



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

By:

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- 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 affection 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



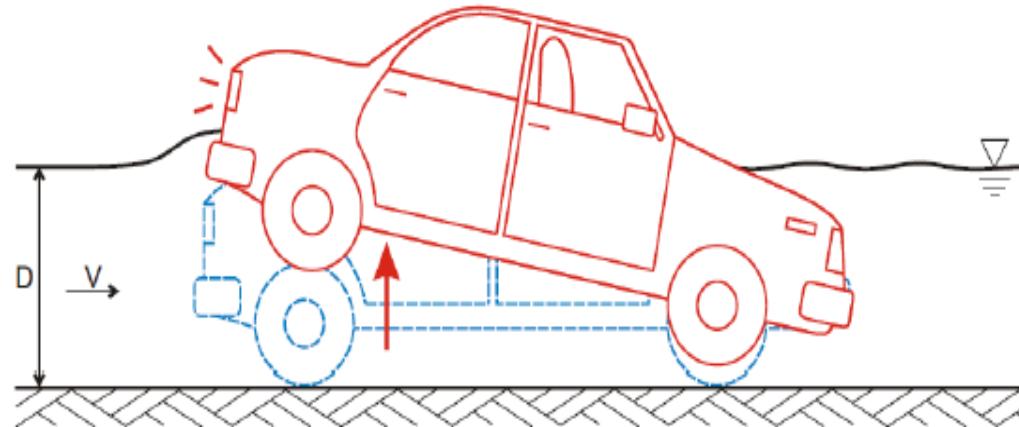
# Objectives



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

## Floating

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



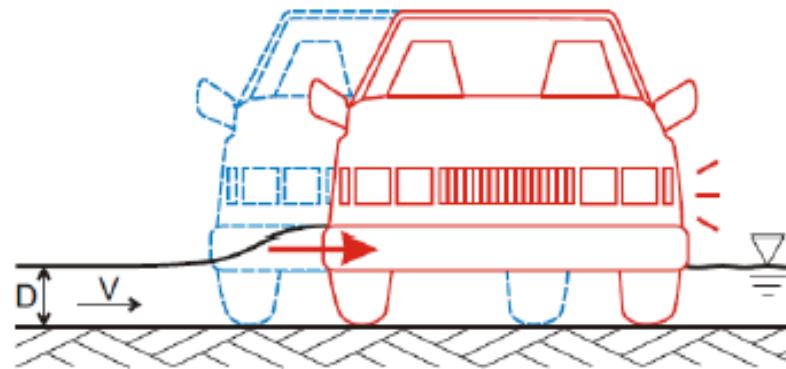
Source: Shand et al. (2011)



<https://www.youtube.com/watch?v=LC5ld79j0IA>  
(Accessed 16/04/2019)

## Sliding

Drag force exceeds the frictional force produced between tires and ground



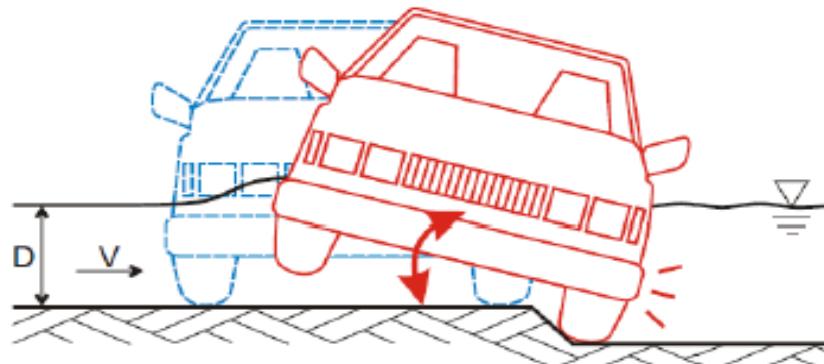
Source: Shand et al. (2011)



<https://www.youtube.com/watch?v=3HrdgaiM9sY>  
(Accessed 16/04/2019)

## 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)

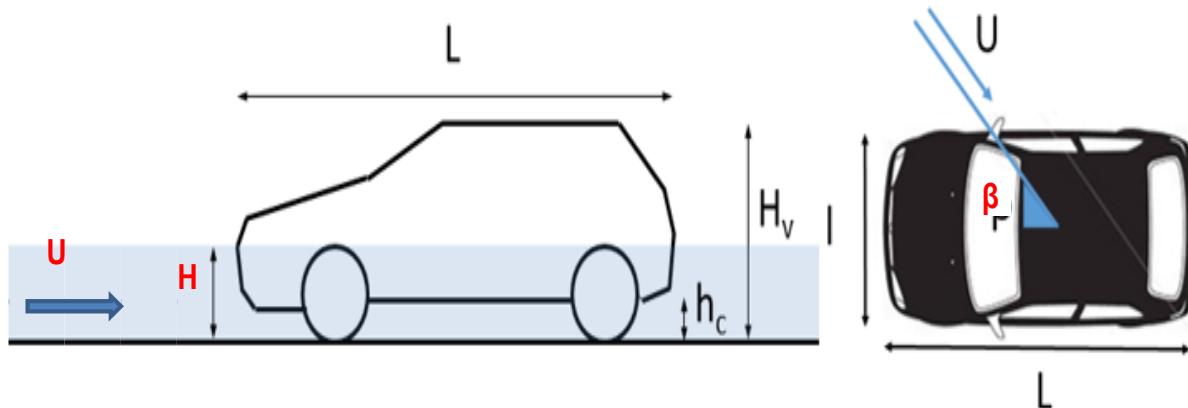


<https://www.youtube.com/watch?v=Va8w7Jng9rM>  
(Accessed 16/04/2019)

