed away by the flow or have floated and found irregular land



Source: Shand et al. (2011)

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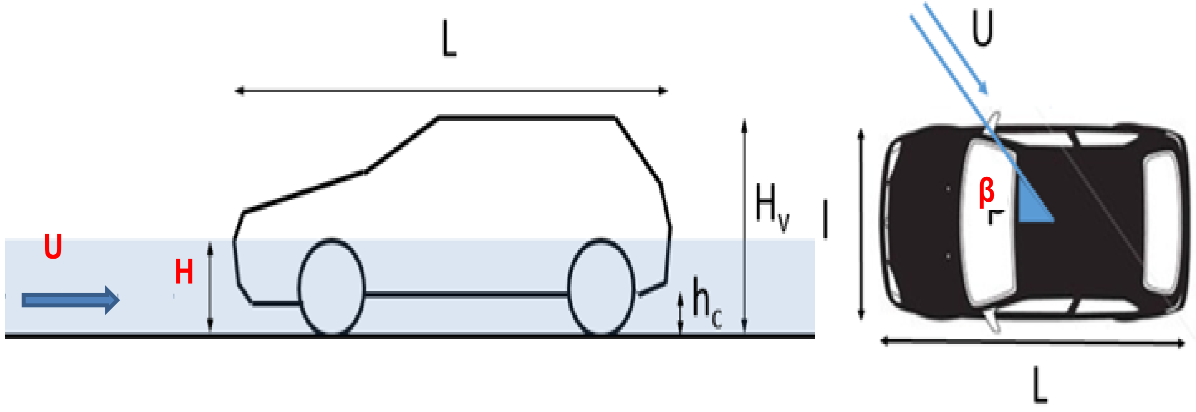
Stability criterion: Arrighi et al. (2016)

Mobility Parameter θ_V

Based on flood (**H**), **vehicle characteristics** and the angle of flow incidence **β**

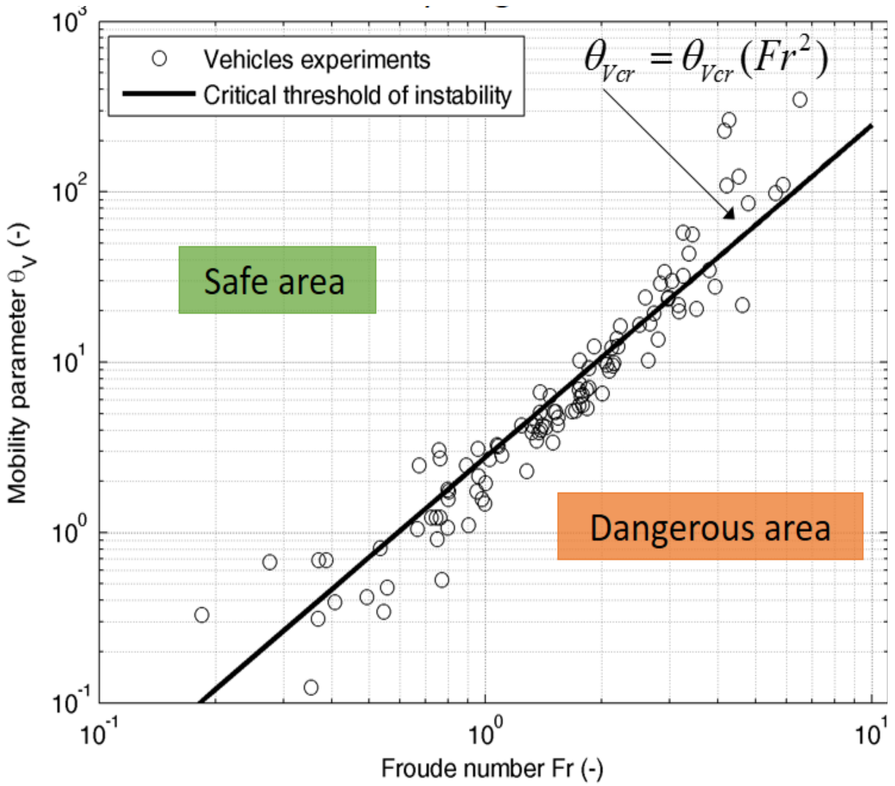
$$\theta_V = \frac{2L}{(H_v - h_c)} * \frac{l}{l * Cos\beta + L * sin\beta} * \left(\frac{\rho_c * (H_v - h_c)}{\rho * (H - h_c)} - 1 \right)$$



Source: Arrighi et al. (2016)

Critical Threshold θ_{Vcr} (H, U)

$$\theta_{Vcr} = 8.2 * Fr^2 - 14.1 * Fr + 5.4$$

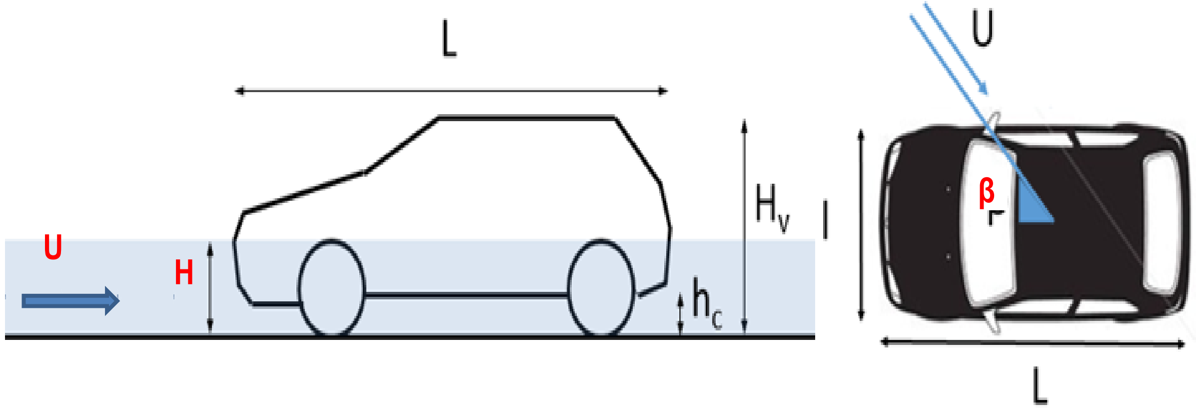


Source: Arrighi et al. (2016)

