XLII

International School of Hydraulics

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# Urban Resilience to Floods:
## Real Challenges and Misleading Myths


*Corrado Gisonni*

Università
degli Studi
della Campania
*Luigi Vanvitelli*
*Dipartimento di Ingegneria*

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# Introduction

Risk **R** is traditionally expressed as:

$$\boldsymbol{R = H \times E \times V}$$

Review of the Risk Assessment process (UNDRR, formerly UNISDR, 2009)

$$R = \frac{H \times V \times E}{C}$$


UNDRR
UN Office for Disaster Risk Reduction

The risk assessment (and corresponding mapping) includes:

- Study of the technical characteristics of the **hazard *H***, such as location, intensity and likelihood of occurrence;
- Analysis of the **exposed values *E*** (safety, social, economic and environmental);
- Estimation of the (intrinsic) **vulnerability *V*** of the exposed assets; the vulnerability is expressed as a number between 0 (no damage) and 1 (total loss);
- Assessment of the **capability *C*** to cope with risk scenarios and its effectiveness.

## Capability C = *non structural resilience*


- Urban planning compatible with risk/hazard assessment
- Detailed information on exposure and vulnerability
- Civil protection organization and exercises
- Early Warning Systems
- Training and information for the public about risk scenarios and standards of behaviour
- Introduction of «best practices»
- Implementation of «Build Back Better» policies (rebuild better and in a resilient way)

$$R = \frac{H \times V \times E}{C}$$

**Return Period *T*:** The return period, also known as a *recurrence interval*, is an estimate of the likelihood of an event (storm, earthquake, volcano eruption…) to occur, and may be expressed as function of the exceedance probability $P_s$:

$$T = \frac{1}{P_s}$$

**Exceedance probability in *N* years:**

$$P_s^N = 1 - \left[1 - \frac{1}{T}\right]^N$$

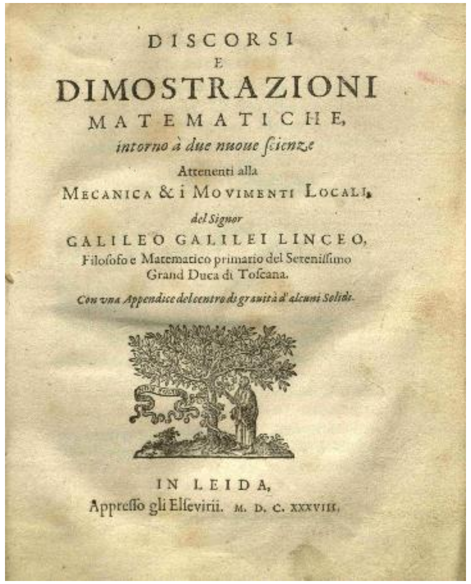
The probability that a structure will have to face an event with return period T equal to design return period $T_p$ ($T=N$) is roughly equal to **63%** (for values of $T$>>1).

| Exceedance probability $P_s$ | Return period T | Occurrence probability 1 event in 80 years | Occurrence probability 2 event in 80 years | Occurrence probability 3 event in 80 years |
|---|---|---|---|---|
| 20.0% | 5 | 100.00% | 100.00% | 100.00% |
| 10.0% | 10 | 99.98% | 99.78% | 98.93% |
| 5.0% | 20 | 98.35% | 91.39% | 76.94% |
| 2.0% | 50 | 80.14% | 47.70% | 21.56% |
| 1.0% | 100 | 55.25% | 19.08% | 4.66% |
| 0.5% | 200 | 33.04% | 6.11% | 0.77% |
| 0.2% | 500 | 14.80% | 1.14% | 0.06% |
| 0.1% | 1000 | 7.69% | 0.30% | 0.01% |

$$F_X(x) = \sum_{k=0}^{x} \binom{n}{k} p^k (1-p)^{n-k}.$$

*Human perception of extreme events and risk…*

«*Le conclusioni vere, benché nel primo aspetto sembrino improbabili, additate solamente qualche poco, depongono le vesti che le occultavano, e nude e semplici fanno de' lor segreti gioconda mostra*»
— Galileo Galilei (*Discorsi e dimostrazioni matematiche intorno a due nuove scienze*. Giornata prima. 1638)


DISCORSI
E
DIMOSTRAZIONI
MATEMATICHE,
intorno à due nuoue scienze
Attenenti alla
MECANICA & i MOVIMENTI LOCALI,
del Signor
GALILEO GALILEI LINCEO,
Filosofo e Matematico primario del Serenissimo
Grand Duca di Toscana.
Con una Appendice del centro di grauità d'alcuni Solidi.
IN LEIDA,
Appresso gli Elsevirii. M. D. C. XXXVIII.

**"Man can believe the impossible, but man can never believe the improbable"**
*Oscar Wilde*

# October 4th 2010

Urban flooding in Sestri Ponente (Genua, Italy)

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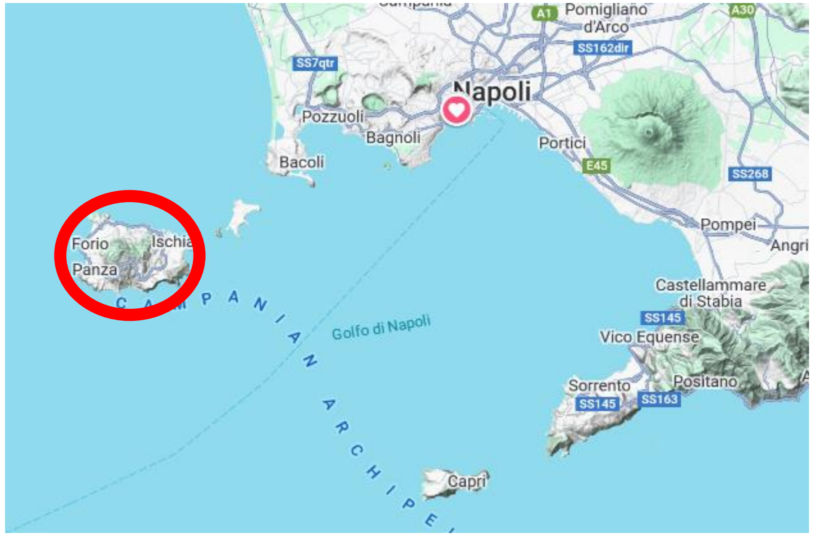
*Before…* *… after the care!*

Giotto street n. 15, in Sestri Ponente (Liguria, Italy), called «Palazzo dei Veleni» (Poisons' Palace), obstructed the Chiaravagna creek. In 2013, the demolition of the building was completed after years of legal battles to clarify the ownership of the building (*twenty years* of discussions between residents and the State).
During the flood of October 4, 2010, the building was "protagonist actor" and this made the inevitable decision to evacuate the apartments and demolish the structure.





Ischia island (Naples, Italy) – Municipality of Serrara Fontana.
Creek intercepted and obstructed by hotel structure in proximity of the river estuary.