## Mobility Parameter $\theta_v$

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

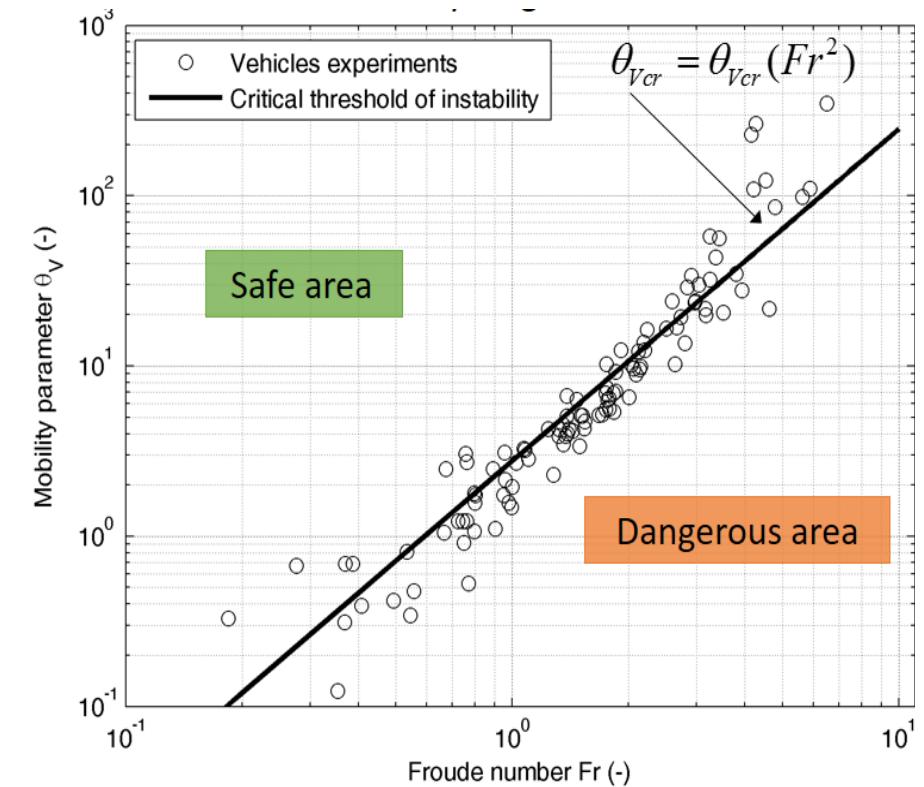
$$\theta_v = \frac{2L}{(H_v - h_c)} * \frac{l}{l * \cos\beta + L * \sin\beta} * \left( \frac{\rho_c * (H_v - h_c)}{\rho * (H - h_c)} - 1 \right)$$



Source: Arrighi et al. (2016)

## Critical Threshold $\theta_{Vcr}(H, U)$

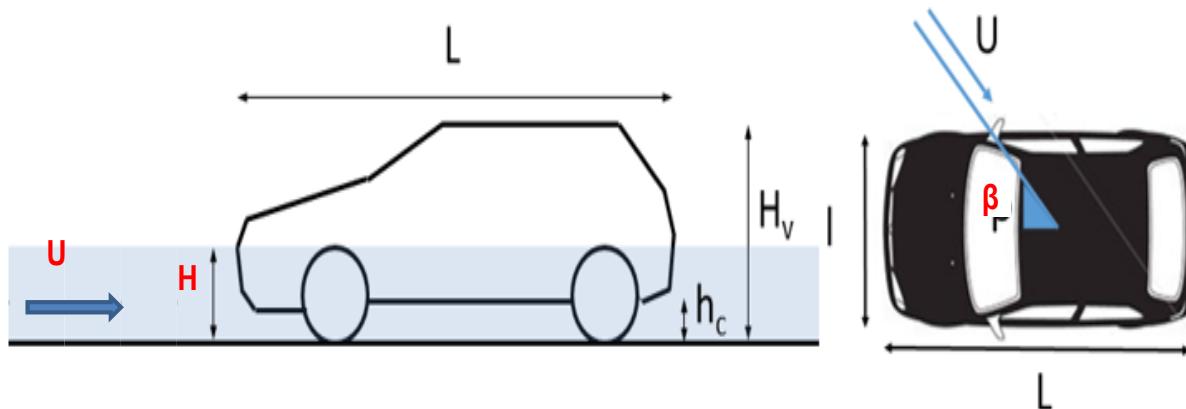
$$\theta_{Vcr} = 8.2 * Fr^2 - 14.1 * Fr + 5.4$$



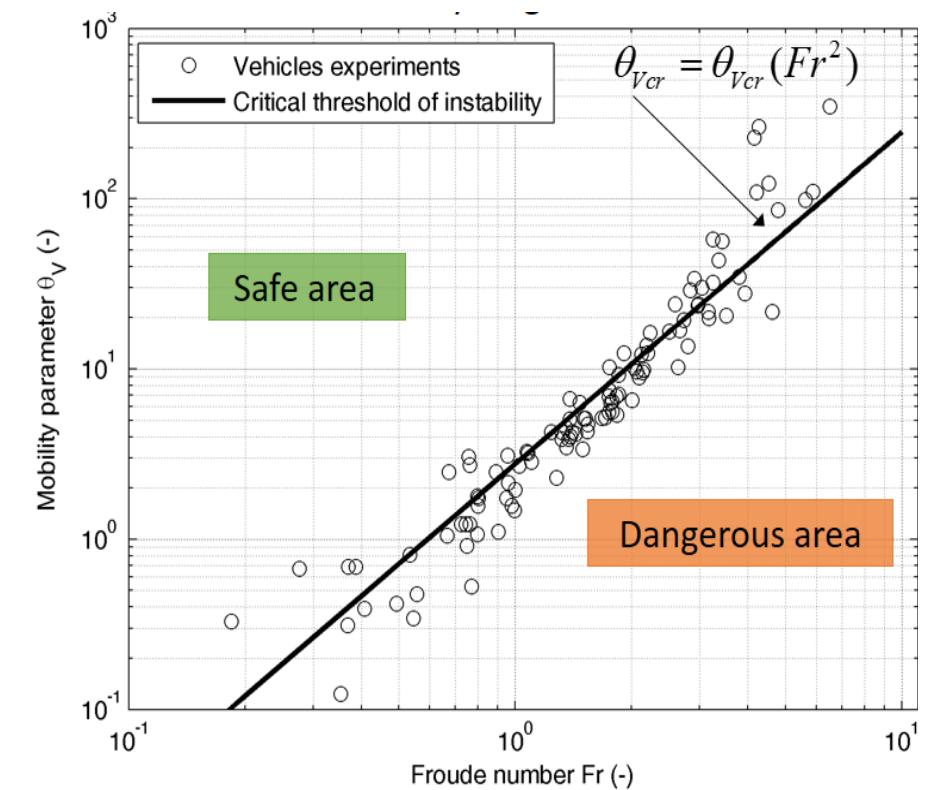
Source: Arrighi et al. (2016)