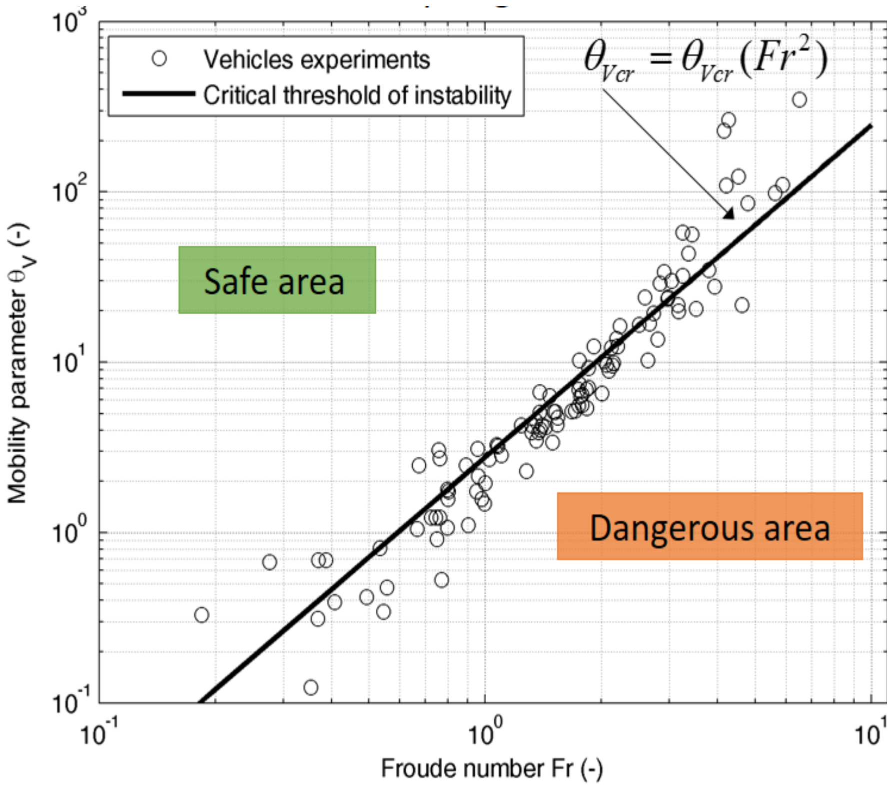
Stability criterion: Arrighi et al. (2016)

Stability criterion:

$$S_i \begin{cases} \geq 1 & \text{Incipient motion by sliding} \\ \in [0, 1[& \text{Vehicle at rest} \\ < 0 & \text{In motion by floating} \end{cases}$$



Source: Arrighi et al. (2016)



Source: Arrighi et al. (2016)

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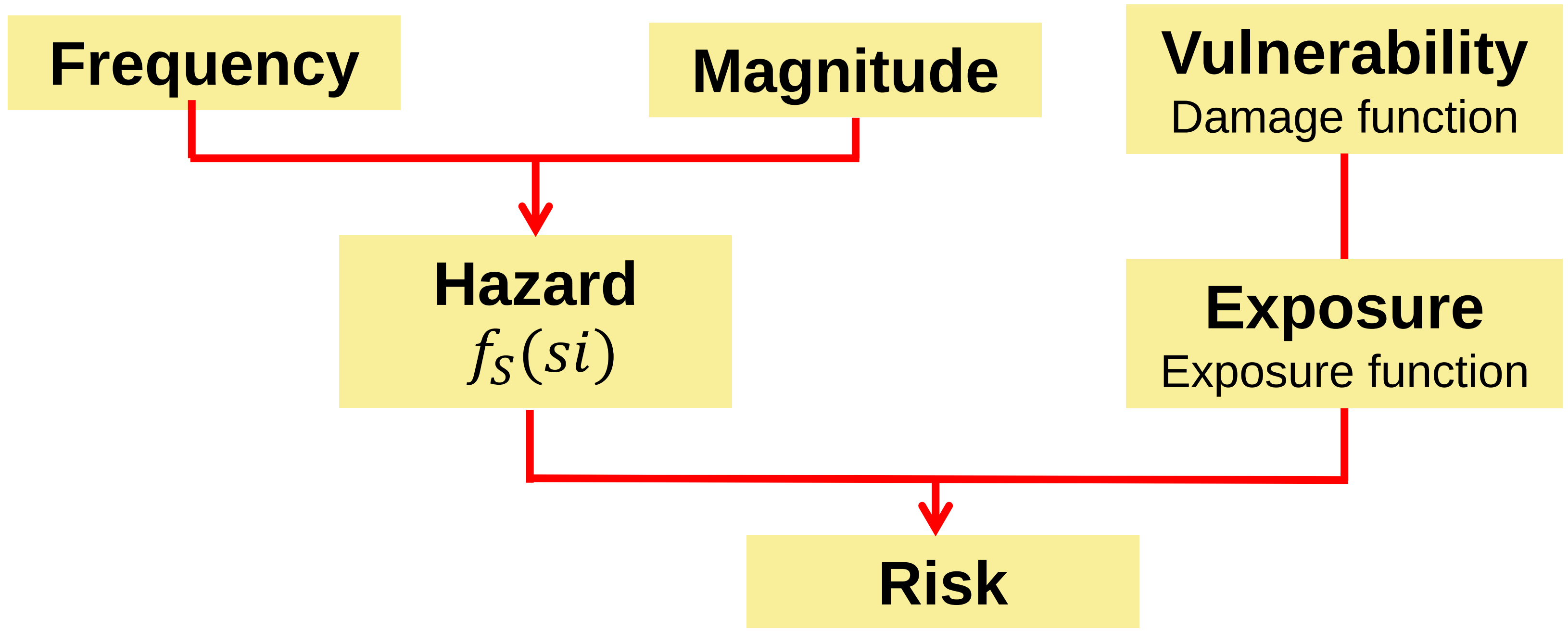
Risk of vehicle instability

- Defined as the mean number of vehicles that would destabilize annually per unit area at a specific point



