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How to increase resilience of the road network in the Dominican Republic?

Margreet van Marle, Mike Woning

02/12/2021

Challenges in the Dominican Republic

- The Dominican Republic is exposed to many natural hazards
  - Hydrometeorological hazards (tropical storms, floods)
  - Geophysical (earthquakes, tsunamis, landslides)
- Major uncertainties
  - Climate Change
  - Socio economic changes

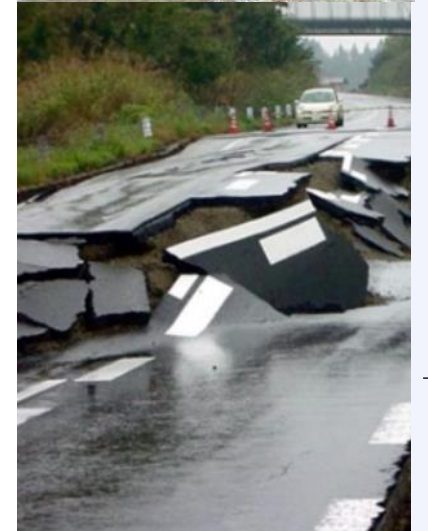**Uncertainties**

Climate Change

Socio-economic changes

Goals of the project – Improve Resilience of the Road network
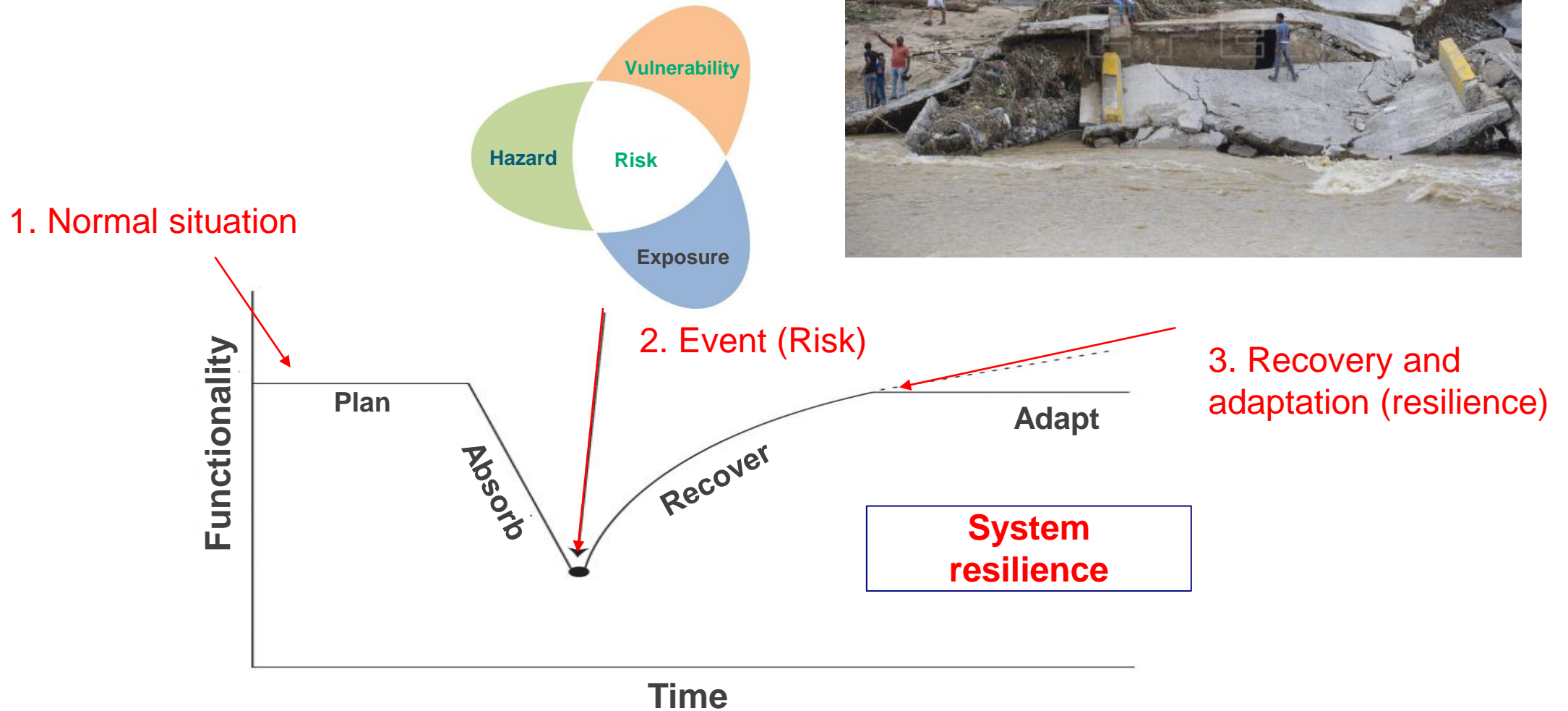
To support the government in:

- How to **objectively prioritise the locations** where natural hazards may affect the road network?
- What actions (measures) can be taken to **reduce the impact**?
- Make **decisions** taking into account an **uncertain future** (climate, economy).
- **Efficient, effective and sustainable use** of (limited) resources to build resilience of the road network against natural hazards.

Furthermore a 2-week training and implementation course based on hands-on excercises with goals:
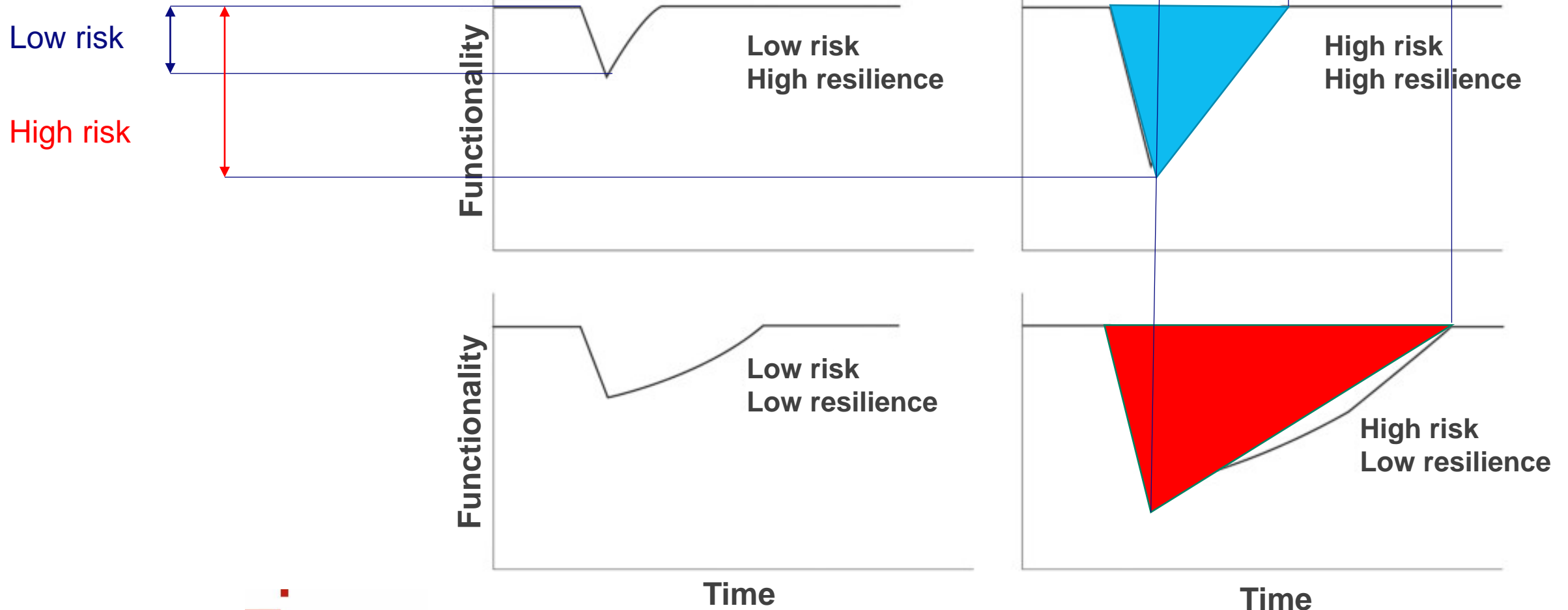
- **Apply** the results of the project to potential real situations.
- Train the **decision-makers** and **technical experts** of the government of the Dominican Republic to be able to use the results.

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What is resilience?

1. Normal situation

Vulnerability

Hazard   **Risk**

Exposure

2. Event (Risk)

3. Recovery and adaptation (resilience)

Functionality

Plan

Absorb

Recover

Adapt

System resilience

Time

The concepts of resilience and risk
(Linkov, Nature Climate Change, 2014)

What is resilience?