## Stability criterion:

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

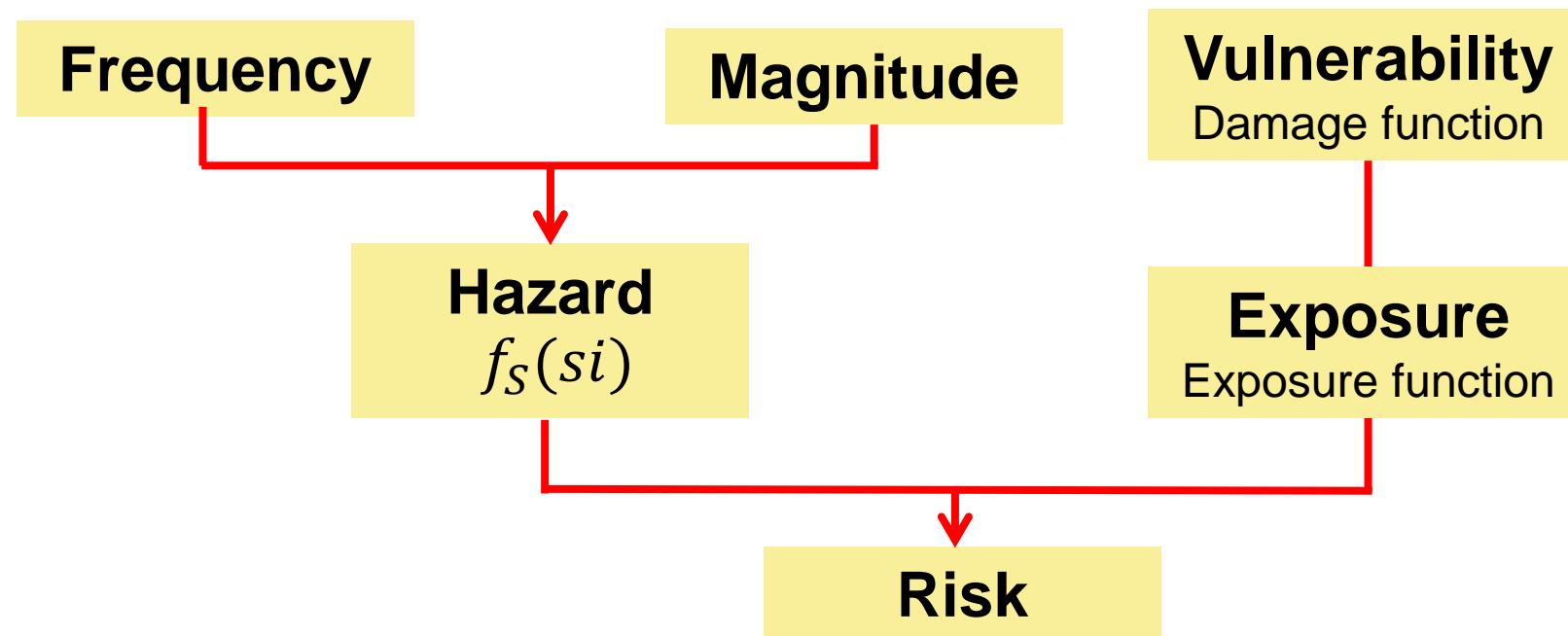


Source: Arrighi et al. (2016)

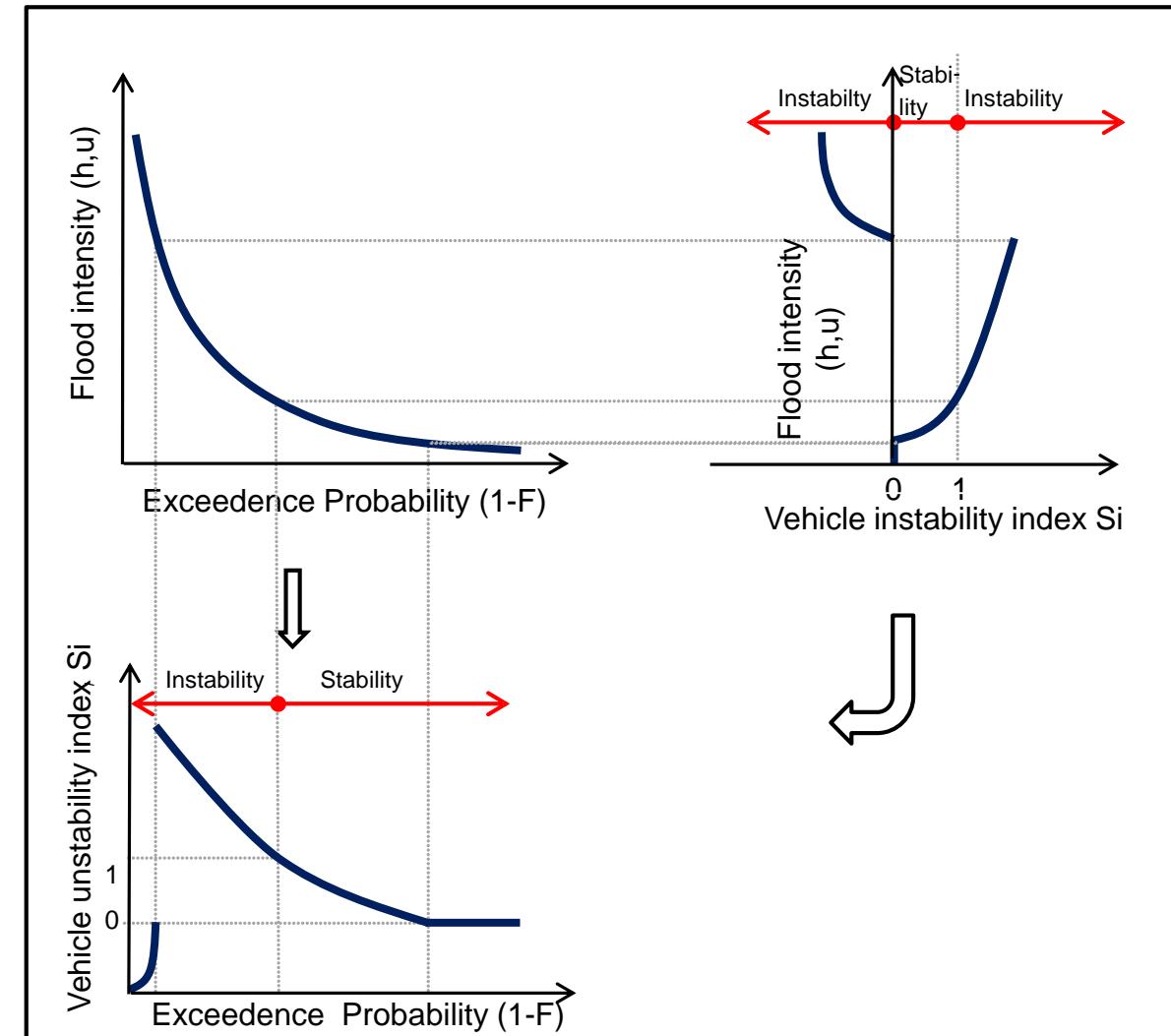
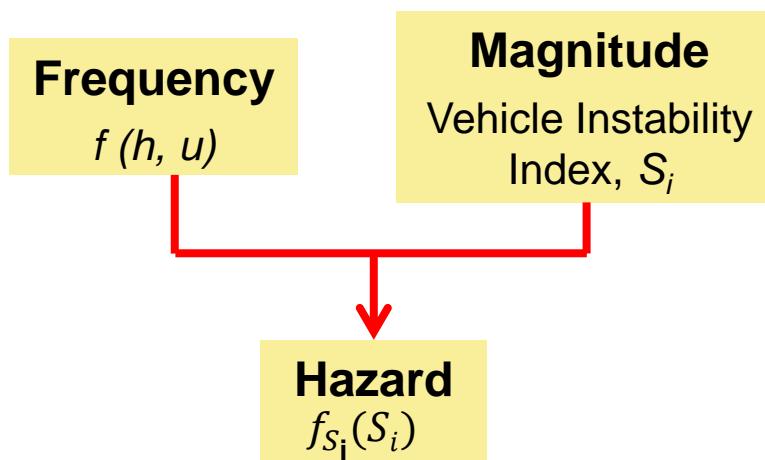