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# Flood Disasters

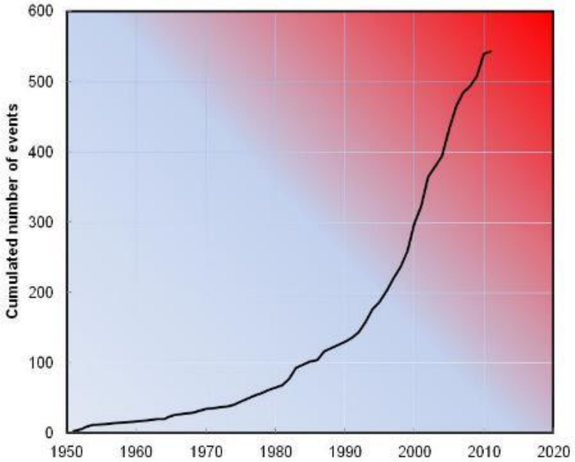
The consequences of events classified as Floods and Mudslides are dramatic, as evidenced by statistics extracted from the International Disaster Database(CRED, Université Catholique de Louvain - UCL, Brussels, Belgium; http://www.emdat.be)

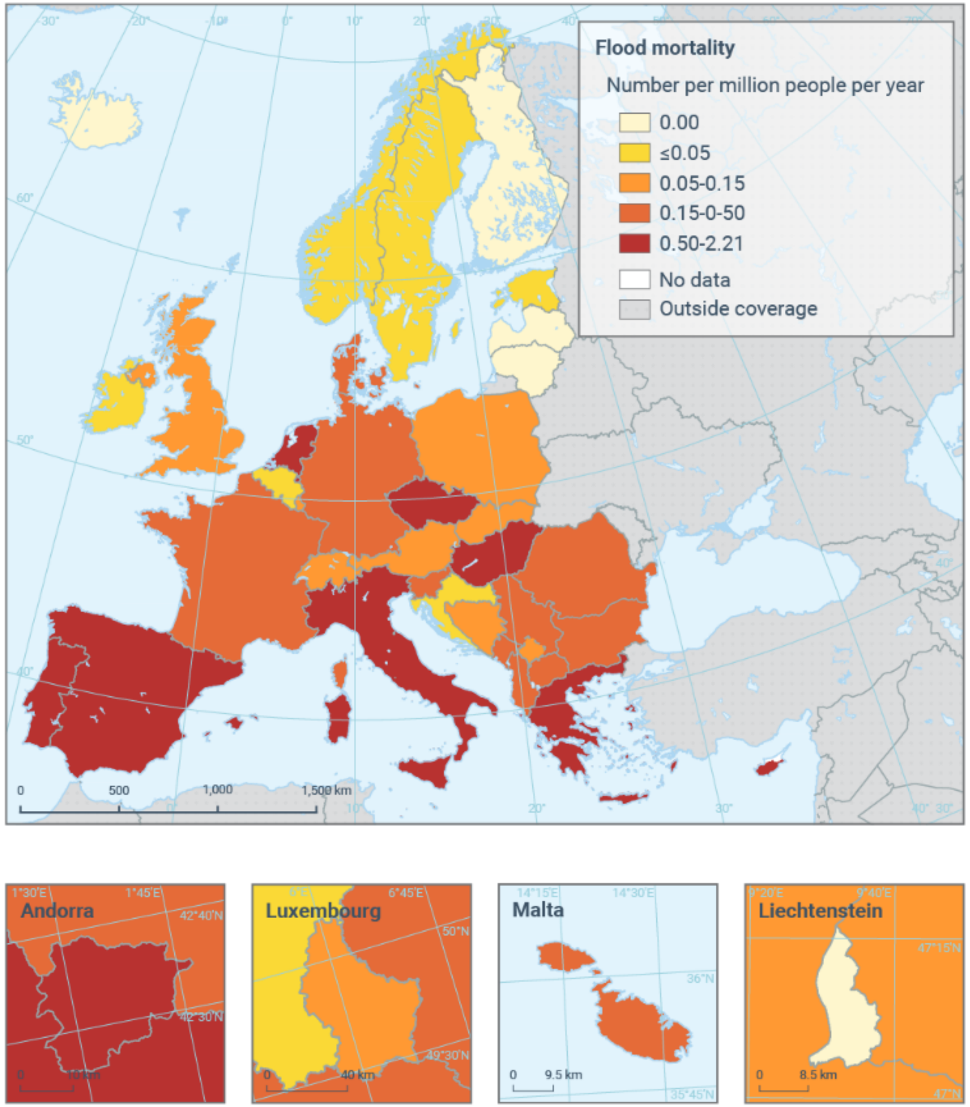
| Total Deaths | No. Injured | No. Affected | No. Homeless | Total Affected | Total Damage, Adjusted ('000 US$) |
|---|---|---|---|---|---|
| 31296 | 35391 | 26425725 | 2584321 | 29045437 | 566589035 |


- From 1920 to the present, the estimated economic damage is about **570 billion Euro**;

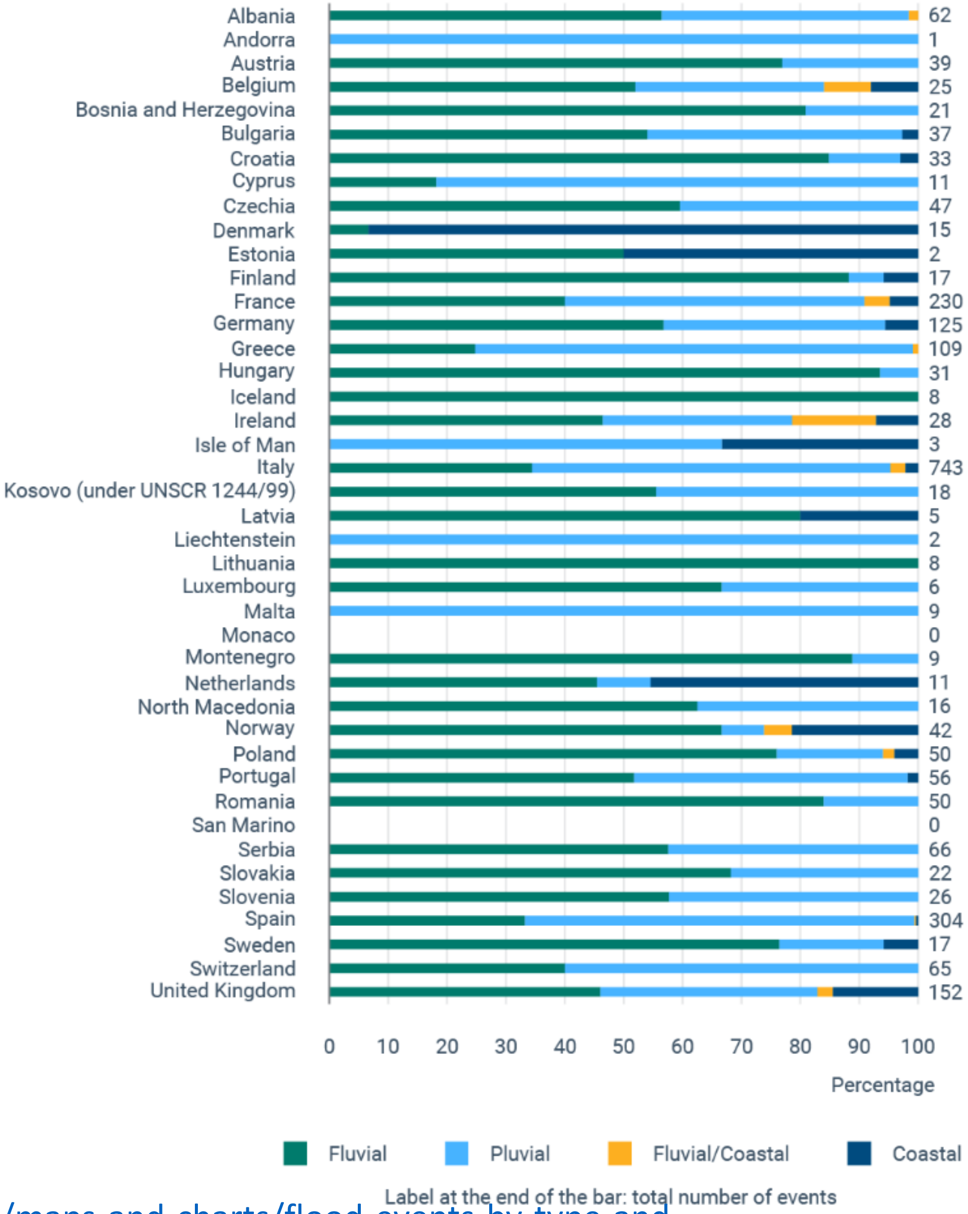
- During the last century, more than **29 million** people have been affected by destructive events, for a total of over **31,000 fatalities**;

- More than **500 events** have been recorded in the last 60 years, with a trend that is clearly growing in the last decades.






Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO




https://www.eea.europa.eu/en/analysis/maps-and-charts/flood-events-by-type-and



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**The Guardian**

## Deadly floods and storms affected more than 400,000 people in Europe in 2024

European State of the Climate report 'lays bare' impact of fossil fuels on continent during its hottest 12 months on record

More than 250 people died after floods swept through towns in eastern Spain in October 2024. Photograph: Alberto Saiz/AP

(https://www.theguardian.com/environment/2025/apr/15/europe-storms-floods-and-wildfires-in-2024-affected-more-than-400000)

**CNN INTERNATIONAL**

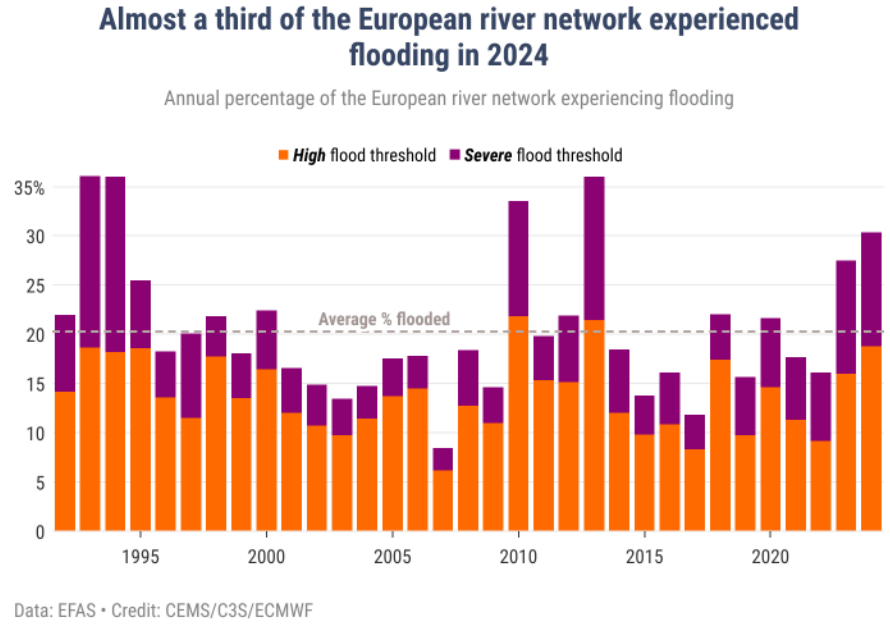
## Entire city evacuated after floods, 7 die in wildfires as extreme weather sweeps Europe

A drone view of a flooded area close to the Nysa Klodzka river in Nysa, Poland on September 16, 2024.

https://edition.cnn.com/2024/09/17/europe/europe-floods-evacuation-entire-city-wildfires-portugal-intl

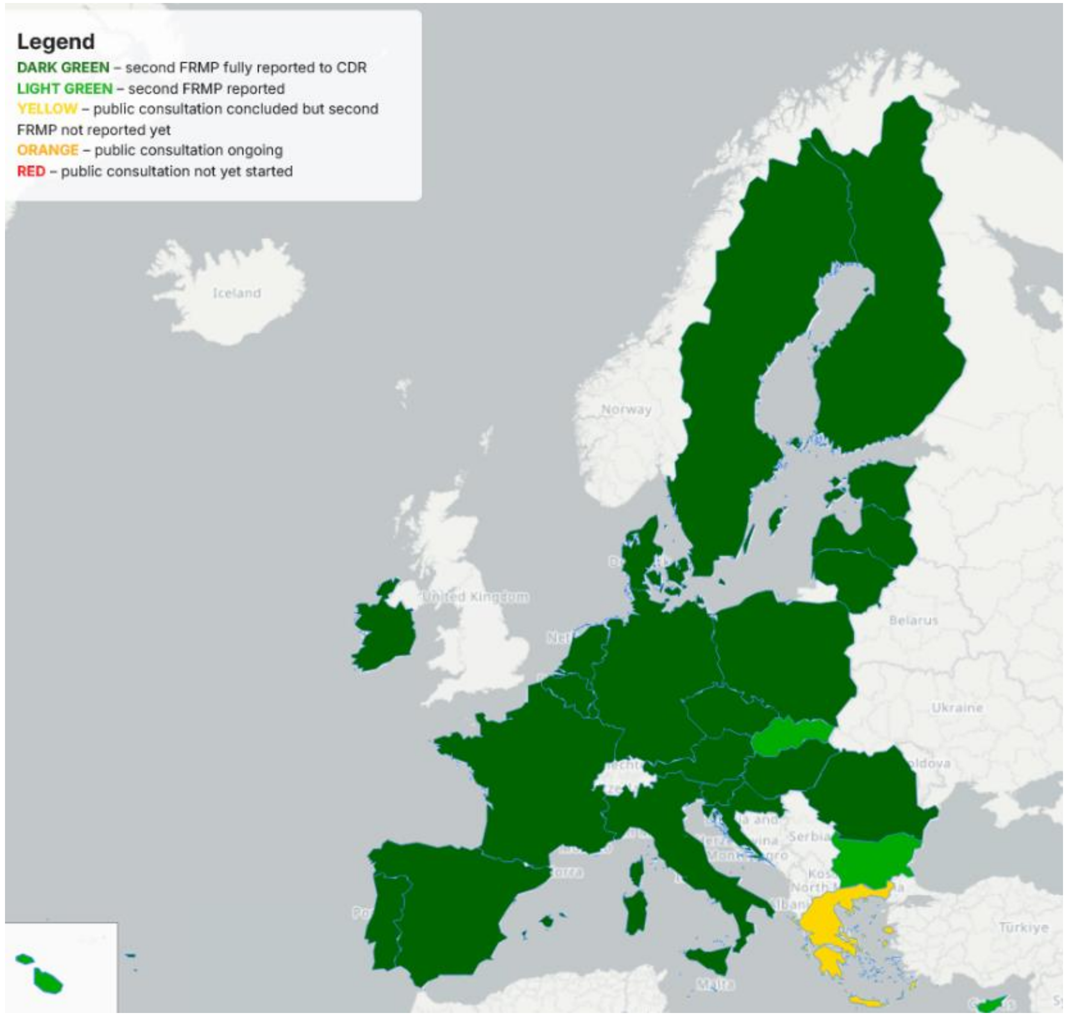
*"Intense or prolonged precipitation are key drivers of flooding. In 2024, storms and flooding affected an estimated **413,000 people**, resulting in the loss of at least **335 lives**. Damage from storms and flooding across Europe during the year is estimated to have cost at least **€ 18 billion**."*

(https://climate.copernicus.eu/esotc/2024/flooding)



## State of play of 2nd Flood Risk Management Plan (FRMP) adoption in EU 27

*last update: 20 December 2023*




(*https://environment.ec.europa.eu/topics/water/floods_en* )

**Brussels, 4.2.2025**

*COM(2025) 2 final*

**REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT**

*on the implementation of the Water Framework Directive (2000/60/EC) and the Floods Directive (2007/60/EC)*

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2025%3A2%3AFIN&qid=1738746144581

*«Although Member States were required to adopt their plans by March 2022, regrettably, many adopted them late. This led the Commission to launch* ***legal proceedings against all Member States in breach of the legal requirements****. Even at the time of finalizing this assessment, not all Member States had adopted their RBMPs and FRMPs and submitted them to the Commission 12. For that reason, this report does not cover those countries or regions... »*