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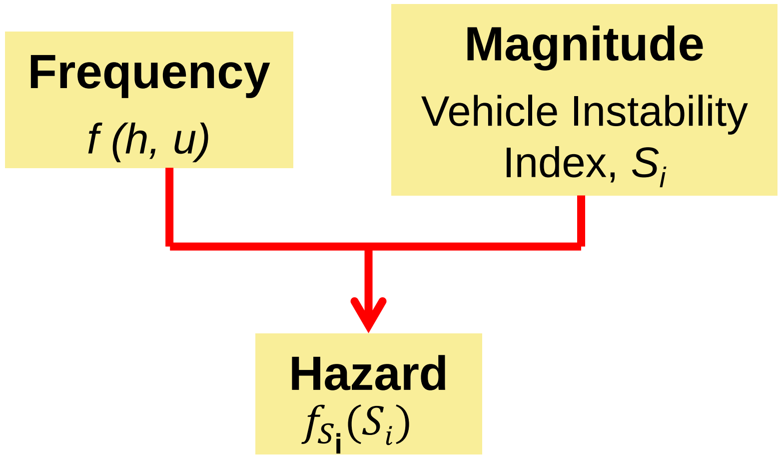
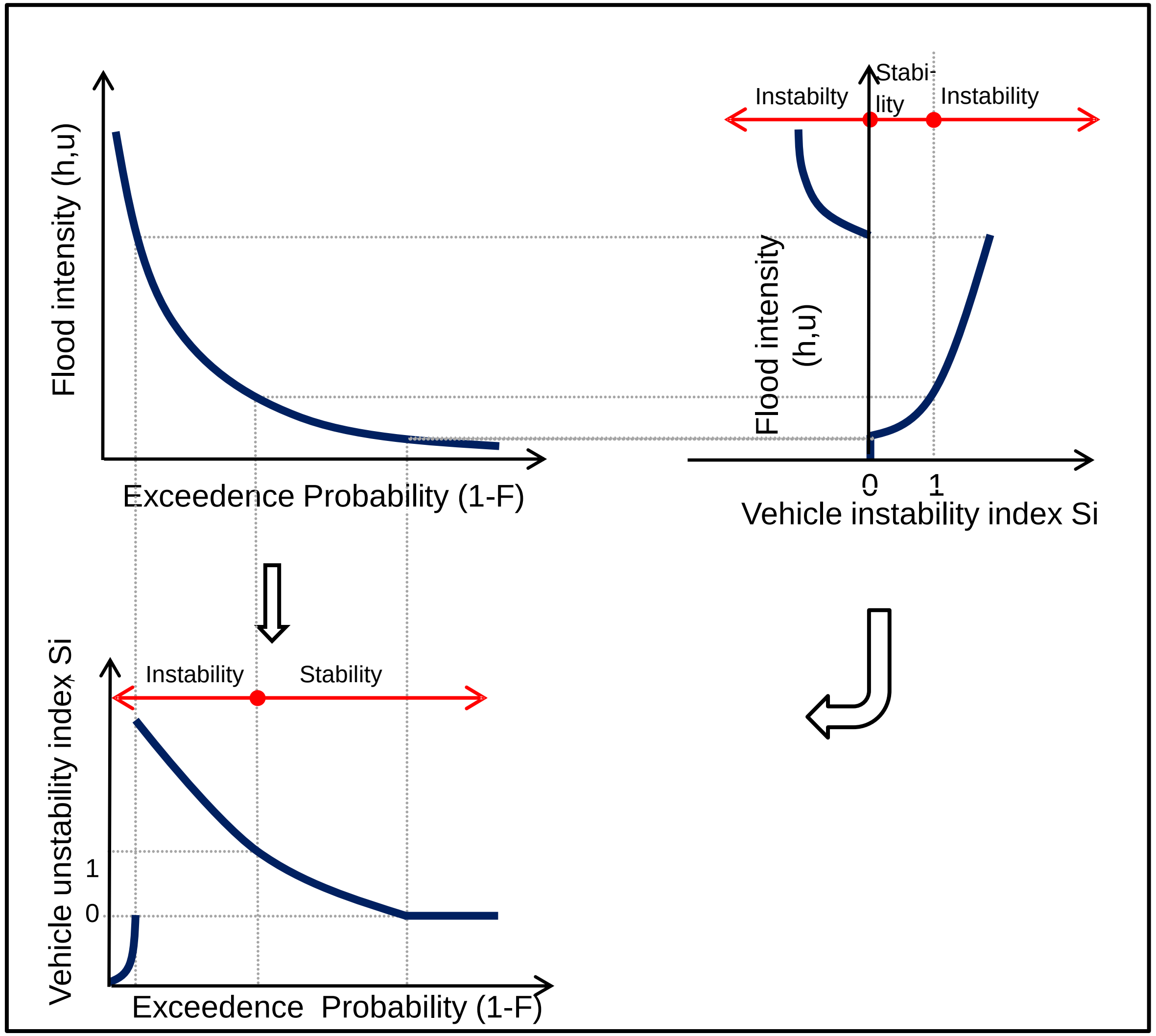
Vehicle instability hazard

- Vehicle flood hazard can be defined as the probability for the conditions that cause the loss of stability of vehicles => depends on type of car i





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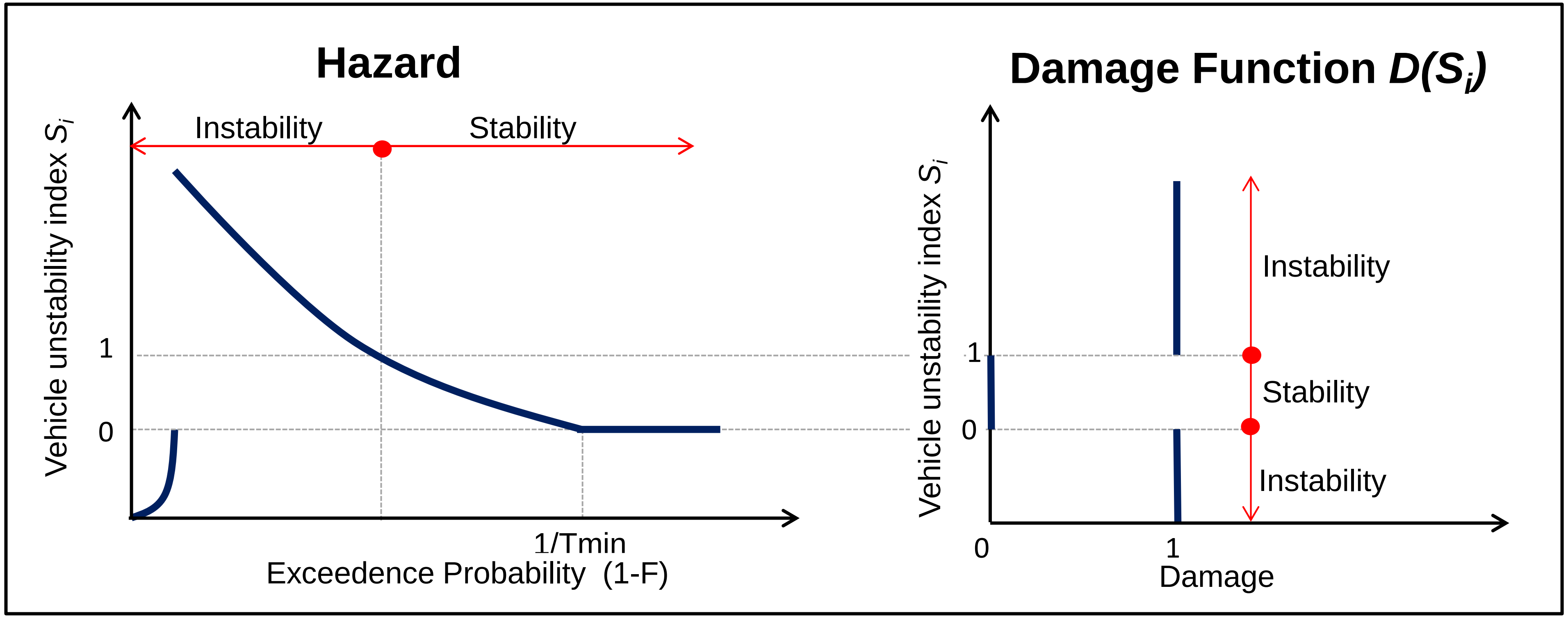
Vulnerability