Source: Arrighi et al. (2016)

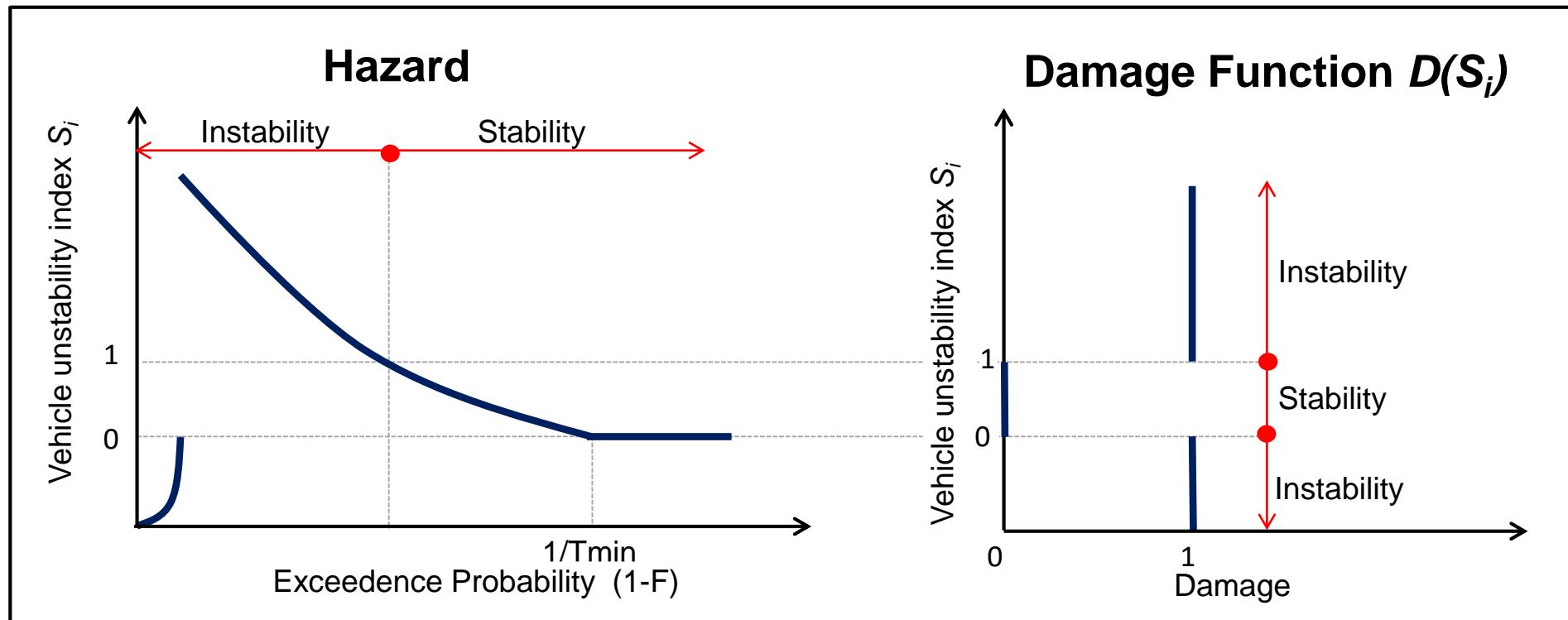
- Defined as the mean number of vehicles that would destabilize annually per unit area at a specific point