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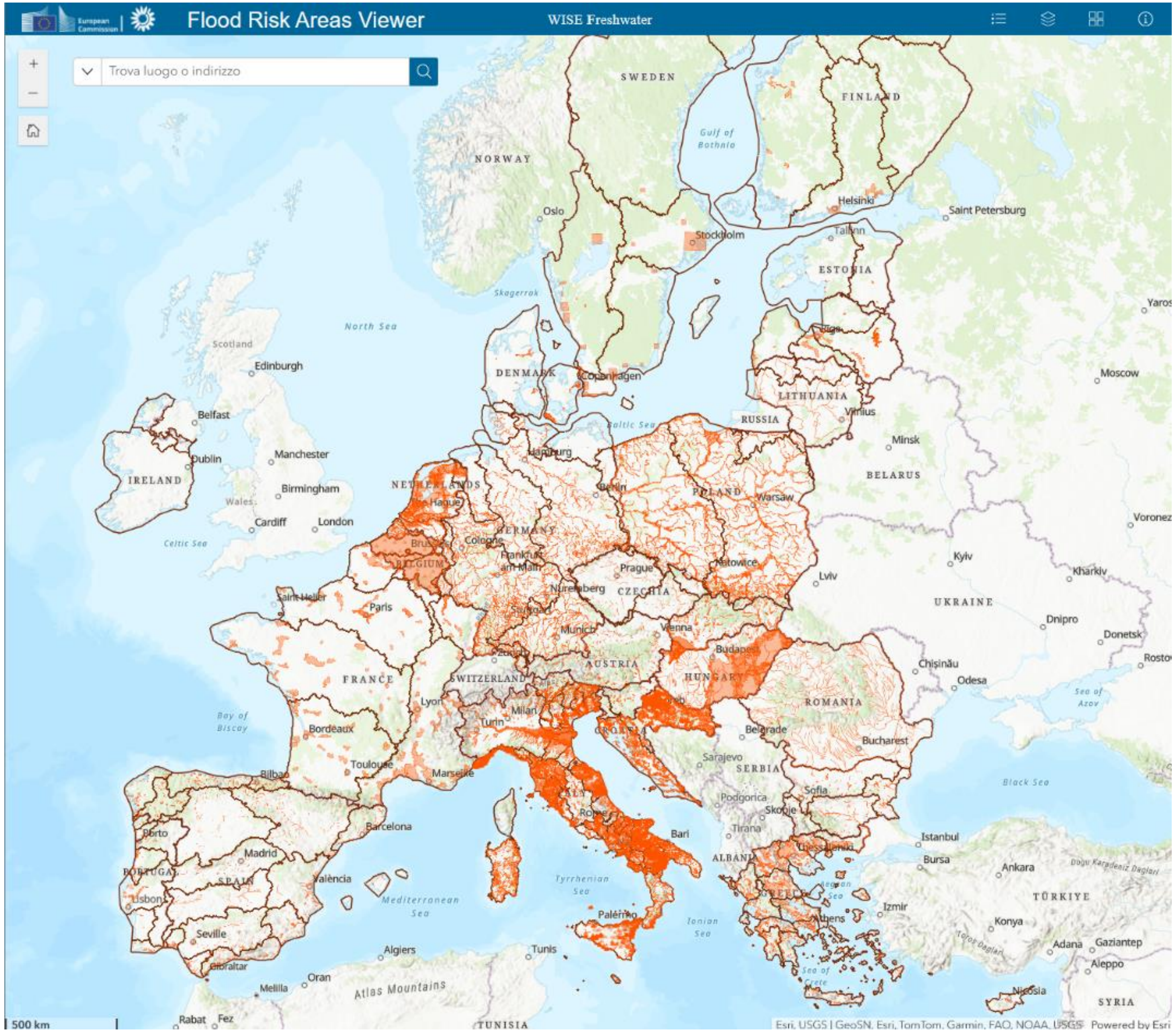
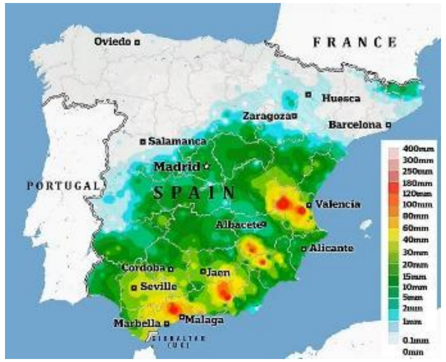
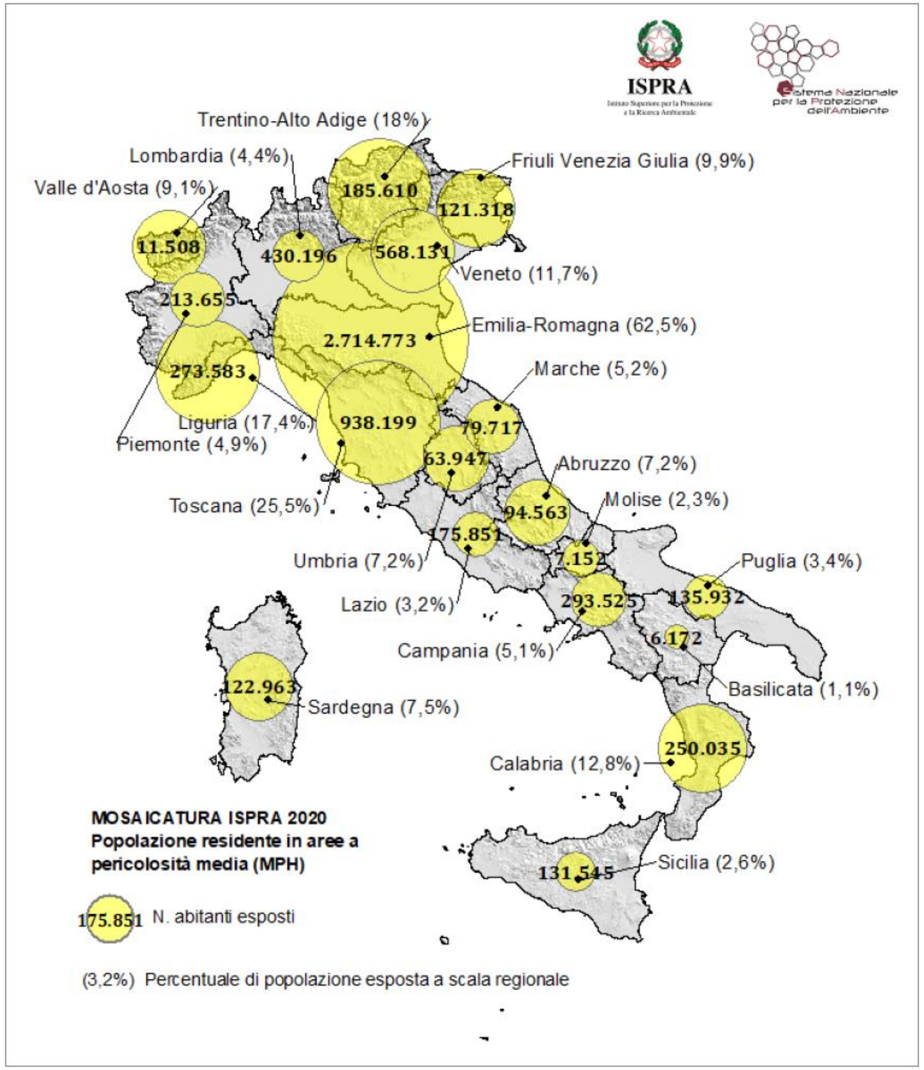



A viewer is provided by the European Commission with the support of the European Environment Agency to raise flood risk awareness.

It reflects the work carried out by the Member States under the **Floods Directive** *(2007/60/EC).*

https://discomap.eea.europa.eu/floodsviewer/?page=Page



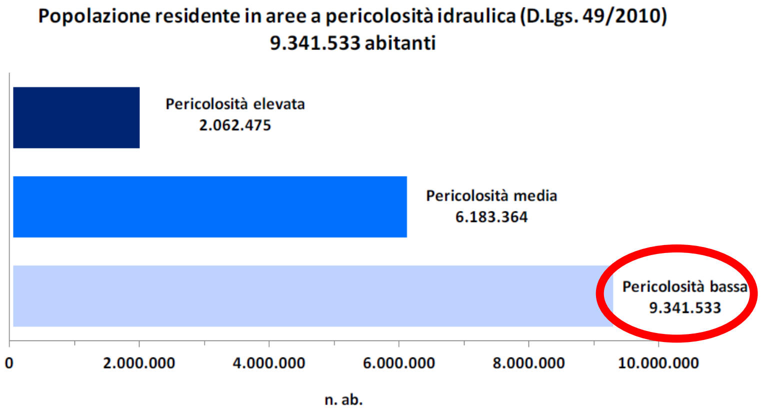




The indicator **Population exposed to flood hazard** was used in the framework of the *Risk Map of Metropolitan Areas* for the identification of municipalities with a higher population exposed to Hydraulic Risk in 14 metropolitan areas. The aim was to establish funding priority for risk mitigation actions (ISPRA, 2018 and 2021).