- Vulnerability depends on the exposure and susceptibility of the elements that could be affected by the flood
- Susceptibility is established through a damage function $D(S_i)$



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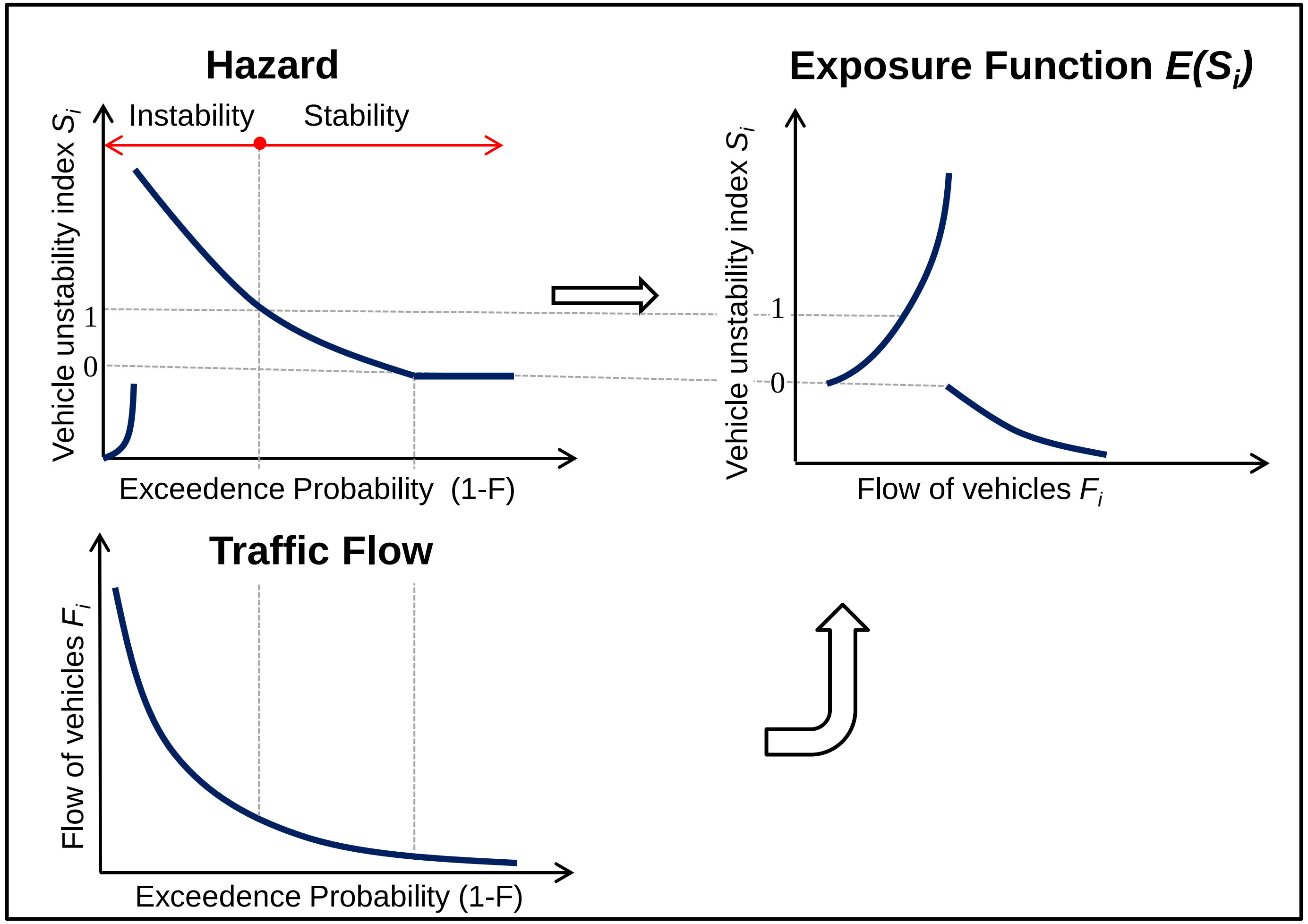
Exposure