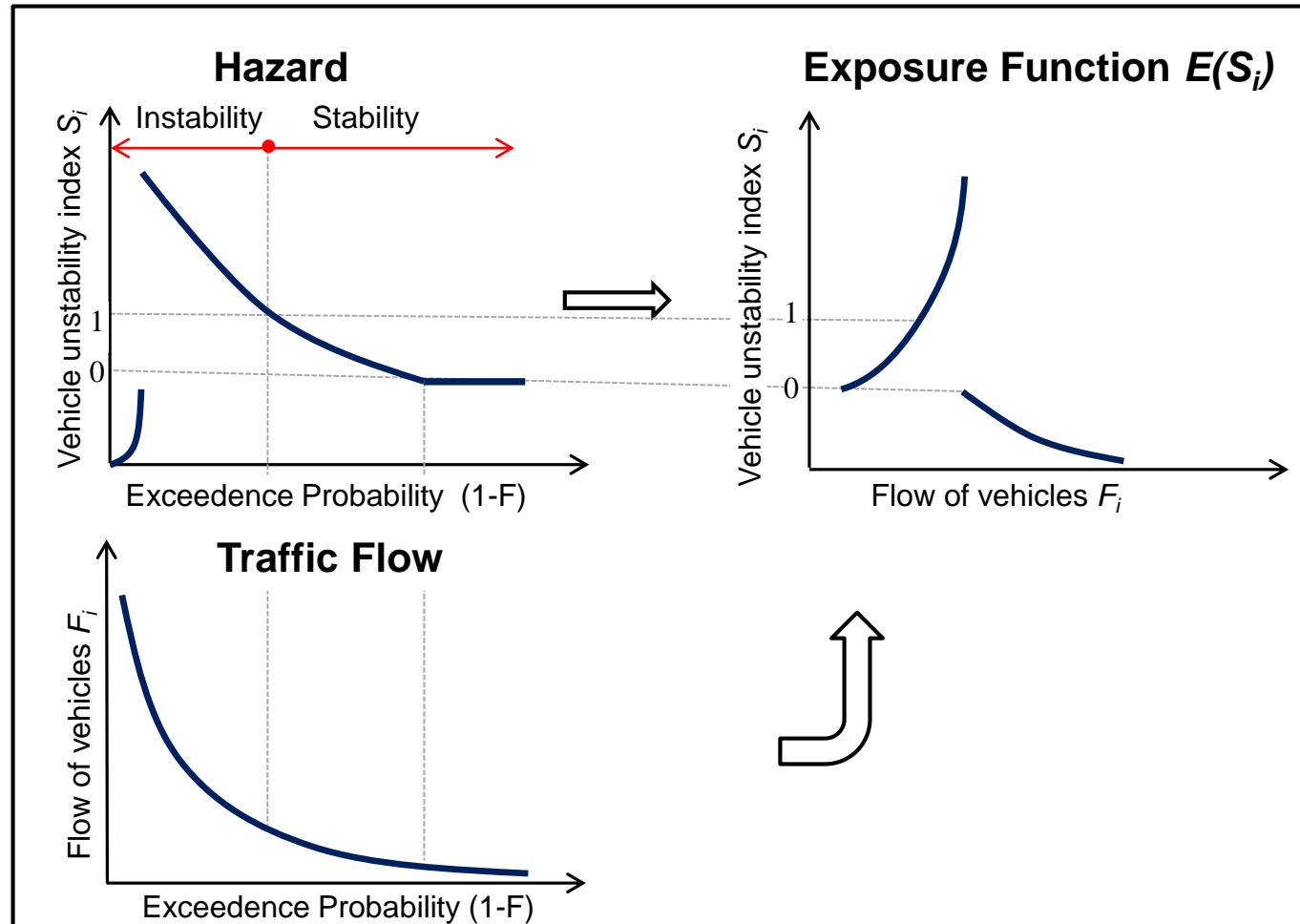
- Vehicle flood hazard can be defined as the probability for the conditions that cause the loss of stability of vehicles => depends on type of car i

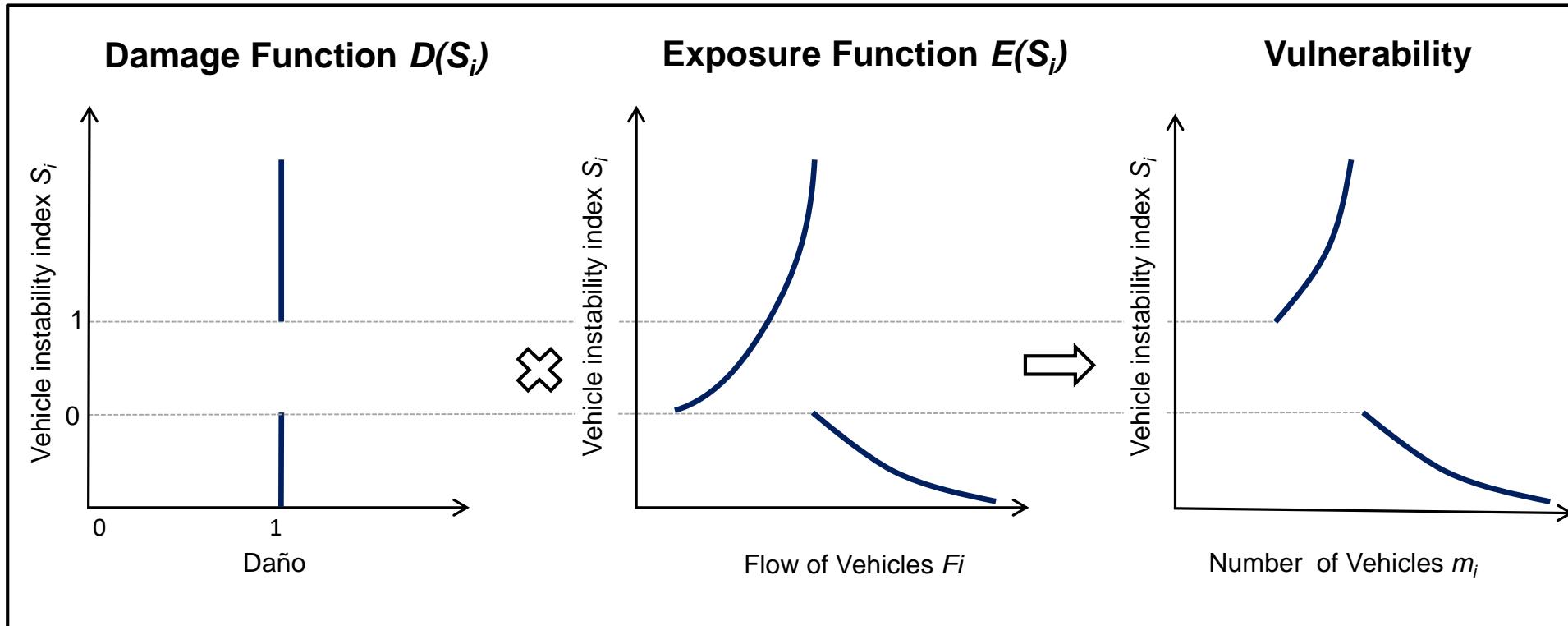


- Vulnerability depends on the exposure and susceptibility of the elements that could be affected by the flood
- Susceptibility is established through a damage function  $D(S_i)$