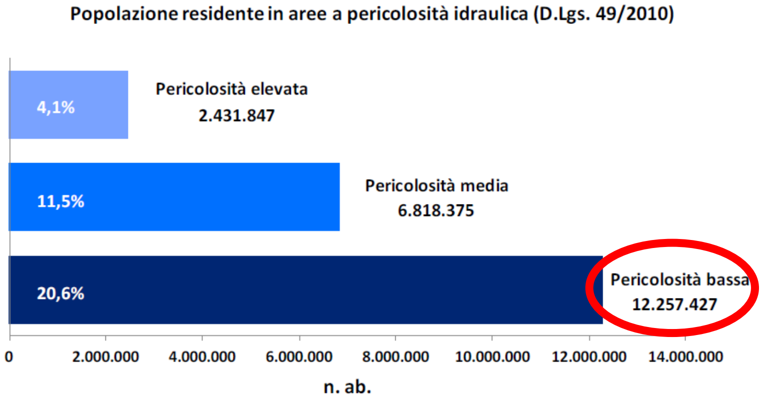
ISPRA: Italian Institute for Environmental Protection and Research

https://www.isprambiente.gov.it/

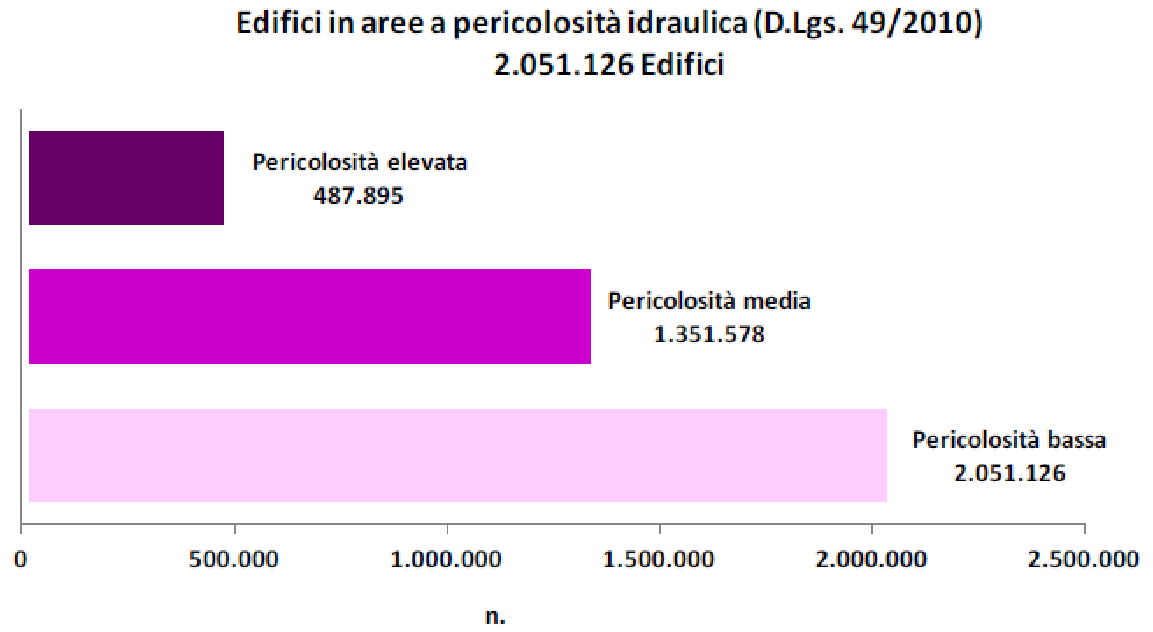
The population exposed has increased by more than 30%

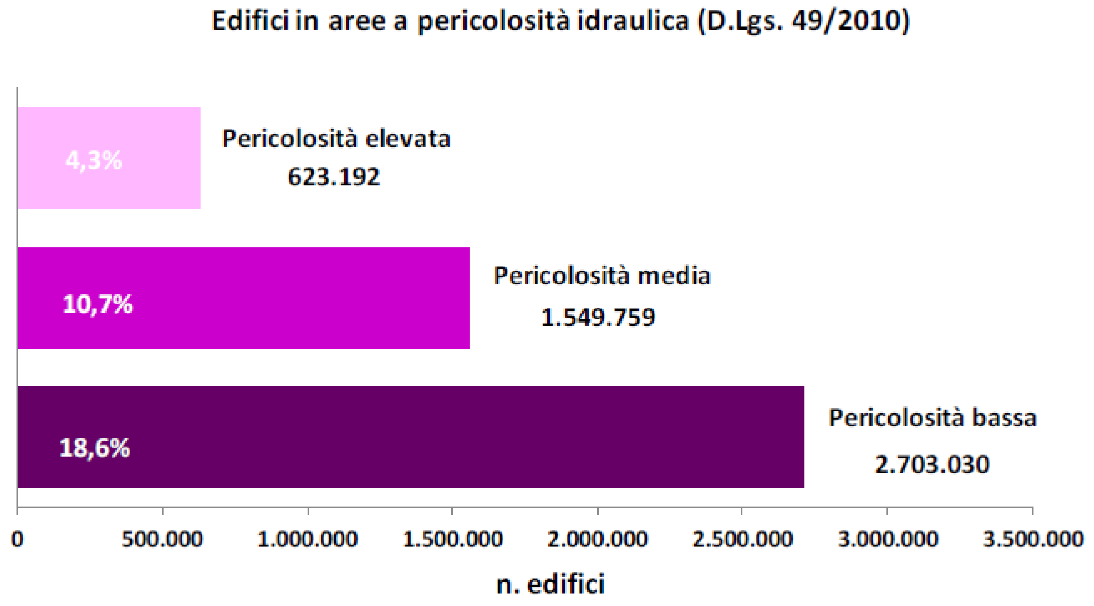



**ISPRA 2018**




**ISPRA 2021**




2018: About **2 million** buildings exposed to flood hazard.

2021: About **2.7 million** buildings exposed to flood hazard.

Comparing the 2021 and the 2018 Flood Hazard Maps:

- Increase of 1.3% in surface area with high flood hazard P3,
- Increase of 1.6% in surface area with average flood hazard P2,
- Increase of 3.1% in surface area with low flood hazard P1

*«The increase is mainly linked to an improvement of the knowledge framework carried out by the Hydrographic District Authorities with more detailed studies and mapping of new landslide phenomena or recent flood events».*

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# Risk assessment

**DIRECTIVE 2007/60/EC**

**Article 6 - FLOOD HAZARD MAPS AND FLOOD RISK MAPS**

3. Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

(a) floods with a low probability, or extreme event scenarios;

(b) floods with a medium probability (likely return period ≥ 100 years);

(c) floods with a high probability, where appropriate.

***Italy - D. Lgs. 49/2010***

**Article 6 - FLOOD HAZARD MAPS AND FLOOD RISK MAPS**

2. Flood hazard maps define (highlighting areas where high *volume sediment transport* and *debris flows* may occur) the perimeter of geographical areas that could be affected by floods according to the following scenarios:

a) extremely rare and intense floods: return period up to 500 years (low probability);

b) rare floods: return period between 100 e 200 years (medium probability);

c) frequent floods: return period between 20 and 50 years (high probability).