Low risk

High risk

High resilience | Low resilience

**Low risk
High resilience**

**High risk
High resilience**

**Low risk
Low resilience**

**High risk
Low resilience**

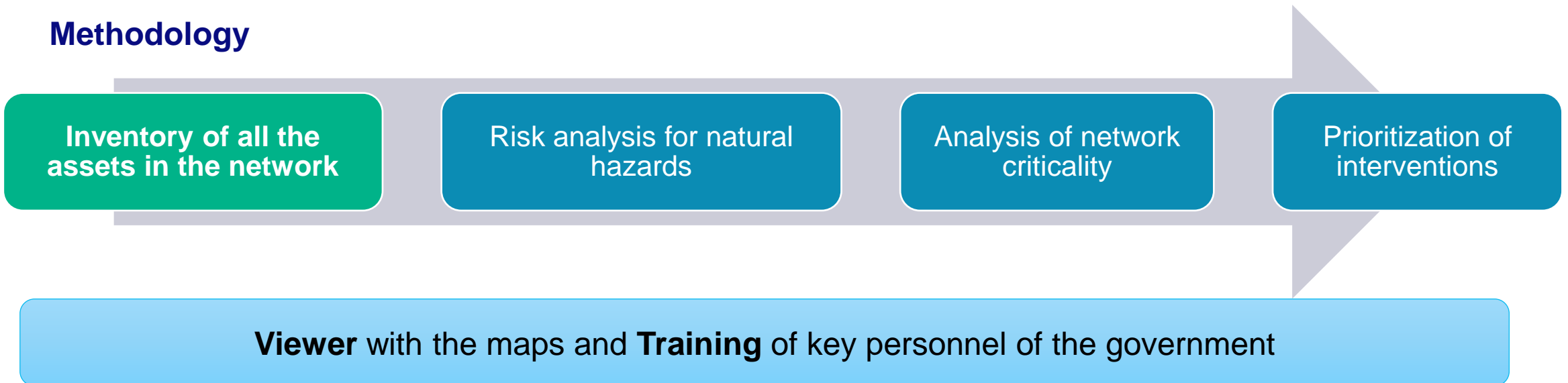Functionality

Time

The concept of risk and resilience

How to make decisions based on a risk-based approach?

The concrete goals for the analyses are:

- **Conduct a risk analysis:** determine where hazards may affect roads, how big the impact is, and what the probability is.

- **Plan action:** determine where to take action, what action to take and formulate an action plan.

Methodology

| Inventory of all the assets in the network | Risk analysis for natural hazards | Analysis of network criticality | Prioritization of interventions |

Viewer with the maps and **Training** of key personnel of the government

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General methodology

Inventory of all the assets in the network → Risk analysis for natural hazards → Analysis of network criticality → Prioritization of interventions

Inventory of the system

- Bridges, tunnels, type of pavement

Results of traffic model

- Quantity of vehicles per day on every road stretch

- ¿What infrastructure is at risk?

- (Who would be affected by the Hazard? -> traffic modeling)

General methodology

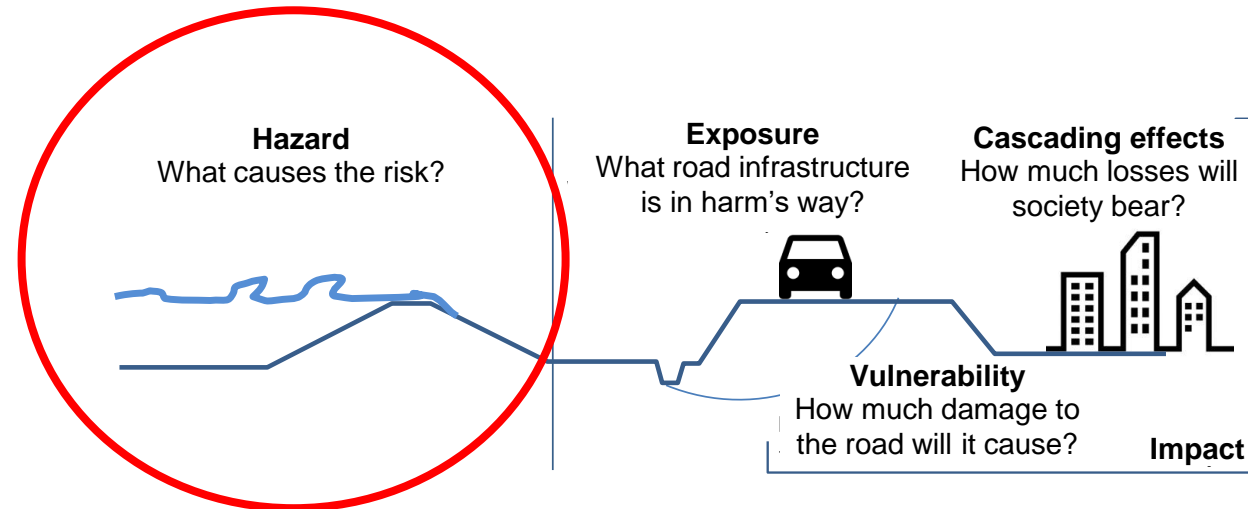| Inventory of all the assets in the network | **Risk analysis for natural hazards** | Analysis of network criticality | Prioritization of interventions |

Risk analysis for natural hazards

- **Hazards**
  - Collection of existing Hazard maps

- **Analysis of exposure**
  - Level of Hazard intensity per asset

- **Vulnerability**
  - Creation of vulnerability curves and the reparation costs

Risk = Hazard x Exposure x Vulnerability

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Risk analysis

Components of risk
(UNISDR 2016)

Hazard
What causes the risk?

Exposure
What road infrastructure
is in harm's way?

Cascading effects
How much losses will
society bear?

Vulnerability
How much damage to
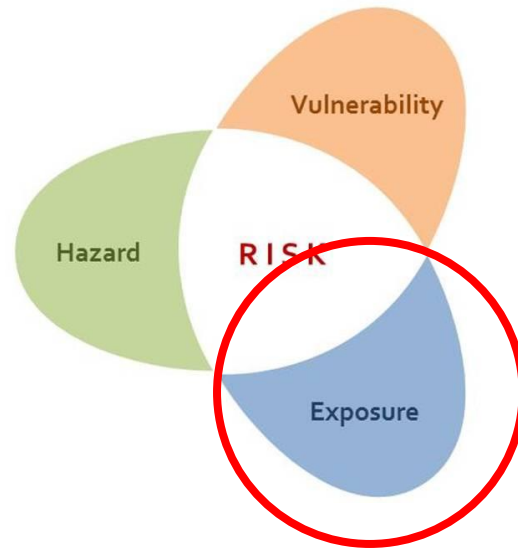the road will it cause?

Impact

The context of risk analysis for road infrastructure
(Bles et. al 2019)

Natural Hazards included

Natural hazards	Return period	Intensity of the hazard
Inundación por lluvia huracanada	1:50, 1:100, 1:500, 1:1000	Flood depth (m)
Inundación	Varios	Flood depth (m)
Landslides (Solely susceptibility)	*No*	*Susceptibility (qualitative)*
Earth quakes *(Susceptibility for liquefaction)*	1:200, 1:475, 1:1000, 1:2500	PGA acceleration for different vibration period (gale = 0,01 m/s^2)
Tsunami	1:50, 1:100, 1:475, 1:1000	Flood Depth (m)

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Risk analysis

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The context of risk analysis for road infrastructure
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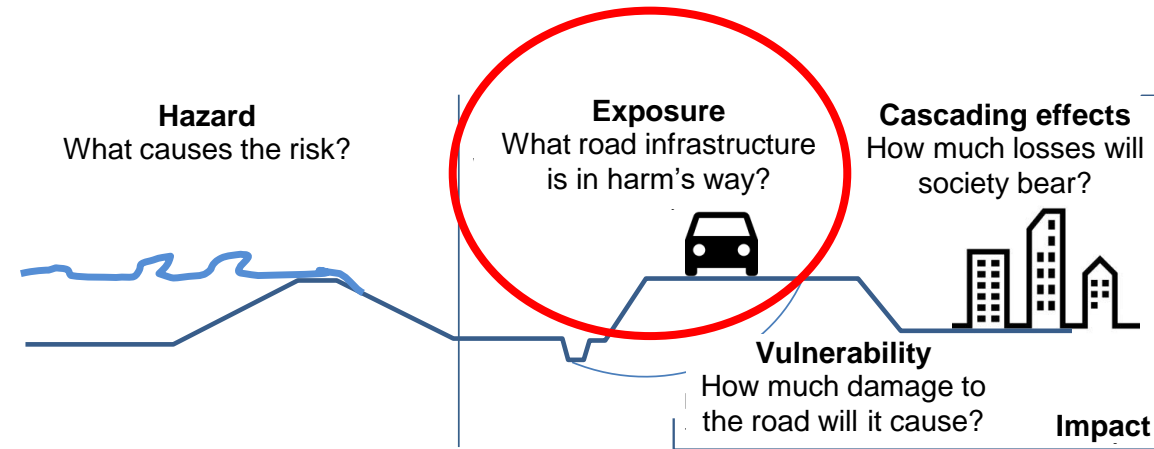
Exposure analysis