- Exposure is established through a exposure function $E(S_i)$



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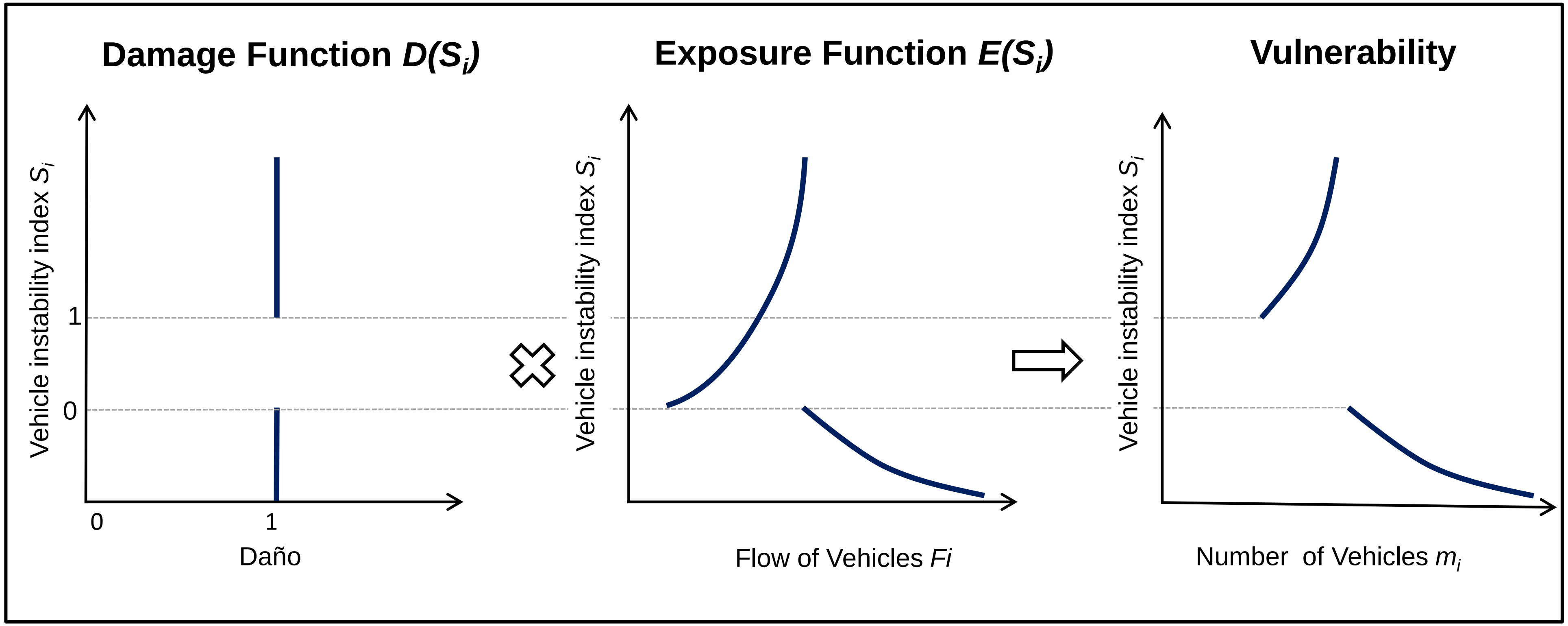
Vulnerability



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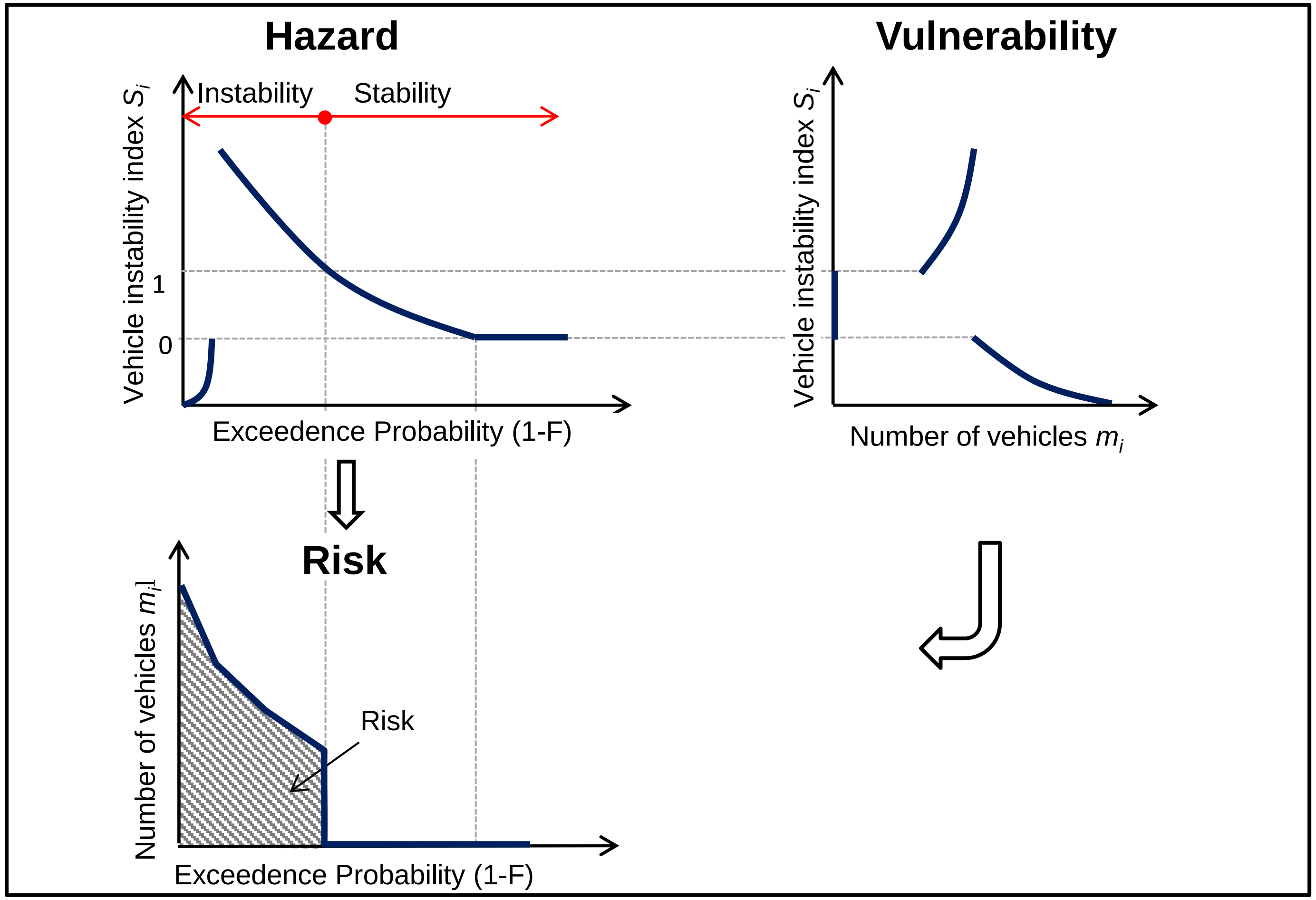
Risk of vehicle instability

- Risk for a vehicle type *i* corresponds to the area under the curve in the graph of risk



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Risk of vehicle instability: **r**

- It can be estimated as:

$$r = \sum_{i=1}^{K} g_i \int_0^1 D(s_i)E(s_i)dF_{S_i} = \sum_{i=1}^{K} g_i \int_0^\infty D(s_i)E(s_i)f_{S_i}(s)ds$$

where:

$D(s_i)$ = damage function for car type i,   i= 1, …, K

$E(s_i)$ = exposure function for car type i

g_i = proportion of car type i

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Risk of vehicle instability: r