# HYDRAULIC HAZARD

**Article 6 - FLOOD HAZARD MAPS AND FLOOD RISK MAPS:**

***3.*** Flood hazard maps shall cover the geographical areas which could be flooded according to the following scenarios:

*(a) floods with a low probability, or extreme event scenarios;*
*(b) floods with a medium probability (likely return period ≥ 100 years);*
*(c) floods with a high probability, where appropriate.*

**4.** For each scenario referred to in paragraph 3 the following elements shall be shown**:**

*(a) the flood extent;*
*(b) water depths or water level, as appropriate;*
*(c) where appropriate, the flow velocity or the relevant water flow.*

The level of **HYDRAULIC HAZARD** must be defined according to two parameters:

- **PROBABILISTIC PARAMETER** → **RETURN PERIOD T:** also known as a *recurrence interval*, average time interval between two extreme events;
- **HYDRODYNAMIC PARAMETER** → **HAZARD INDEX $I_p$:** depends on the hydraulic parameters (flow depth *h*, velocity *v* and discharge *Q*) of the flow.

**The current legislation does not define/provide criteria for the formulation of the HAZARD INDEX!**

# Hydraulic Hazard Mapping
# 1-D or 2-D Models?

The current Legislation does not establish the most appropriate method/model to characterize the hazard and the hydrogeological risk; indeed unexpectedly, it leaves to the River Authorities a wide freedom of decision, just prescribing the objectives to be achieved through the application of hydraulic models and analysis.

**WARNING!!!**




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# … what is *HYDRAULICALLY* hazardous?




# HAZARD INDEX $I_p$

The hazard index $I_p$ shall be expressed by means of hydraulic parameters which account for the main hydrodynamic characteristics of the flow determining the hazard.

Since the mid-1970s, the water science community (e.g. Foster & Cox, 1973; Gordon & Stone, 1973; Abt et al., 1989; Keller & Mitsch, 1992 e 1993; Xia et al., 2009 e 2010 …) has investigated, albeit in a non-systematic way, **CRITERIA FOR THE STABILITY OF PEDESTRIANS, CARS AND STRUCTURES IN FLOOD AREAS**.

**The hydrodynamic Hazard Index can be thus related to the velocity *v* and the water depth *h*.** Then, it is possible to refer to the **flow momentum**:

$$I_p = v \cdot h$$

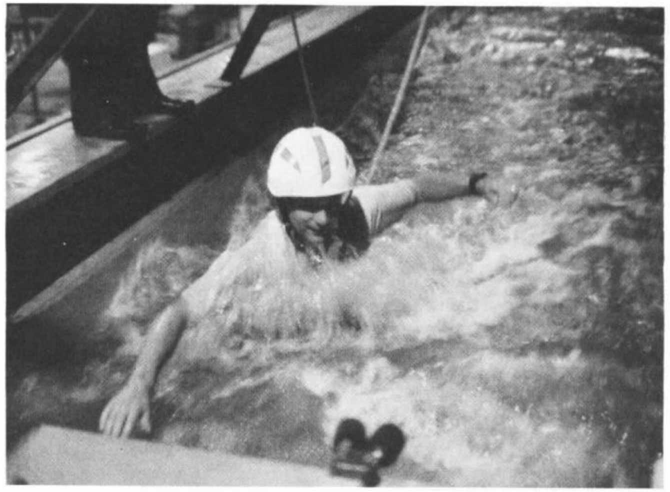
# FLOOD HAZARD

The main risk factor in an flooded urban environment is the loss of a human stability.

VOL. 25, NO. 4 WATER RESOURCES BULLETIN
AMERICAN WATER RESOURCES ASSOCIATION AUGUST 1989

**HUMAN STABILITY IN A HIGH FLOOD HAZARD ZONE[1]**

*S.R. Abt, R.J. Wittler, A. Taylor, and D.J. Love[2]*



Testing carried out on 20 individuals (18 men and 2 women), age ranging from 19 to 54 years, whose weight and height varied between 41 and 91 Kg, and between 152 e 183 cm, respectively.

**All individuals were in excellent health**.

**Limitations:**

- People *psychologically prepared* for the event (in subsequent trials they developed training)
- *The testers were safe*, unrealistic conditions (equipped with safety harness)
- *No child or senior* used as tester…
- Ideal conditions (no accessory weight, no impact of objects dragged by the current, etc.)
- *Good light exposure* during tests
- The ambient and water *temperature* was quite comfortable (20-25° C)
- …..



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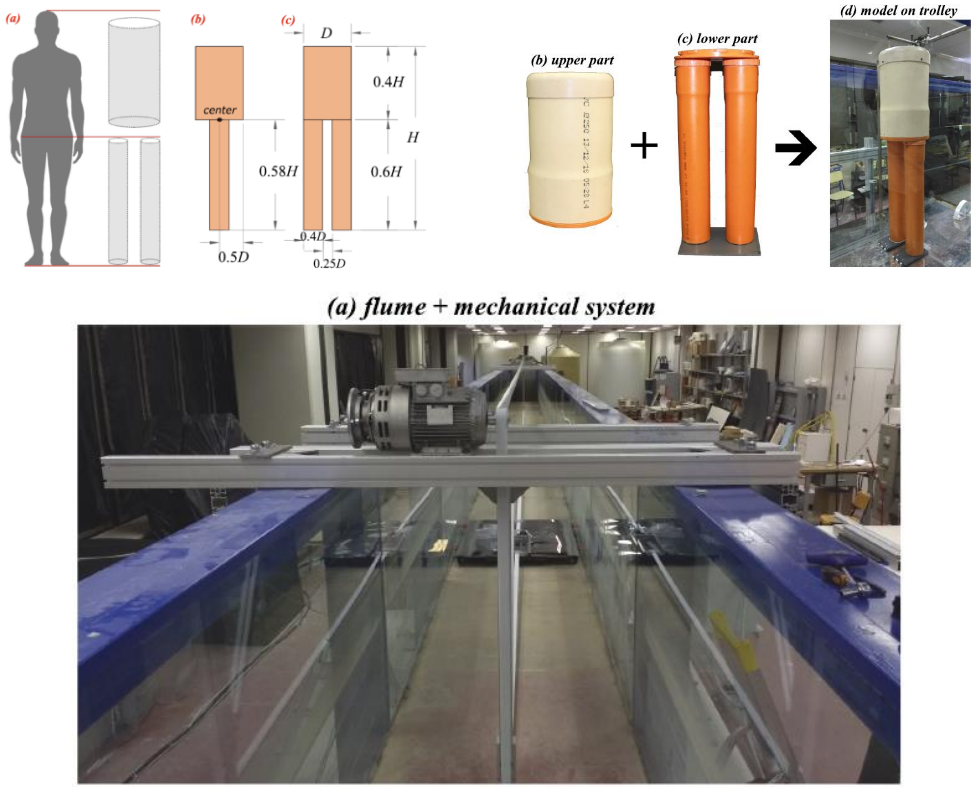
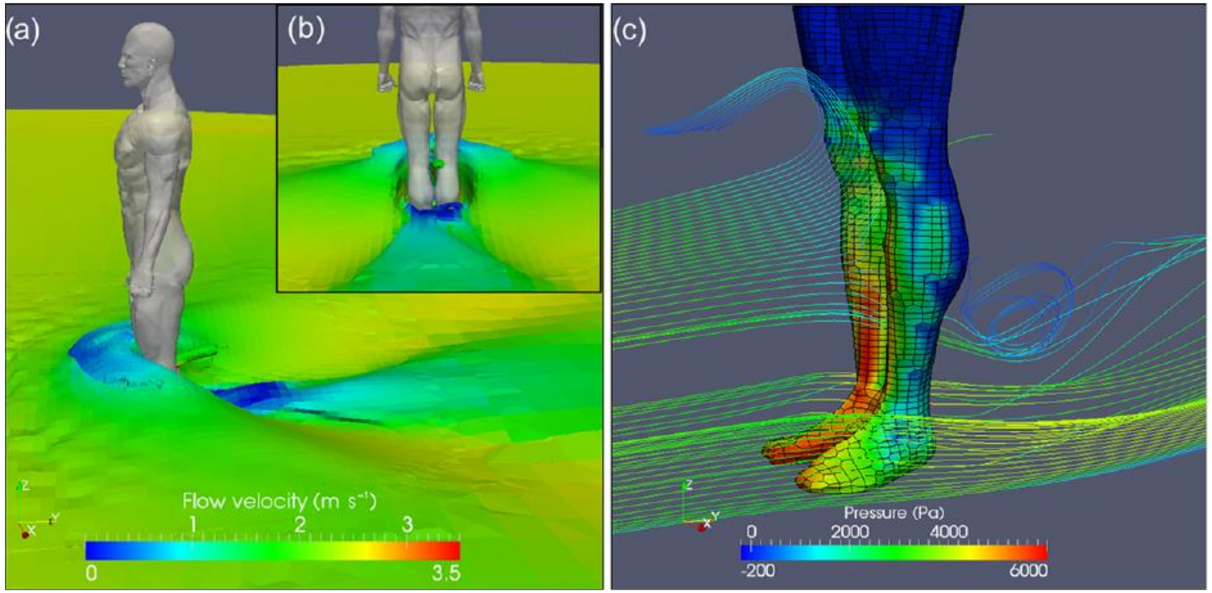
# FLOOD HAZARD




M. Postacchini et al. *Human stability during floods: Experimental tests on a physical model simulating human body*. Safety Science, Volume 137, 2021.