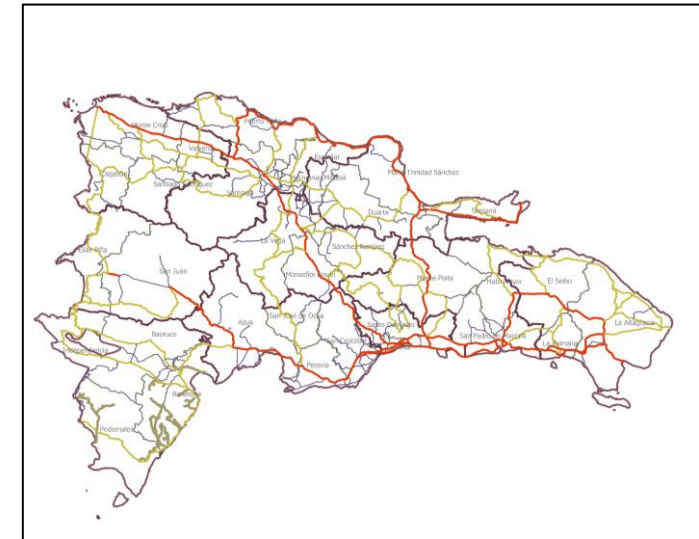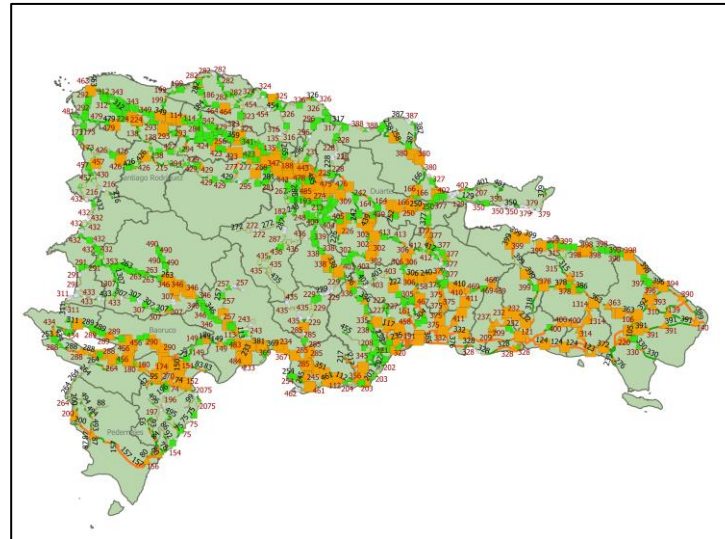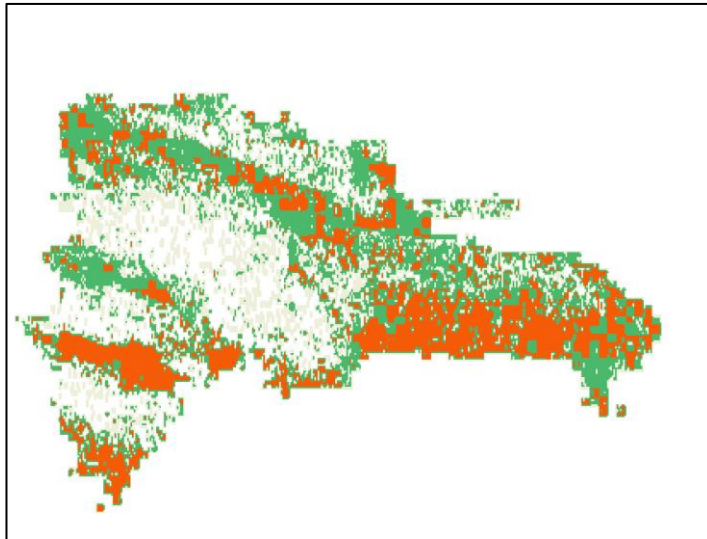- Intersection of hazard scenario maps with road network asset maps.

Hazard maps
(Floods, earthquakes, …)

Exposure maps for every scenario and asset

Road network assets
(Road, Bridges, Tunnels, Culverts)

Risk analysis

Components of risk
(UNISDR 2016)

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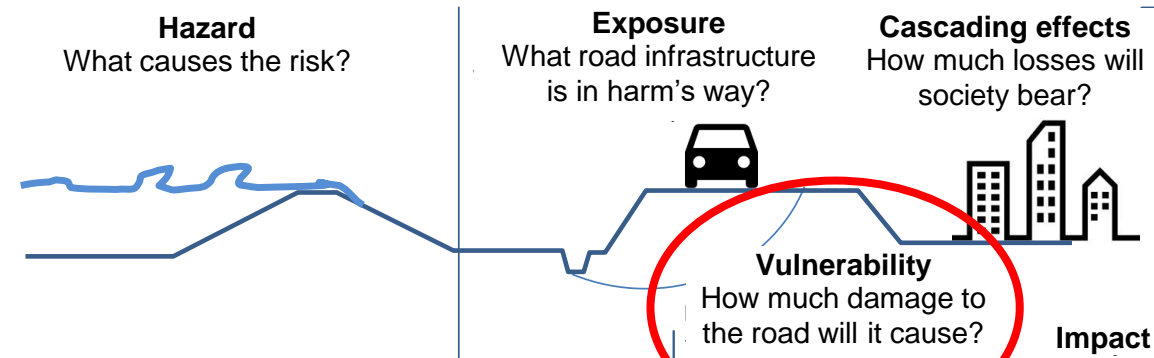
The context of risk analysis for road infrastructure
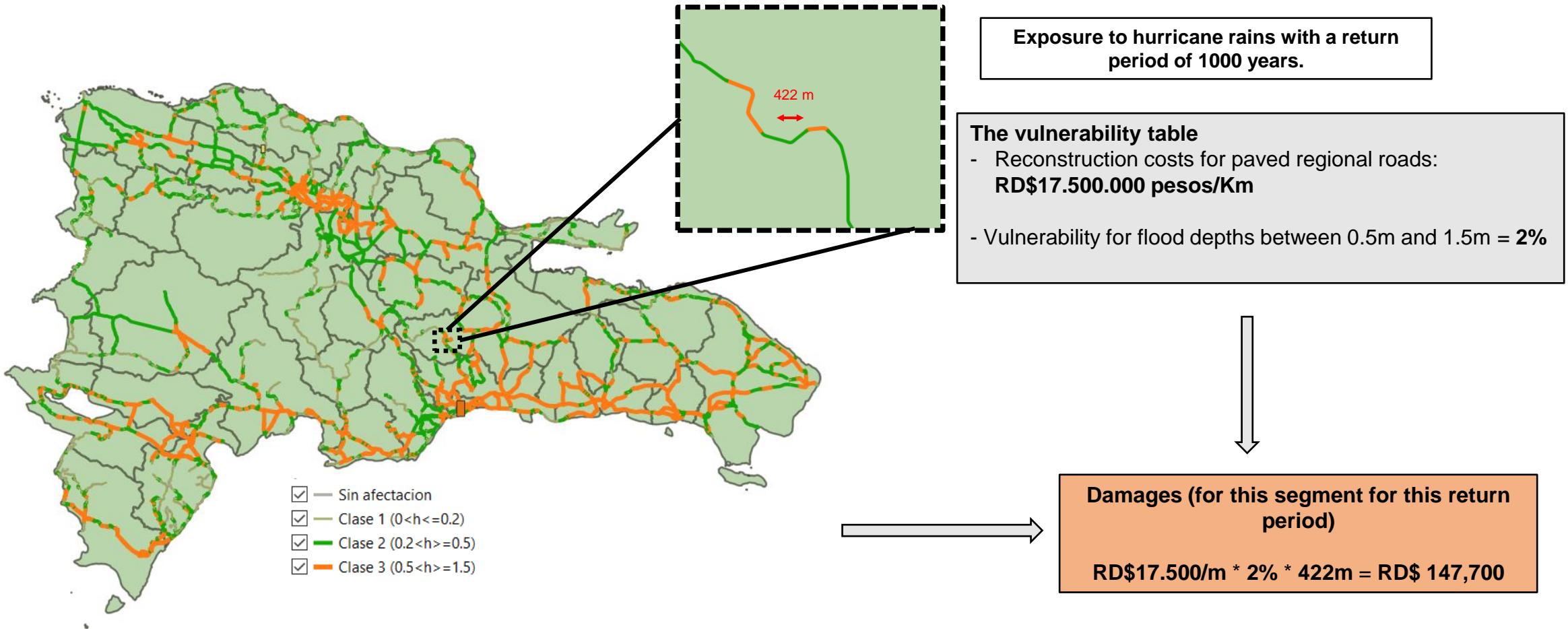(Bles et. al 2019)