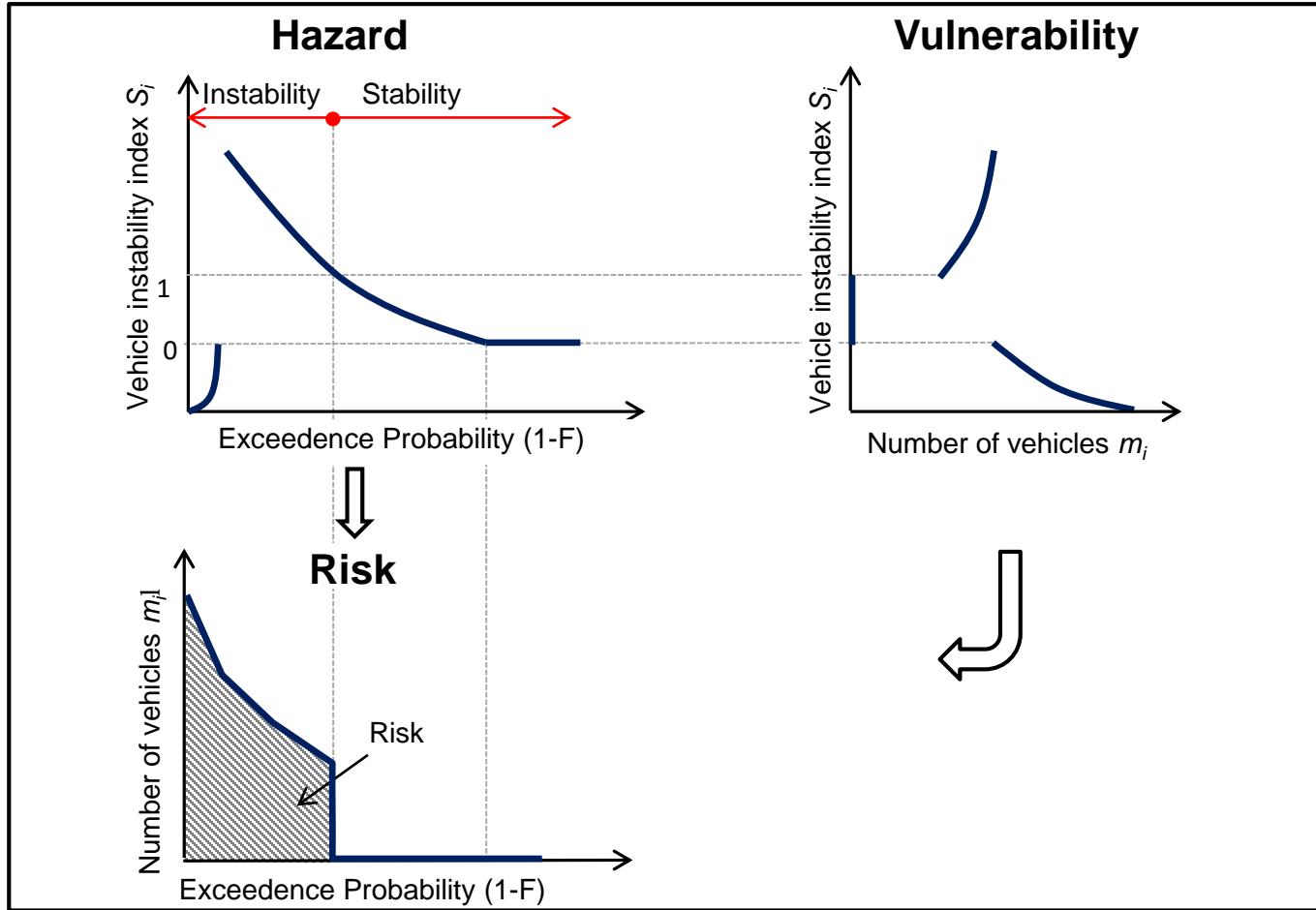


- Exposure is established through a exposure function  $E(S_i)$





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



- 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,  $i = 1, \dots, K$

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

$g_i$  = proportion of car type i

- 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:

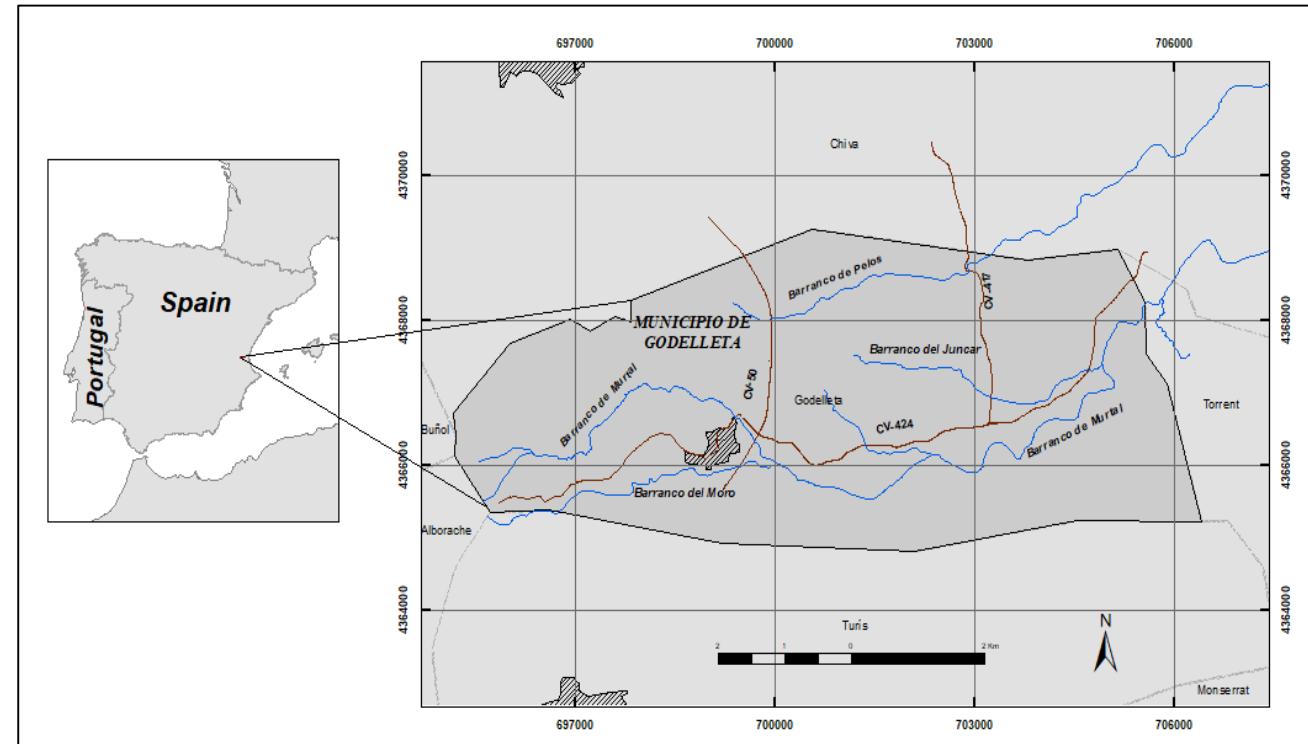
j= flood hazard map for return period  $T_j$ ,

$T_{min}$  corresponds to the lowest return period for inundation

$T_{max}$  corresponds to the highest return period with information

# Case study: Municipality of Godelleta

- Municipality area = 37.5 Km<sup>2</sup>
- 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