C. Arrighi et al.: Hydrodynamics of pedestrians' instability in floodwaters. *Hydrol. Earth Syst. Sci., 21, 515–531*, 2017.

# HAZARD INDEX $I_p$

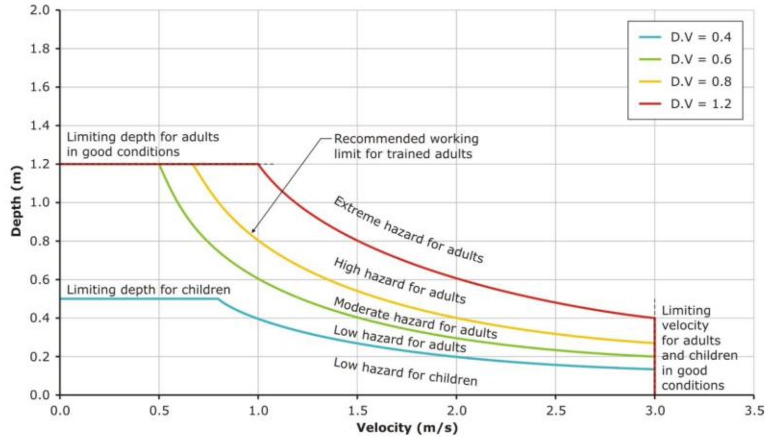
The scientific literature presents numerous references dedicated to the **loss of stability in pedestrians** impacted by a flood wave in an urban environment.

However, the results are not always in good agreement since the variables involved are numerous (age, size, etc.), but generally, it is possible to identify the following **limit conditions**:

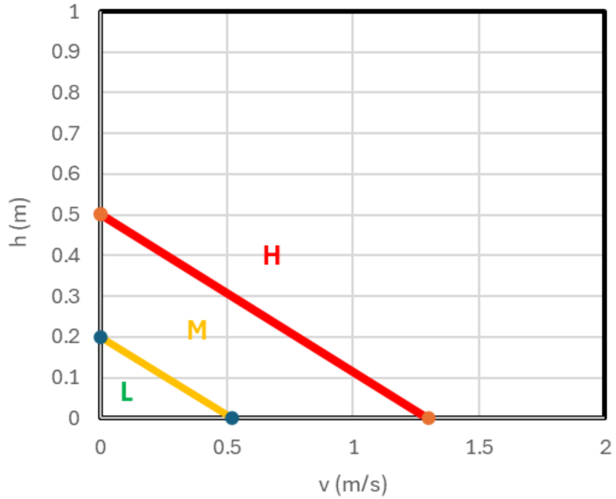
$$h_{MAX} = 0,5 \div 1,2 \text{ m}$$

$$v_{MAX} = 1,5 \div 2 \text{ m/s}$$

$$(v \cdot h)_{MAX} = 0,5 \div 1,0 \text{ m}^2\text{/s}$$




Smith GP, Davey EK, Cox RJ, (2014). *Flood Hazard*, WRL Technical Report 2014/07, UNSW Water Research Laboratory.




**HAZARD**

**Low**: $(h + 0.385 \cdot v) < 0.2$

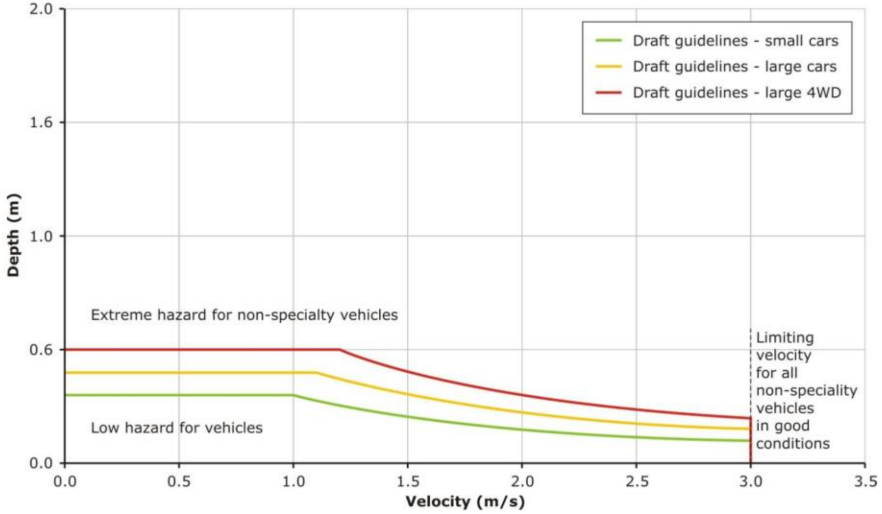
**Medium**: $0.2 \leq (h + 0.385 \cdot v) < 0.5$

**High**: $(h + 0.385 \cdot v) \geq 0.5$

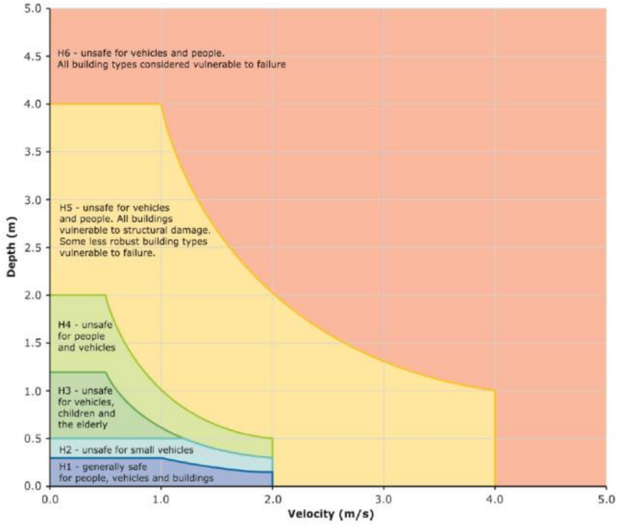
# HAZARD INDEX $I_p$

The hydraulic risk factors must include the **condition of car stability** loss during an alluvial event.

Draguignan, Francia sud-orientale, 2010




Smith GP, Davey EK, Cox RJ, (2014). *Flood Hazard*, WRL Technical Report 2014/07, UNSW Water Research Laboratory




G P Smith, B D Modra, T A Tucker and R J Cox (2017). *Vehicle Stability Testing for Flood Flows*. UNSW Australia Water Research Laboratory Technical Report

Flooded cars in the Toowoomba (Queensland, Australia) floods of January 2010

# HAZARD INDEX $I_p$ → HYDRAULIC HAZARD

Based on a literature review, corroborated by a wise dose of "*good judgment*", it is possible to define **3 classes for the Hazard Index $I_p$**:

- **$I_{p1}$ – Moderate Hazard Index:** $0.10 < h < 0.50$ m *AND* $0.10 \le v \cdot h < 0.50$ m²/s
- **$I_{p2}$ – Medium Hazard Index:** $0.50 \le h < 1.00$ m *OR* $0.50 \le v \cdot h < 1.00$ m²/s
- **$I_{p3}$ – Large Hazard Index:** $h \ge 1.00$ m *OR* $v \cdot h \ge 1.00$ m²/s

**4 classes of Flood Hazard**

**H4: Very high; H3: high; H2: average; H1: moderate**

*Qualitative Hazard Matrix*: combination of Return Period (probabilistic factor) and Hazard Index (hydrodynamic factor).