- And can be approximated by:

$$r = \sum_{i=1}^{K} g_i \sum_{j=Tmin}^{Tmax} D(s_i)E(s_i)\left(\frac{1}{T_{j-1}} - \frac{1}{T_j}\right)$$

where:

j= flood hazard map for return period $T_{j,}$

Tmin corresponds to the lowest return period for inundation

Tmax corresponds to the highest return period with information

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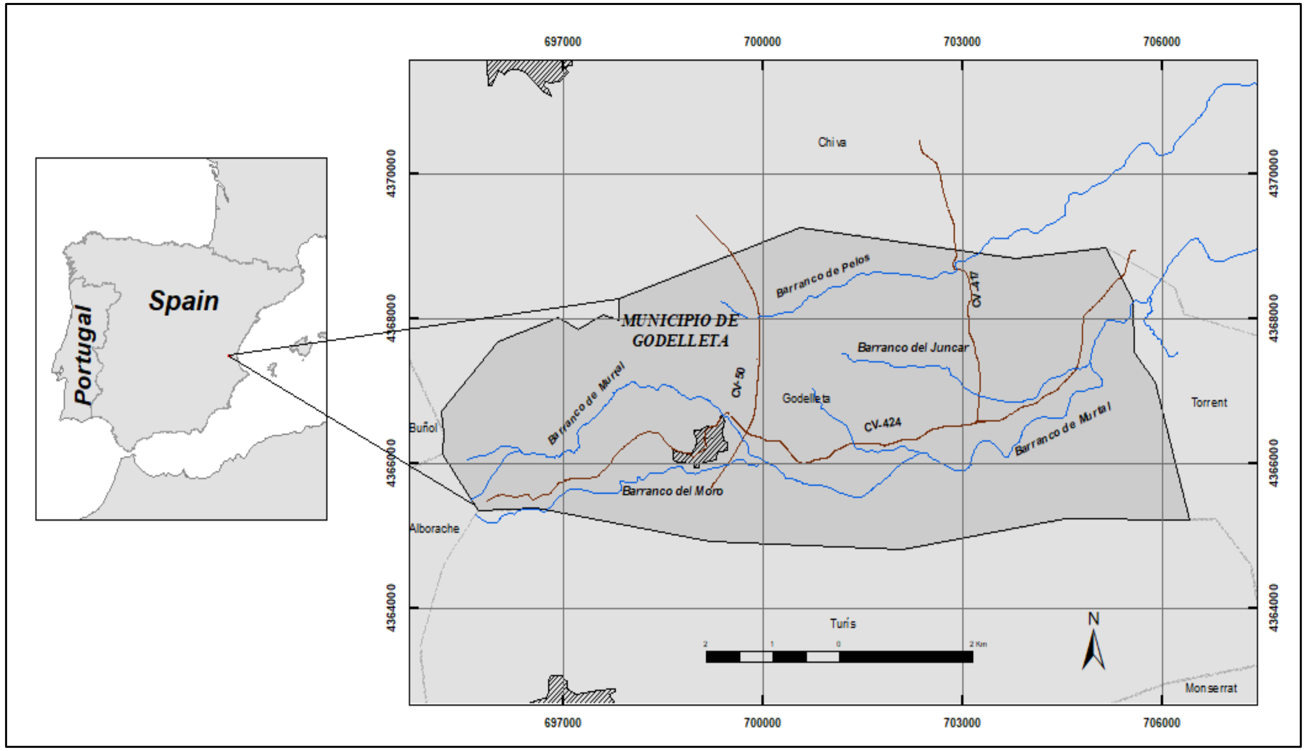
Case study: Municipality of Godelleta

- Municipality area = 37.5 Km^2
- Located in the middle part of the catchment of the Rambla del Poyo
- Mediterranean climate
- Drainage network is formed by several ephemeral rivers with a torrential regime
- The road network is relatively dense and is formed by regional and local roads, which are in good condition
- 26 intersection points: 18 culverts and 8 fords



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Characteristics of vehicles

Parameter	Vehicle i			
	Utility Seat Ibiza	**Compact** Seat León	**Small SUV** Peugeot 2008	**Medium SUV** Volkswagen Tiguan
Length (m)	3.683	4.184	4.159	4.433
Width (m)	1.610	1.742	1.739	1.809
Height (m)	1.421	1.439	1.556	1.665
Ground clearance (m)	0.124	0.12	0.165	0.175
Density (Kg/m³)	108.00	125.86	104.41	115.26
Proportion gi	0.262	0.322	0.148	0.268