Vulnera

- Vulnerabili
- Informatio
  - For eve
  - For eve
- Table with

Amenazas		Costos de reparación como porcentaje de los costos promedios de reconstrucción, por nivel de amenaza, por tipo de activo			Con asfalto				Sin asfaltar			Tunel	Obra de drenaje	Puentes
					Troncal	Regional	Local	Caminos (1,5 veces daño)	Regional	Local	Caminos (1,5 veces daño)			
	Inundaciónes	Profundidad de inundación		0 - 0,2 (m)	0,0%	0,0%	0,0%	0,0%	1,0%	1,0%	1,5%	1,0%	5%	3%
				0,2 - 0,5 (m)	1,0%	1,0%	1,0%	1,5%	20,0%	20,0%	30,0%	3,0%	10%	5%
				0,5 - 1,5 (m)	2,0%	2,0%	2,0%	3,0%	50,0%	50,0%	75,0%	5,0%	20%	10%
				> 1,5 (m)	20,0%	20,0%	20,0%	30,0%	100,0%	100,0%	100,0%	20,0%	40%	20%
	Terremotos	PGA		0 - 200 (cm/s2)	X							0%	0%	0%
				200 - 400 (cm/s2)								0%	5%	5%
				400 - 600 (m/s2)								10%	10%	10%
				600 - 800 (m/s2)								20%	20%	20%
				800 - 1000 (m/s2)								45%	35%	35%
				1000 - 1200 (m/s2)								60%	40%	40%
				1200 - 1400 (m/s2)								75%	50%	50%
		PGA+Potencial Licuefacción	Potencial de liquefacción muy elevado	0 - 92 (cm/s2)	0%								X	
				92 - 180 (cm/s2)	10%									
				180 - 340 (cm/s2)	25%									
				340 - 650 (cm/s2)	40%									
				> 650 (cm/s2)	100%									
		PGA+Potencial Licuefacción	Potencial de liquefacción elevado	0 - 92 (cm/s2)	0%								X	
				92 - 180 (cm/s2)	0%									
				180 - 340 (cm/s2)	10%									
				340 - 650 (cm/s2)	25%									
				> 650 (cm/s2)	40%									
		PGA+Potencial Licuefacción	Potencial de liquefacción médio	0 - 92 (cm/s2)	0%								X	
				92 - 180 (cm/s2)	0%									
				180 - 340 (cm/s2)	0%									
				340 - 650 (cm/s2)	10%									
				> 650 (cm/s2)	25%									
		PGA+Potencial Licuefacción	Potencial de liquefacción bajo	0 - 92 (cm/s2)	0%								X	
				92 - 180 (cm/s2)	0%									
				180 - 340 (cm/s2)	0%									
				340 - 650 (cm/s2)	0%									
				> 650 (cm/s2)	10%									

Calculation of damages

Exposure to hurricane rains with a return period of 1000 years.

The vulnerability table
- Reconstruction costs for paved regional roads: **RD$17.500.000 pesos/Km**

- Vulnerability for flood depths between 0.5m and 1.5m = **2%**

Damages (for this segment for this return period)

RD$17.500/m * 2% * 422m = RD$ 147,700

422 m

Legend:
- ☑ — Sin afectacion
- ☑ — Clase 1 (0<h<=0.2)
- ☑ — Clase 2 (0.2<h>=0.5)
- ☑ — Clase 3 (0.5<h>=1.5)

- For each hazard scenario - resulted in 100 damage maps (4 hazards, for each return period, for each asset).

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Calculation of annual expected damages (AED)

In order to have an overview of the possible annual investment to be made for each hazard, we have calculated the AEDs.

1) Damage is calculated, per road stretch (sum of bridges, culverts, tunnels and road network), for all hazard scenarios.

2) DAE is calculated per hazard per road stretch

Ejemplo: Inundación por lluvias huracanadas – Daños por tramo (suma de activos), por escenario de amenaza
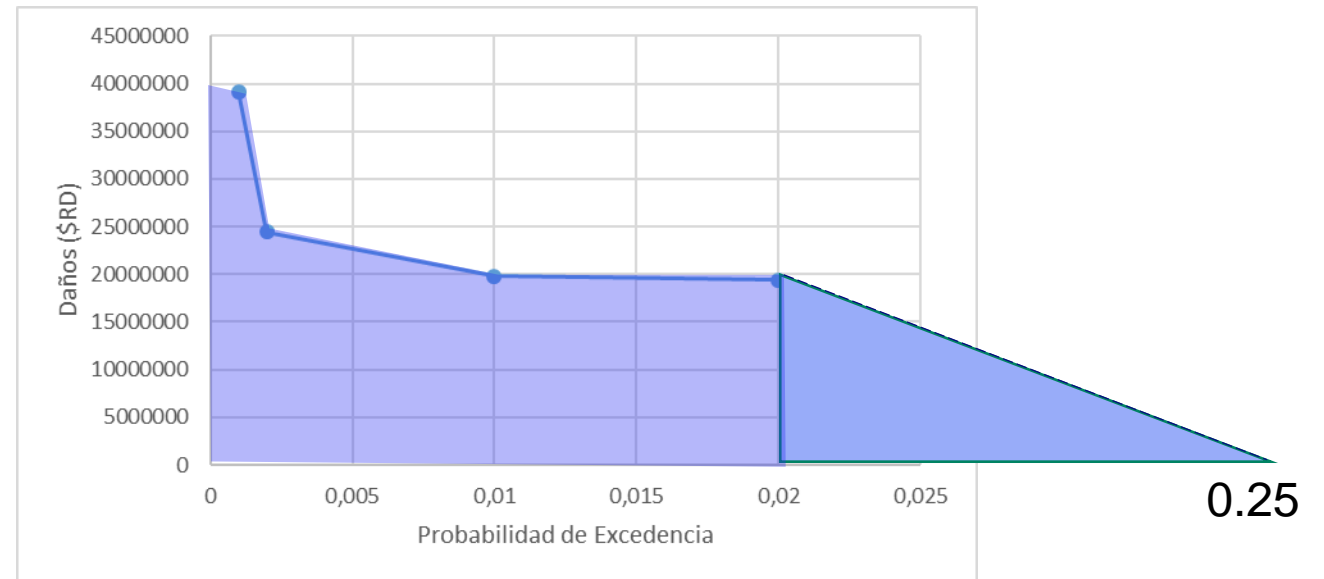**1:1000 años**

ID_Tramo = 374

0 1 2 km

2 obras de drenaje: 150.546 + 150.546 = 301.092 $RD Pesos

1 puente: 21.641.963 $RD Pesos

red vial: 17.243.588 $RD Pesos

Total: 39.186.643 $RD Pesos

Inundation for hurricane rains Road stretch 374		
Return period (years)	Probability of exceedance	Damages ($RD Pesos)
50	0.02	19.415.937
100	0.01	19.770.706
500	0.002	24.422.428
1000	0.001	39.186.643

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Calculation of risk – Annual Expected Damages (AED)

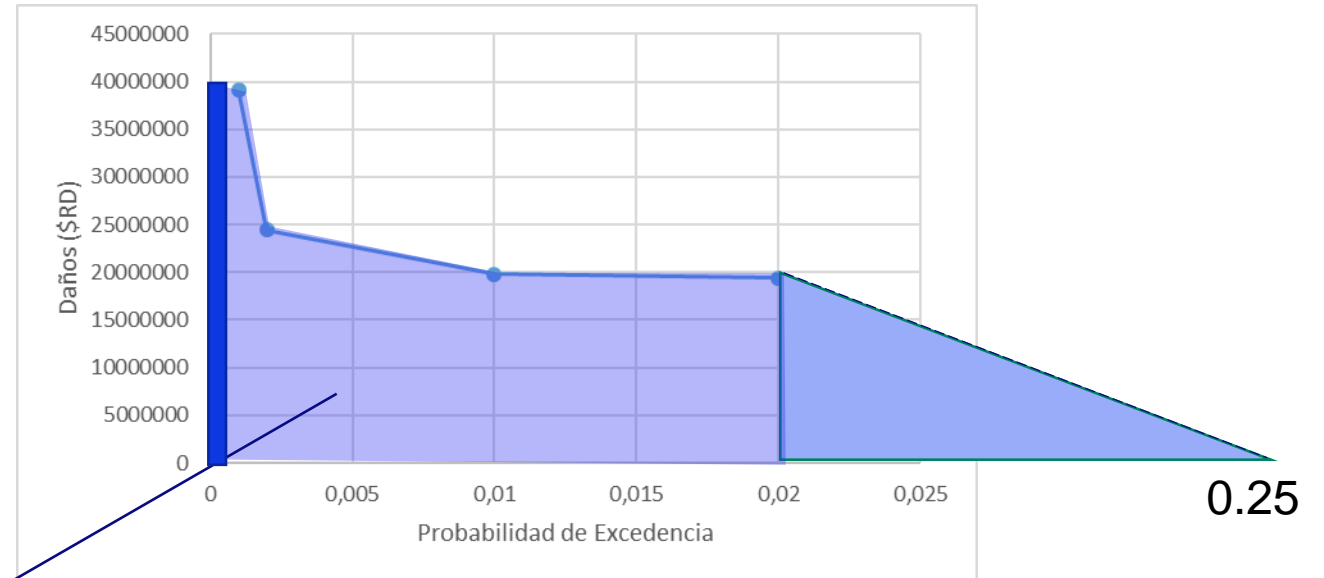**Example: Flooding due to hurricane rains – Annual Expected Damages per road stretch**