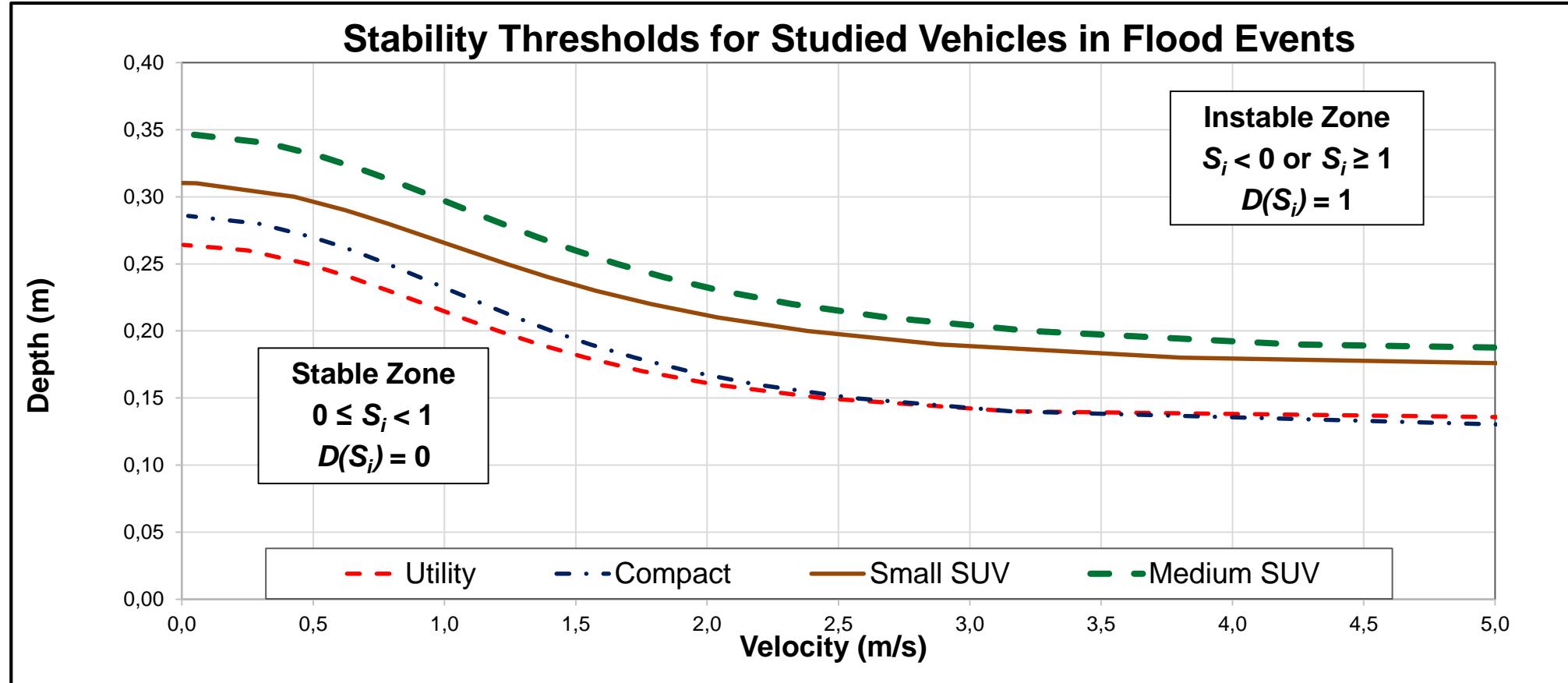
Parameter	Vehicle i			
	Utility Seat Ibiza	Compact Seat León	Small SUV Peugeot 2008	Medium SUV Volkswagen Tiguan
Length (m)	3.683	4.184	4.159	4.433
Width (m)	1.610	1.742	1.739	1.809
Height (m)	1.421	1.439	1.556	1.665
Seat Ibiza	Seat León	Peugeot 2008		Volkswagen Tiguan
Ground clearance (m)	0.11	0.12	0.14	0.175
Density (Kg/m <sup>3</sup> )	108.00	125.80	104.41	115.26
Evaluating and mapping the hazard and risk of vehicle instability within a flood prone area				
Proportion $q_i$	0.262	0.322	0.148	0.268

## Fords



## Culverts





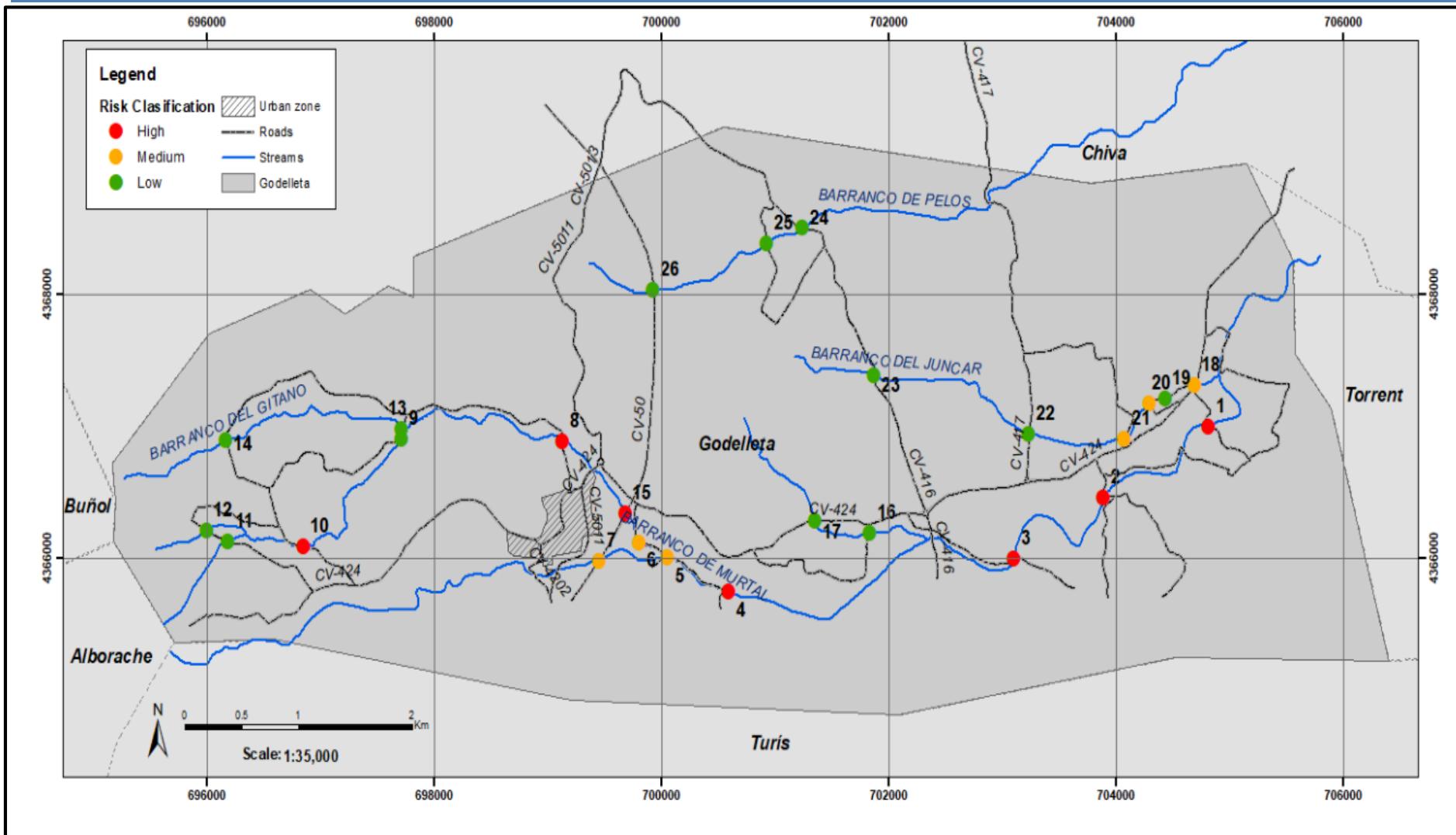
- It was assumed that drivers decided to stop circulating in the flooded area when the water depth reaches a value of 0.3 m