Seat Ibiza

Seat León

Peugeot 2008

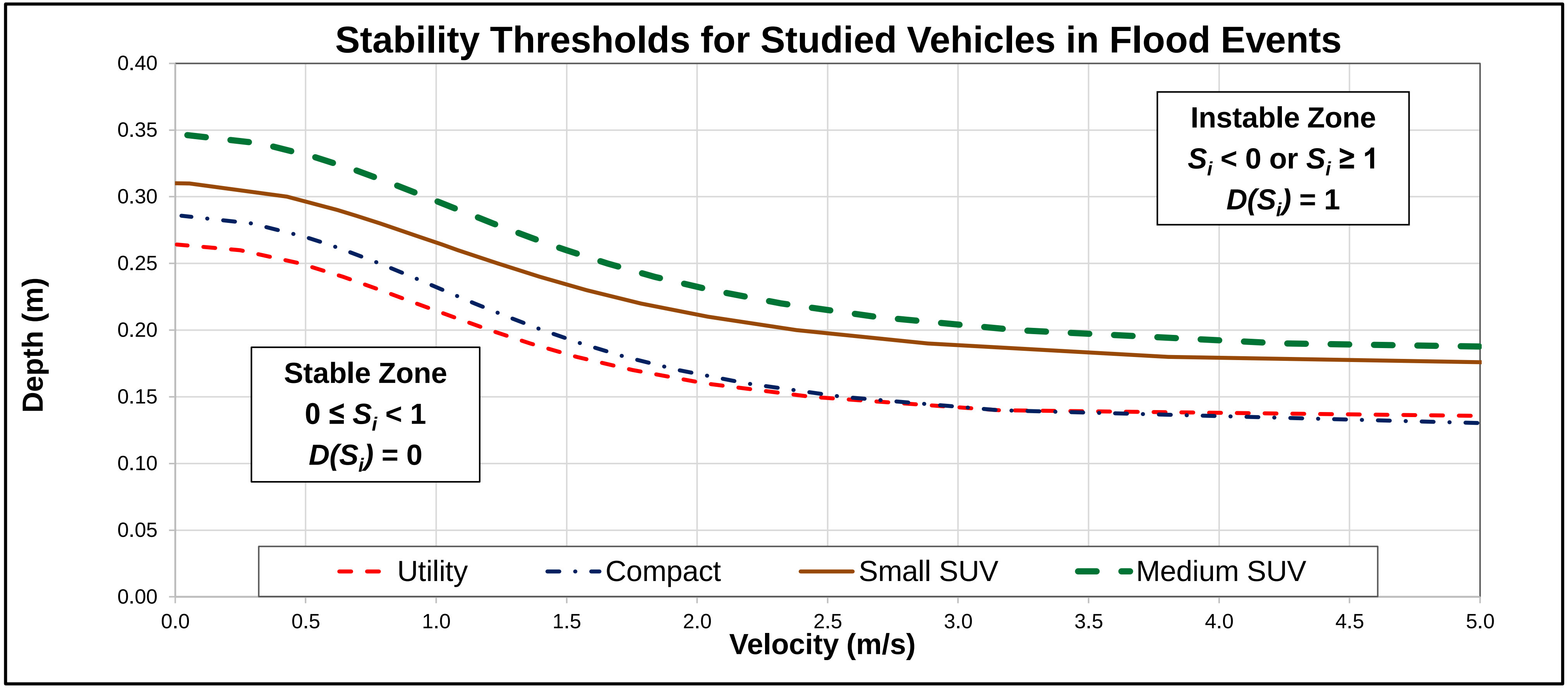
Volkswagen Tiguan

Intersection sites

Fords

Culverts

Vulnerability



- It was assumed that drivers decided to stop circulating in the flooded area when the water depth reaches a value of 0.3 m

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Vehicle instability hazard

- Discharge were calculated for Tr = 1, 2, 5, 10, 25, 50, 100 y 500 years using this expression:

$$Q = 0.4929 \ A_d^{0.75} \ T_r^{0.6512}$$

- Cross sections of the streams were obtained from DEM generated for the Centro Nacional de Información Geográfica de España

- Velocities and depths water were obtained using the software HEC - RAS

- Hazard index S_i were calculated for every type of vehicle and for every Tr

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Risk of vehicle instability

Inter-section Point	Stream	Work	Vehicular Flow (Cars/hour)	Flood Tr 50 años					Risk of Instability (Cars/year)	
				Dis-charge (m^3/s)	Hazard index S_i				Actual	Poten-tial
					Vehicle Type					
					Small cars	Com-pacts	SUVs small	SUVs med.		
1	Ravine Del Murtal	Culvert	45.32	73.71	-0.42	-0.43	-0.45	-0.52	0.35	4.67
2		Culvert	0.50	70.80	-0.14	-0.14	-0.14	-0.15	0.21	1.85
3		Culvert	1.51	67.68	-0.26	-0.25	-0.26	-0.28	0.22	3.80
4		Ford	1.01	53.55	-0.86	-0.82	-0.86	-0.90	1.12	2.37
5		Culvert	1.51	47.71	-0.22	-0.21	-0.22	-0.23	0.11	2.99
6		Ford	0.21	33.13	-0.13	-0.12	-0.13	-0.13	0.11	0.46
7		Culvert	214.21	32.96	0.00	0.00	0.00	0.00	0.16	2.21
8		Culvert	4.03	25.72	-0.21	-0.20	-0.21	-0.23	0.65	2.13
9		Culvert	6.04	13.41	-0.22	-0.21	-0.22	-0.24	0.08	1.56
10		Ford	3.02	8.58	-74.99	26.73	7.79	3.80	0.39	0.48
11		Ford	0.33	2.87	-0.72	-0.89	-1.14	-4.20	0.01	0.02

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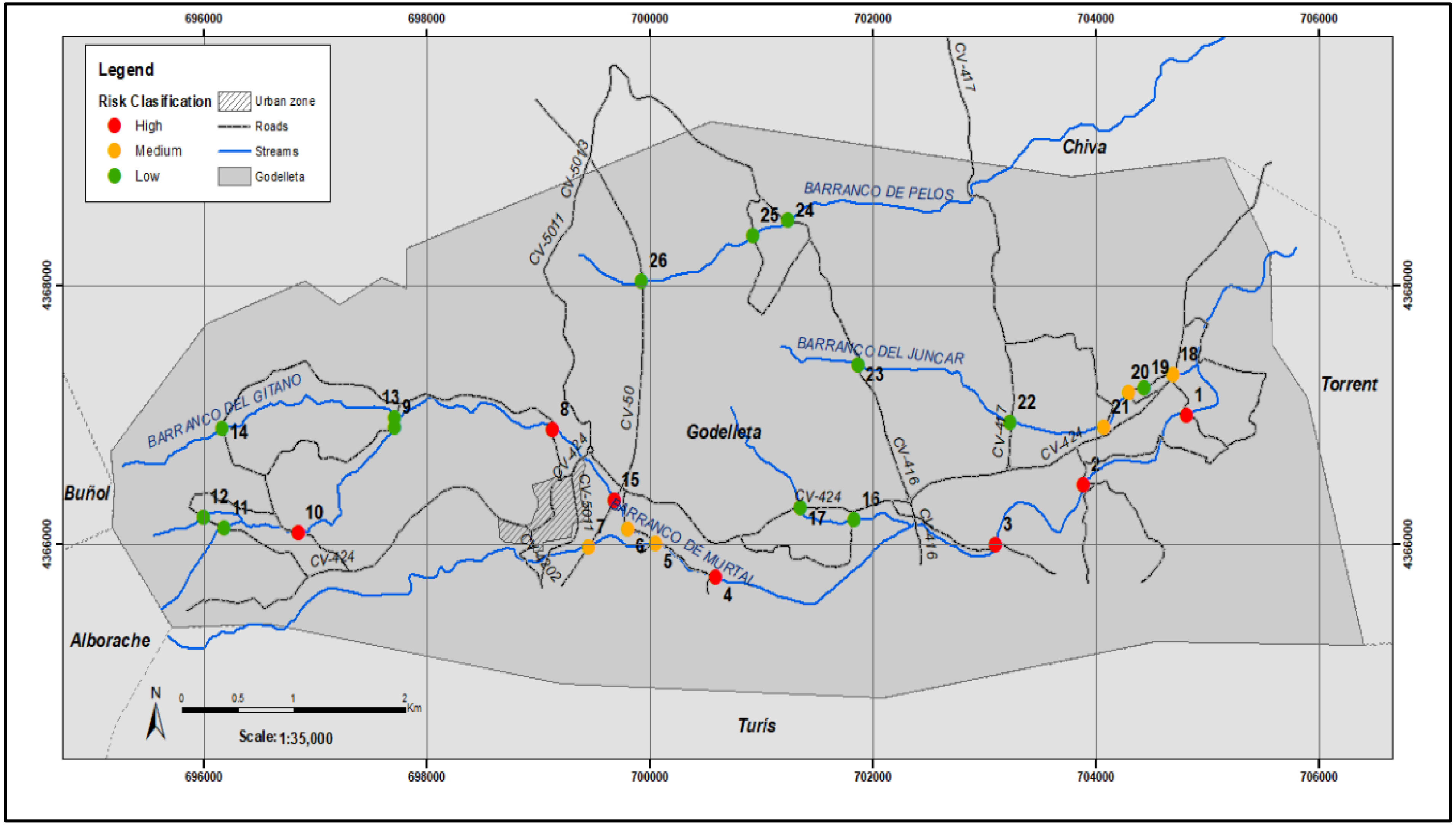
Risk of vehicle instability