Inundation for hurricane rains Road stretch 374		
Return period (years)	Probability of exceedance	Damages ($RD Pesos)
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0.25

Calculation of risk – Annual Expected Damages (AED)

Example: Flooding due to hurricane rains – Annual Expected Damages per road stretch

Inundation for hurricane rains Road stretch 374		
Return period (years)	Probability of exceedance	Damages ($RD Pesos)
50		
100		
500		
1000	0.001	39.186.643

0.25

Area = AED =

= 0.001 *39.186.643 +

Calculation of risk – Annual Expected Damages (AED)

Example: Flooding due to hurricane rains – Annual Expected Damages per road stretch

Inundation for hurricane rains Road stretch 374		
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100		
500	0.002	24.422.428
1000	0.001	39.186.643

0.25

Área = EAD =

= 0.001 *39.186.643 + (0.002-0.001) * ((39.186.643 + 24.422.428)/2)

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Calculation of risk – Annual Expected Damages (AED)

Example: Flooding due to hurricane rains – Annual Expected Damages per road stretch

Inundation for hurricane rains Road stretch 374		
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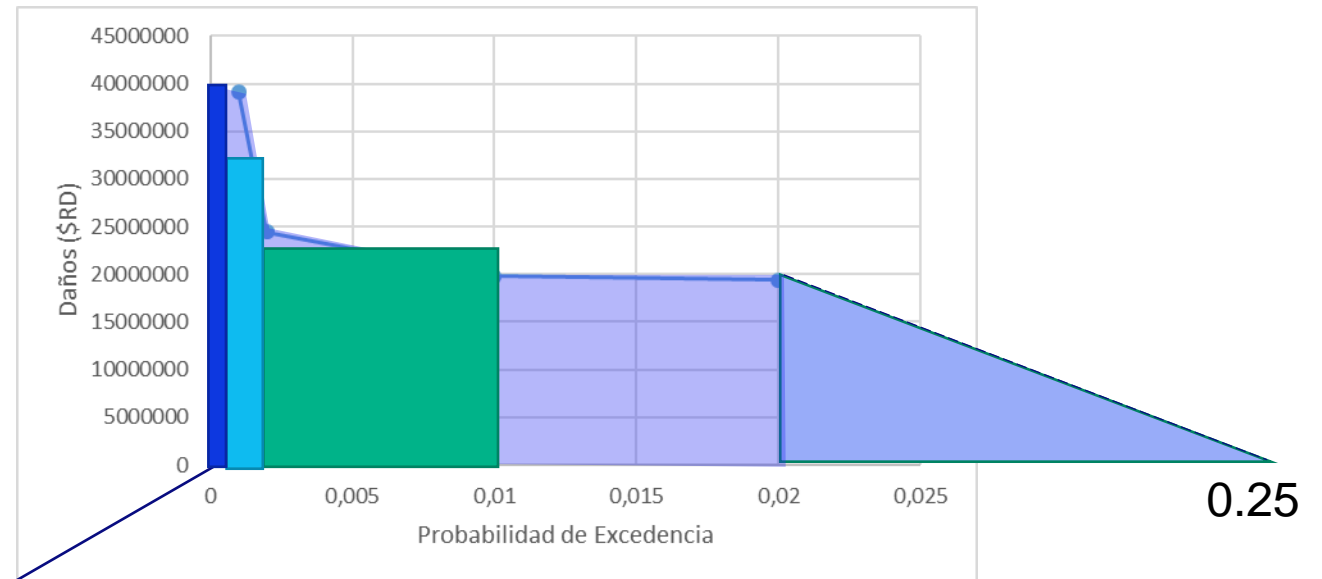
Área = EAD =

= 0.001 *39.186.643 + (0.002-0.001) * ((39.186.643 + 24.422.428)/2) + (0.01-0.002) * ((24.422.428 +19.770.706)/2)

Calculation of risk – Annual Expected Damages (AED)

Example: Flooding due to hurricane rains – Annual Expected Damages per road stretch

Inundation for hurricane rains Road stretch 374		
Return period (years)	Probability of exceedance	Damages ($RD Pesos)
50	0.02	19.415.937
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1000	0.001	39.186.643

0.25

Área = EAD = 2.676.529 $RD/año

= 0.001 *39.186.643 + (0.002-0.001) * ((39.186.643 + 24.422.428)/2) + (0.01-0.002)
* ((24.422.428 +19.770.706)/2) + (0.02-0.01)*((19.770.706 + 19.415.937 /2)

Calculation of risk – Annual Expected Damages (AED)

Example: Flooding due to hurricane rains – Annual Expected Damages per road stretch

Inundation for hurricane rains Road stretch 374		
Return period (years)	Probability of exceedance	Damages ($RD Pesos)
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0.25

Área = EAD = **2.676.529 $RD/año**

= 0.001 *39.186.643 + (0.002-0.001) * ((39.186.643 + 24.422.428)/2) + (0.01-0.002) * ((24.422.428 +19.770.706)/2) + (0.02-0.01)*((19.770.706 + 19.415.937 /2) + (0.25 - 0.02)*((19.415.937 + 0 /2)

General methodology
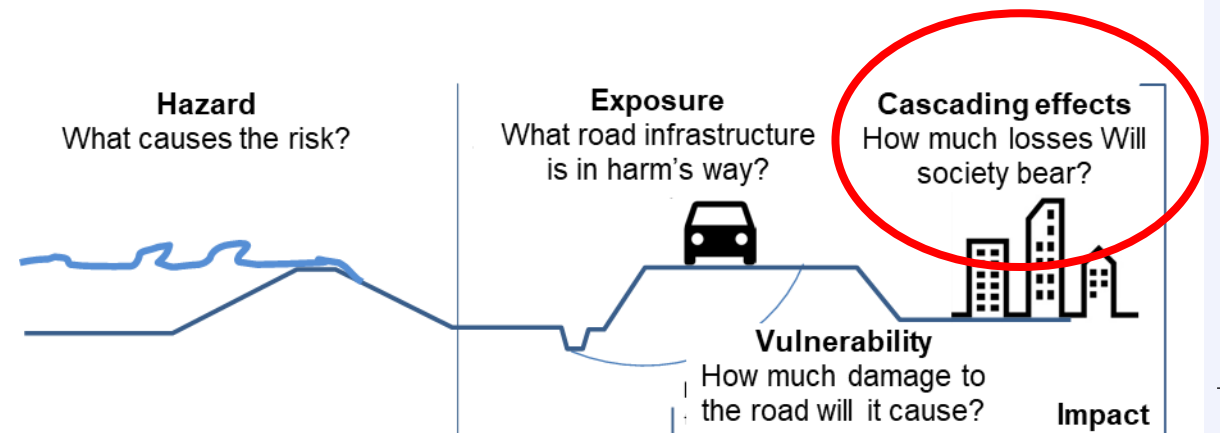
Inventory of all the assets in the network	Risk analysis for natural hazards	**Analysis of network criticality**	Prioritization of interventions

Criticality analysis

- **Quantification of criticality**
  - Analysis of disruption of each road stretch