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

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

- 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  $Tr$

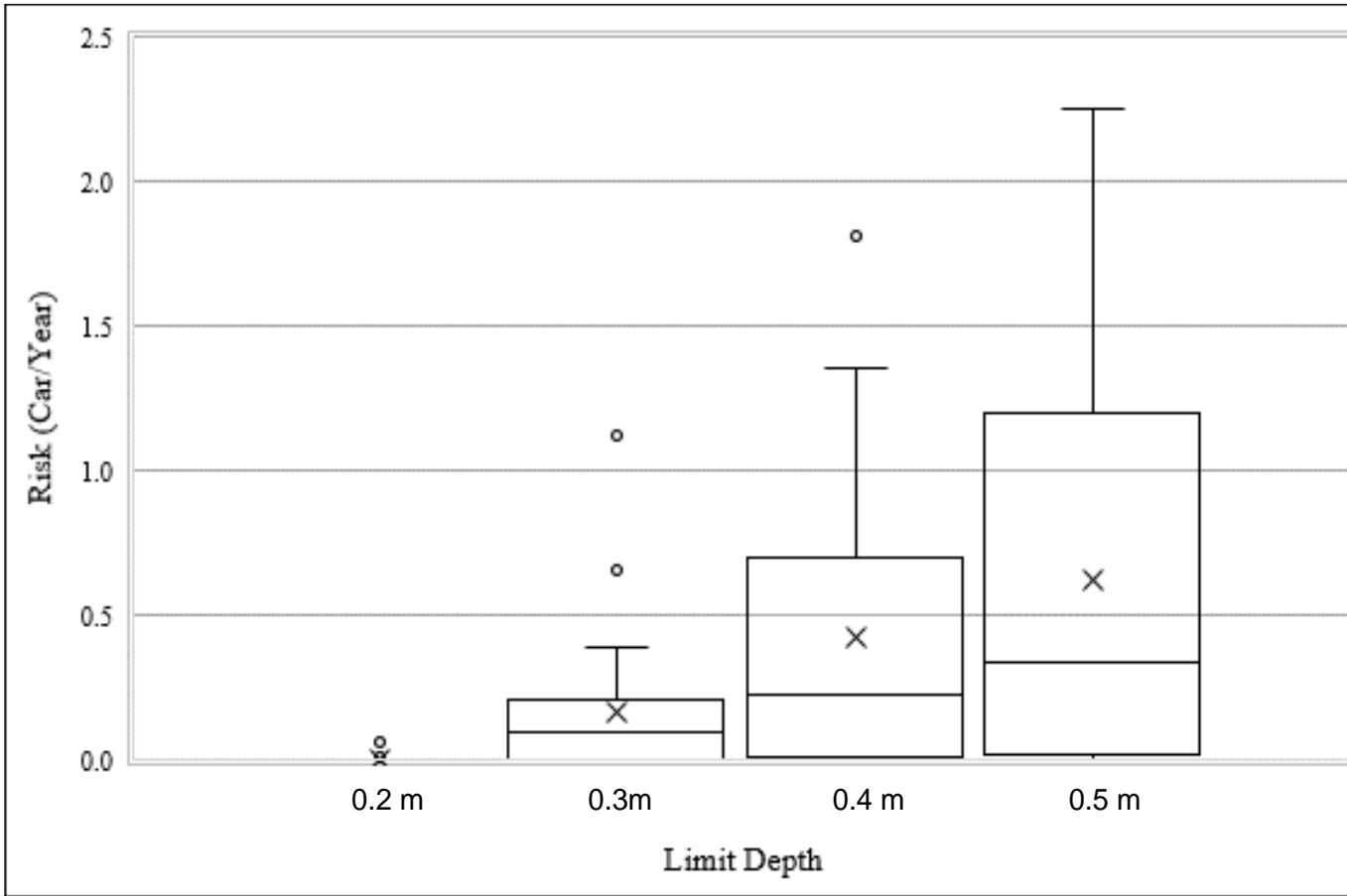
Intersection Point	Stream	Work	Vehicular Flow (Cars/hour)	Flood Tr 50 años				Risk of Instability (Cars/year)		
				Dis-charge (m³/s)	Hazard index $S_i$			Actual	Poten-tial	
					Vehicle Type					
					Small cars	Com-pacts	SUVs small	SUVs med.		



Intersection Points	Risk of vehicle instability (cars/year)	
	Real	Potential
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

Evaluating and mapping the hazard and risk of vehicle instability within a flood prone

## Sensitivity to limit depth to vehicular traffic



## Sensitivity to the state of the culvert

Intersection site	Risk of vehicle instability (Cars/year)	
	Clear	Clogged
3	0.34	0.39
4	0.22	0.47
8	0.11	0.13
12	0.65	0.87

- 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



Thanks for your attention