Inter-section Points	Risk of vehicle instability	
	Real	Poten-tial
1	0.35	4.67
2	0.21	1.85
3	0.22	3.80
4	1.12	2.37
5	0.11	2.99
6	0.11	0.46
7	0.16	2.21
8	0.65	2.13
9	0.08	1.56
10	0.39	0.48
11	0.01	0.02
12	$<10^{-4}$	$<10^{-4}$
13	0.02	0.29
14	0.00	0.01
15	0.20	1.15
16	$2*10^{-4}$	0.004
17	$5*10^{-4}$	0.001
18	0.18	3.71
19	0.04	0.25
20	0.18	0.52
21	0.12	0.42
22	0.02	0.20
23	$3*10^{-4}$	$3*10^{-4}$
24	0.04	0.33
25	0.003	0.04
26	$<10^{-4}$	$<10^{-4}$

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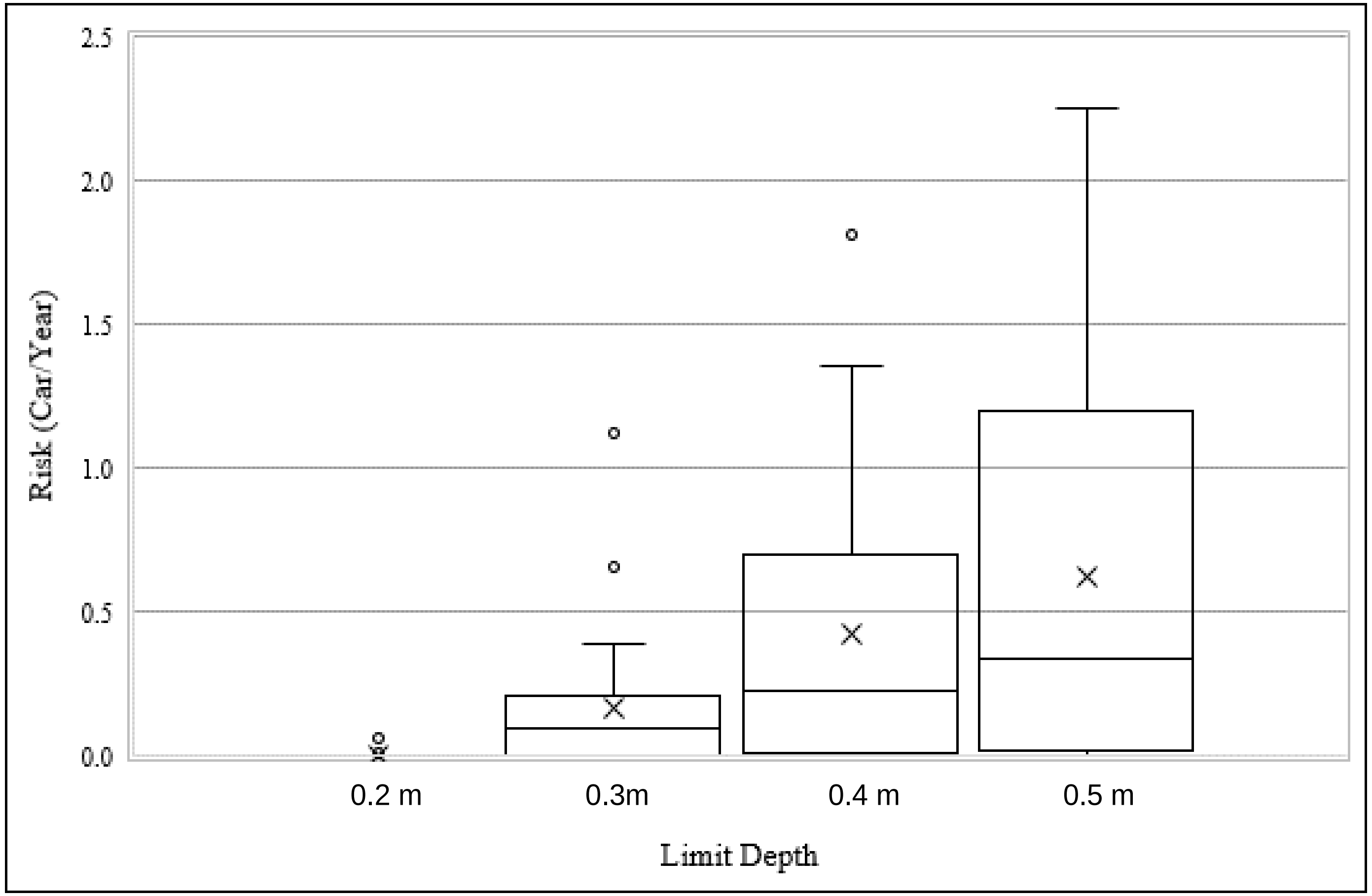
Sensitivity analysis

Sensitivity to limit depth to vehicular traffic



Sensitivity to the state of the culvert

Inter-section site	Risk of vehicle instability (Cars/year)	
	State of the culvert	
	Clear	Clogged
3	0.34	0.39
4	0.22	0.47
8	0.11	0.13
12	0.65	0.87
13	0.08	0.26
18	$2*10^{-6}$	$3*10^{-6}$
19	0.02	0.07
27	0.035	0.042
30	0.017	0.018
31	0.0003	0.0004

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Conclusions

- A methodology to estimate the risk of vehicle instability at intersection points between streams and roads was developed

- In this methodology the risk is determined by a numerical approximation of the statistical integral of the instability hazard and the vehicles' vulnerability

- The methodology was applied in the municipality of Godelleta (Spain). It was found that the risk of vehicle instability is relatively high in approximately 25% of the intersections between roads and streams

- The number of vehicles at risk is sensitive to the condition of the sewers and the depth at which vehicle traffic stops

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Thanks for your attention

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