- **Calculate the economic impact**
  - Economic impact resulting from each type of Hazard, per road stretch
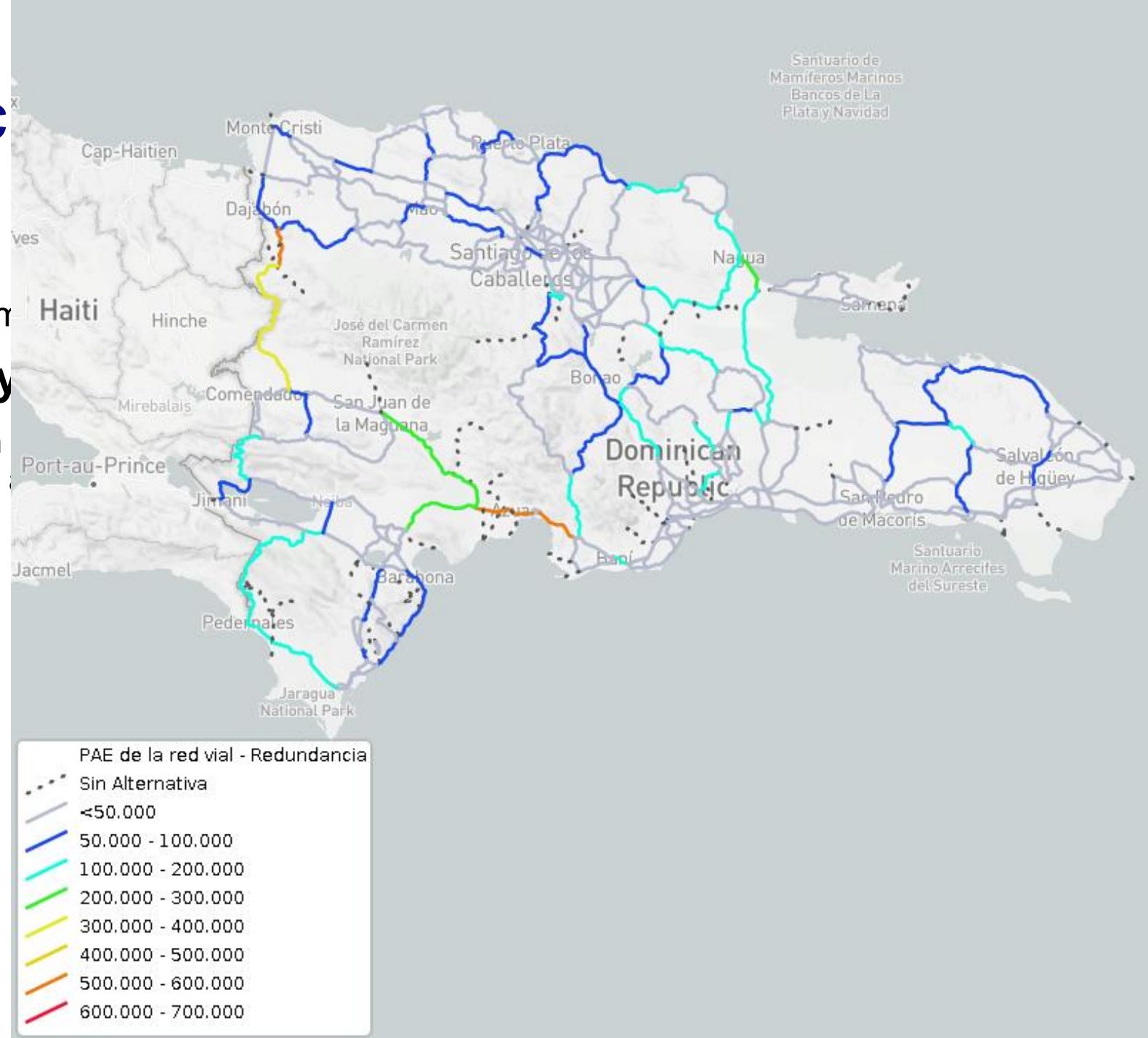

Hazard
What causes the risk?

Exposure
What road infrastructure is in harm's way?

Cascading effects
How much losses Will society bear?

Vulnerability
How much damage to the road will it cause?

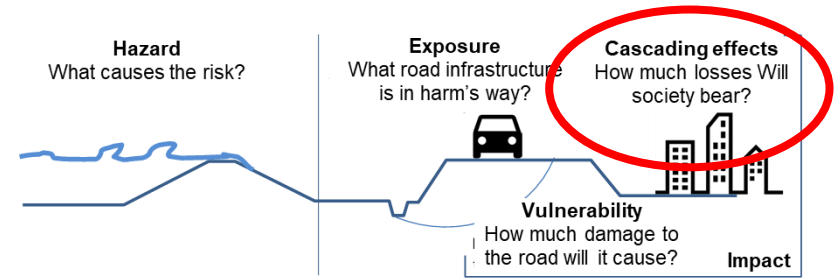**Impact**

Quantification of c

What is criticality?

* Criticality is the measure of the im

How to evaluate criticality

* Criticality is assessed through an
  time is removed and the distance

PAE de la red vial - Redundancia

- - - Sin Alternativa
—— <50.000
—— 50.000 - 100.000
—— 100.000 - 200.000
—— 200.000 - 300.000
—— 300.000 - 400.000
—— 400.000 - 500.000
—— 500.000 - 600.000
—— 600.000 - 700.000

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Criticidad del Sistema y pérdidas económicas

Hazard
What causes the risk?

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Impact

Disrup
of the
stretch

DR   INTRODUCCIÓN   AMENAZAS   EXPOSICIÓN   DAÑOS   PÉRDIDAS   **DAE Y PAE**   PRIORIZACIÓN

▼ ➖ Daños y Pérdidas anuales esperadas

   ▼ ☐ Daños anuales esperados (DAE)

      ☐ Inundaciones Fluviales

      ☐ Inundaciones por lluvias huracanadas
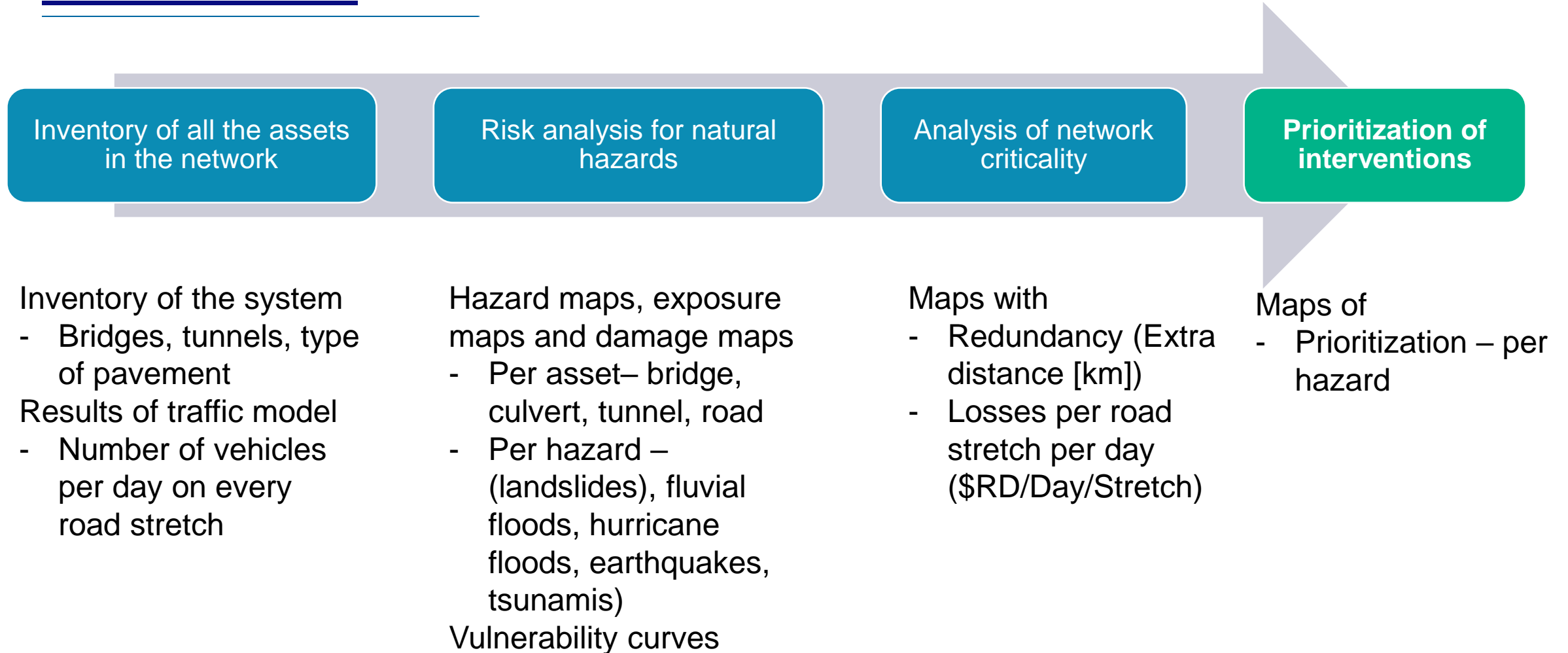
      ☐ Terremotos

      ☐ Tsunamis

      ☐ Total

   ▼ ➖ Pérdidas anuales esperadas (PAE)

      ☐ Inundaciones Fluviales

      ☐ Inundaciones por lluvias huracanadas

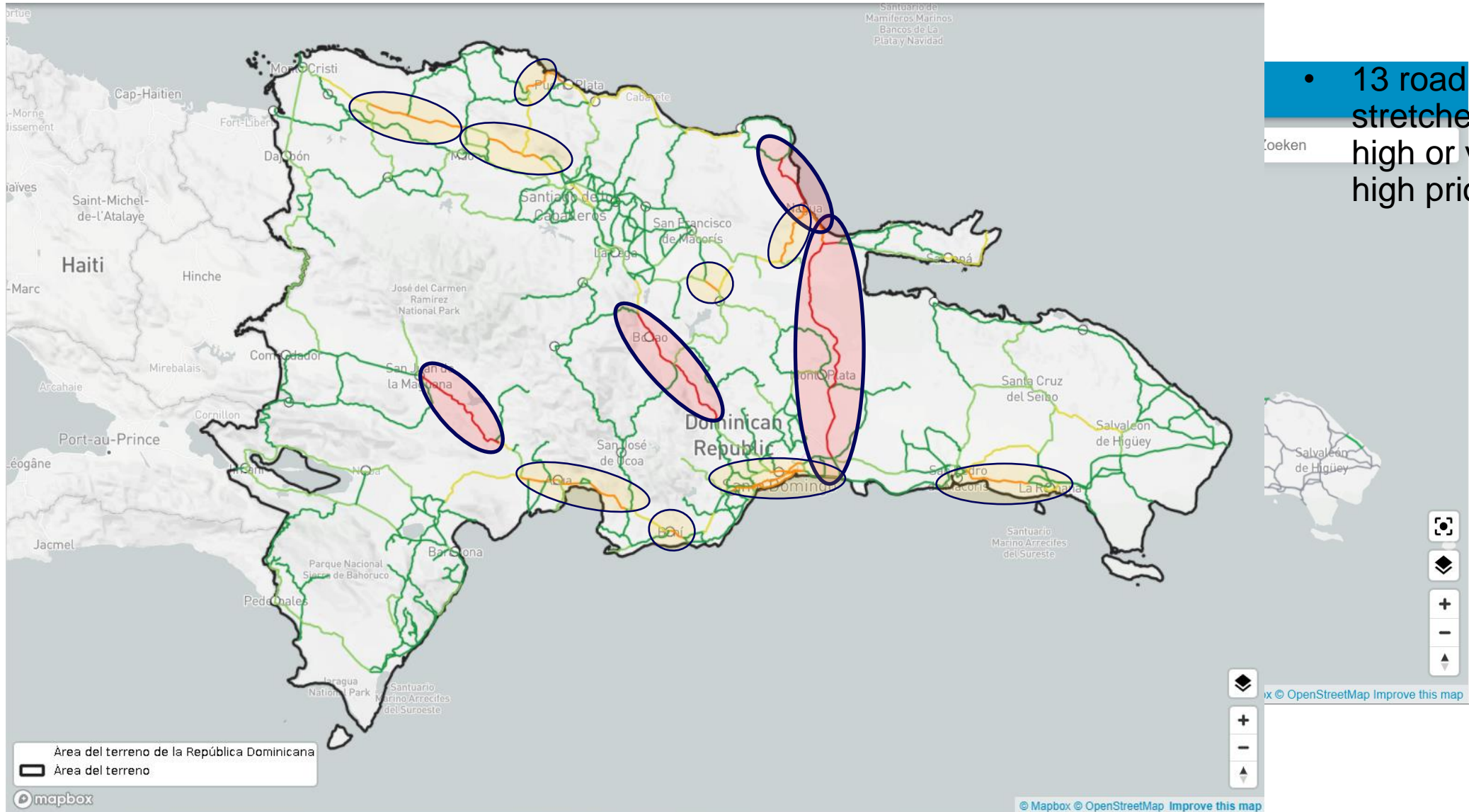   ☐ Terremotos

      ☐ Tsunamis

      ☑ Total

PAE de la red vial - Total (RD$)
- 0 - 1000000
- 1000000 - 2000000
- 2000000 - 4000000
- 4000000 - 6000000
- 6000000 - 8000000
- 8000000 - 10000000
- 10000000 - 15000000
- 15000000 - 30000000

© Mapbox © OpenStreetMap Improve this map

28
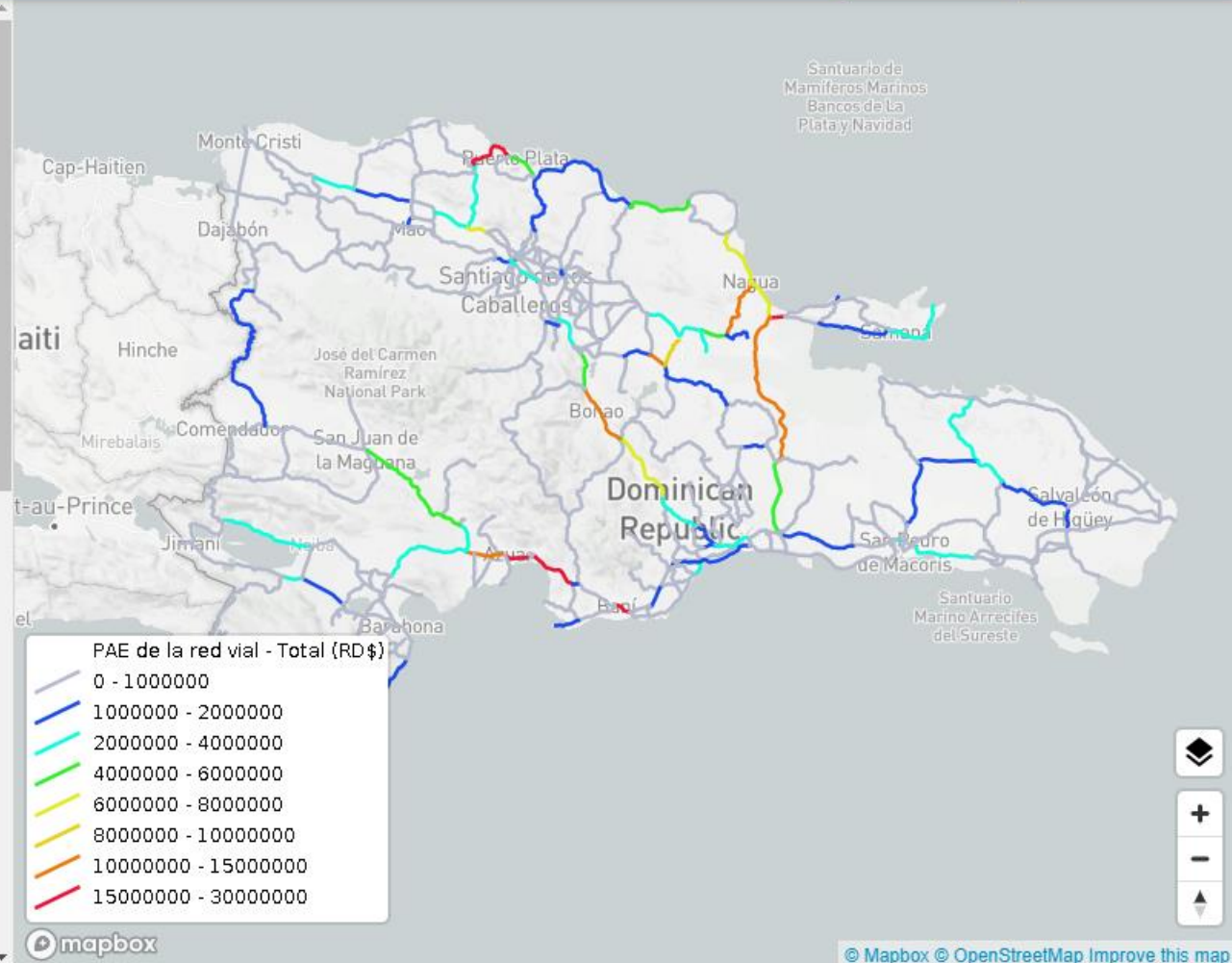
Todos las mapas disponibles - Demonstración de la herramienta

Inventory of all the assets in the network	Risk analysis for natural hazards	Analysis of network criticality	**Prioritization of interventions**

Inventory of the system
- Bridges, tunnels, type of pavement

Results of traffic model
- Number of vehicles per day on every road stretch

Hazard maps, exposure maps and damage maps
- Per asset– bridge, culvert, tunnel, road
- Per hazard – (landslides), fluvial floods, hurricane floods, earthquakes, tsunamis)

Vulnerability curves

Maps with
- Redundancy (Extra distance [km])
- Losses per road stretch per day ($RD/Day/Stretch)

Maps of
- Prioritization – per hazard

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Prioritization

- 13 road stretches with high or very high priority

How to use? Results for asset management
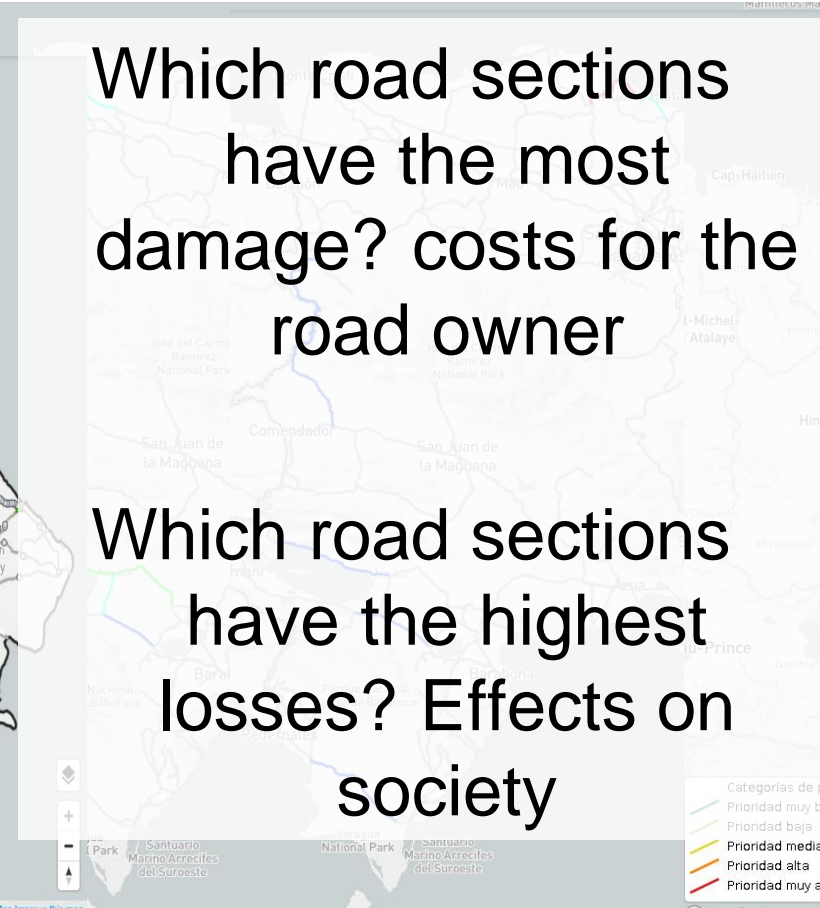
Exposure maps with different return periods

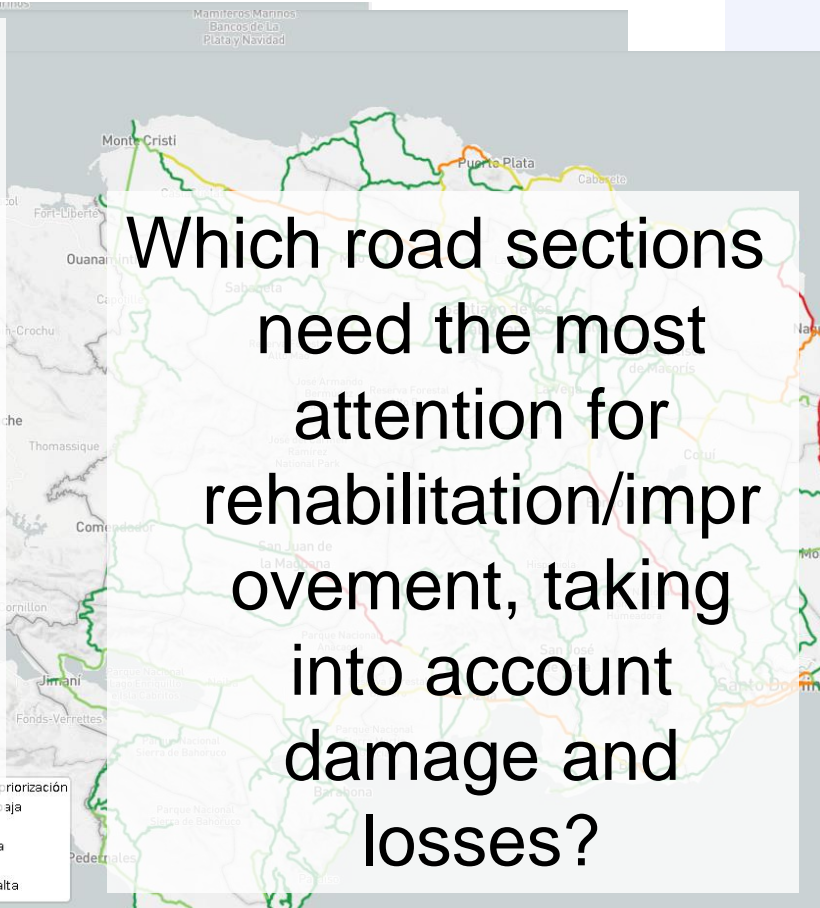**Maps with AED and AEL**

Priority maps

Where are the road and its assets flooded?

Which road sections have the most damage? costs for the road owner

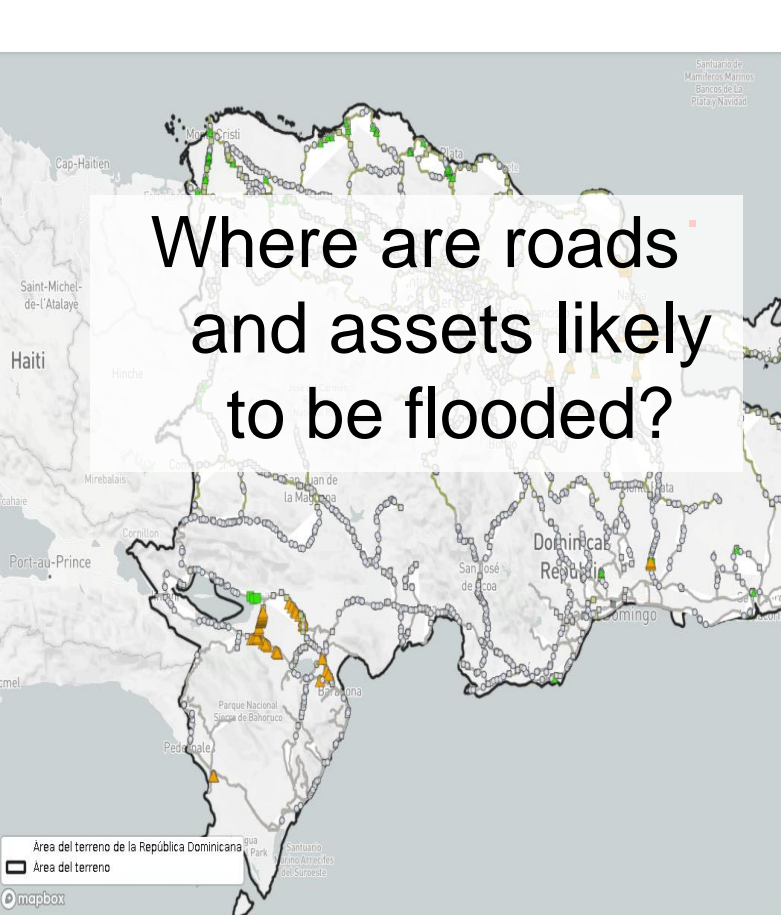Which road sections have the highest losses? Effects on society

Which road sections need the most attention for rehabilitation/improvement, taking into account damage and losses?

How to use? Results for emergency management

Exposure maps with different return periods
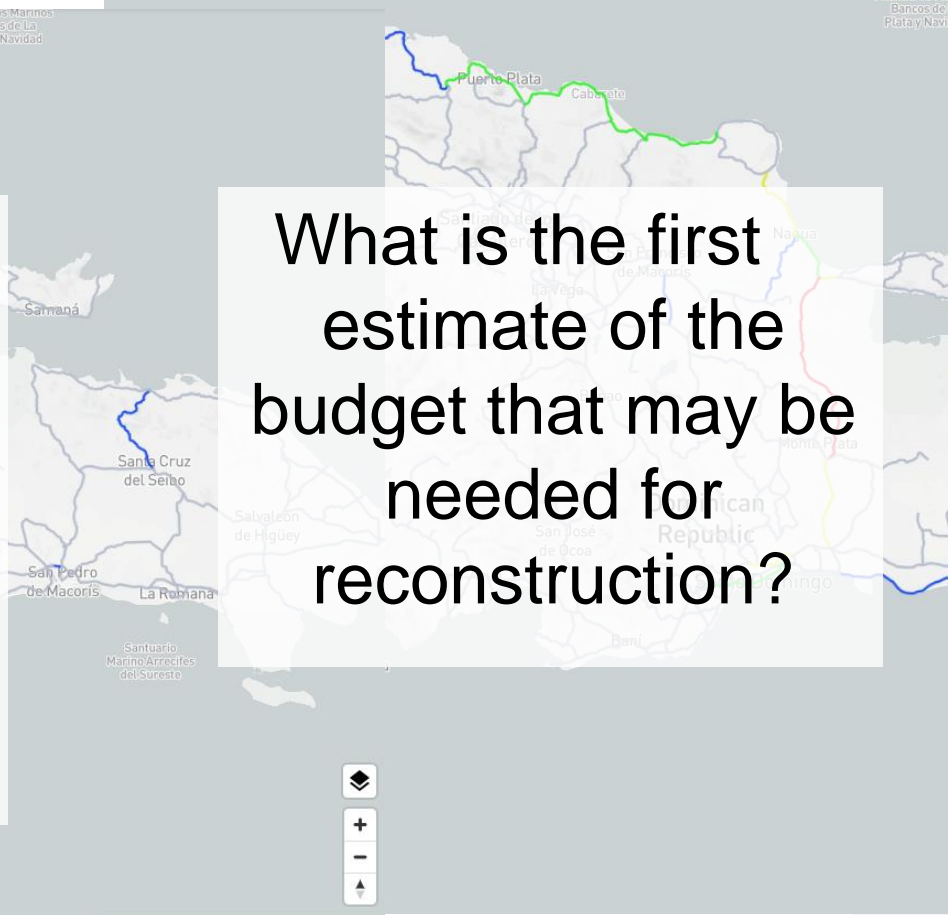
Maps with Annual Expected Losses

Maps with Annual Expected Damages

Where are roads and assets likely to be flooded?

Which road sections are most critical for use and need the most attention, during preparation and response?

What is the first estimate of the budget that may be needed for reconstruction?

Contact

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