*Two possible approaches*.

"Prudential" ASSUMPTIONS

| *T* | *HAZARD INDEX* | | |
|---|---|---|---|
| | $I_{p1}$ | $I_{p2}$ | $I_{p3}$ |
| 20≤ T ≤50 | H3 | H4 | H4 |
| 100≤ T ≤200 | H2 | H3 | H4 |
| 200< T ≤500 | H1 | H2 | H3 |

?

"NON prudential" ASSUMPTIONS

| *T* | *HAZARD INDEX* | | |
|---|---|---|---|
| | $I_{p1}$ | $I_{p2}$ | $I_{p3}$ |
| 20≤ T ≤50 | H2 | H3 | H4 |
| 100≤ T ≤200 | H1 | H2 | H4 |
| 200< T ≤500 | H1 | H2 | H3 |

# From flood HAZARD to flood RISK…

1. Preliminary Flood Risk Assessment
2. Areas of potentially significant flood risk (APSFR)
3. Flood hazard maps
4. Flood risk maps
5. Flood risk management plan (FRMP)

“Prudential” ASSUMPTIONS VS “NON prudential” ASSUMPTIONS

**“Prudential” ASSUMPTIONS**

| *T* | *HAZARD INDEX* | | |
|---|---|---|---|
| | $I_{p1}$ | $I_{p2}$ | $I_{p3}$ |
| 20≤ T ≤50 | H3 | H4 | H4 |
| 100≤ T ≤200 | H2 | H3 | H4 |
| 200< T ≤500 | H1 | H2 | H3 |

| *RISK CLASS* | | *HAZARD CLASS* | | | |
|---|---|---|---|---|---|
| | | H4 | H3 | H2 | H1 |
| *DAMAGE CLASS* | D4 | R4 | R4 | R3 | R2 |
| | D3 | R4 | R3 | R3 | R2 |
| | D2 | R3 | R2 | R2 | R1 |
| | D1 | R2 | R1 | R1 | R1 |

***D=E x V***

**“NON prudential” ASSUMPTIONS**

| *T* | *HAZARD INDEX* | | |
|---|---|---|---|
| | $I_{p1}$ | $I_{p2}$ | $I_{p3}$ |
| 20≤ T ≤50 | H2 | H3 | H4 |
| 100≤ T ≤200 | H1 | H2 | H4 |
| 200< T ≤500 | H1 | H2 | H3 |

| *RISK CLASS* | | *HAZARD CLASS* | | | |
|---|---|---|---|---|---|
| | | H4 | H3 | H2 | H1 |
| *DAMAGE CLASS* | D4 | R4 | R3 | R2 | R1 |
| | D3 | R3 | R2 | R2 | R1 |
| | D2 | R2 | R2 | R1 | R1 |
| | D1 | R1 | R1 | R1 | R1 |

**D.P.C.M. 29.9.1998**

**Moderate R1**: social, economic and environmental damage are marginal;

**Average R2**: possible minor damage to buildings, infrastructure and environmental assets, but without jeopardizing the safety of staff...;

**High R3** : possible problems for the safety of people, functional damage to buildings and infrastructure…;

**Very High R4**: loss of life and serious injury to persons, major damage to buildings, infrastructure and…



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# Form flood HAZARD to flood RISK…

## UMBRIA Region

| | P3 | P2 | P1 |
|---|---|---|---|
| D4 | R4 | R3 | R2 |
| D3 | R3 | R3 | R1 |
| D2 | R2 | R2 | R1 |
| D1 | R1 | R1 | R1 |

## CALABRIA Region

| CLASSI DI RISCHIO | | CLASSI DI PERICO | |
|---|---|---|---|
| | | P3 | P2 |
| CLASSI DI DANNO | D4 | R4 | R4 |
| | D3 | R4 | R3 |
| | D2 | R3 | R2 |
| | D1 | R2 | R1 |

## LOMBARDIA – RB PO River

| CLASSI DI RISCHIO | | CLASSI DI PERICOLOSITA' | | |
|---|---|---|---|---|
| | | P3 | P2 | P1 |
| CLASSI DI DANNO | D4 | R4 | R4 | R2 |
| | D3 | R4 | R3 | R2 |
| | D2 | R3 | R2 | R1 |
| | D1 | R1 | R1 | R1 |

| Risk Assessment Matrix | | Level of exposure and vulnerability | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Moderate | Low | Very low |
| Level of hazard | Very high | Severe | Severe | Significant | Significant | Moderate |
| | High | Severe | Significant | Moderate | Moderate | Minor |
| | Moderate | Significant | Moderate | Moderate | Moderate | Minor |
| | Low | Significant | Moderate | Moderate | Minor | Negligible |
| | Very low | Moderate | Minor | Minor | Negligible | Negligible |

Table 6.1: Example qualitative risk matrix

| Likelihod of consequence | AEP range (%) | Level of consequence: Insignificant | Minor | Moderate | Major | Catastrophic |
|---|---|---|---|---|---|---|
| Likely | >10 | | | | | |
| Unlikely | 1 to 10 | | | | | |
| Rare to very rare | 0.01 to 1 | | | | | |
| Extremely rare | <0.01 | | | | | |

Risk: Very low Low Medium High Extreme

AEP = annual exceedance probability

| Flood Risk [1] | | Flood Vulnerability | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| Flood Hazard | 1 | 1 | 1 | 2 | 3 | 4 | 4 |
| | 2 | 1 | 2 | 3 | 3 | 4 | 4 |
| | 3 | 2 | 2 | 3 | 3 | 4 | 5 |
| | 4 | 2 | 3 | 3 | 4 | 5 | 5 |
| | 5 | 3 | 3 | 4 | 4 | 5 | 6 |
| | 6 | 3 | 4 | 4 | 5 | 6 | 6 |

# Form flood HAZARD to flood RISK…

"Prudential" ASSUMPTIONS VS "NON prudential" ASSUMPTIONS

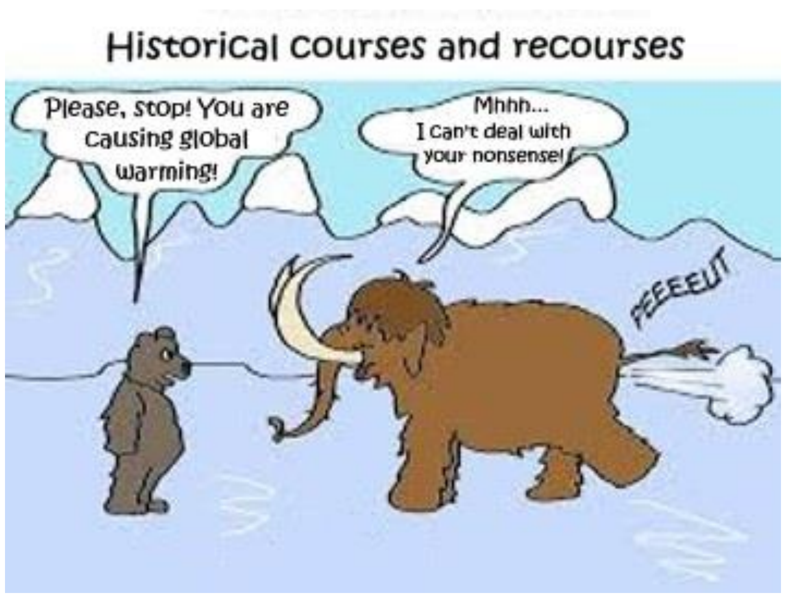

# Table of contents



# Open issues

- **<u>Climate change</u>**

  **DIRECTIVE 2007/60/EC- Article 14 -** Reviews
  *4. The likely **impact of climate change** on the occurrence of floods shall be taken into account in the reviews referred to in paragraphs 1 and 3.*

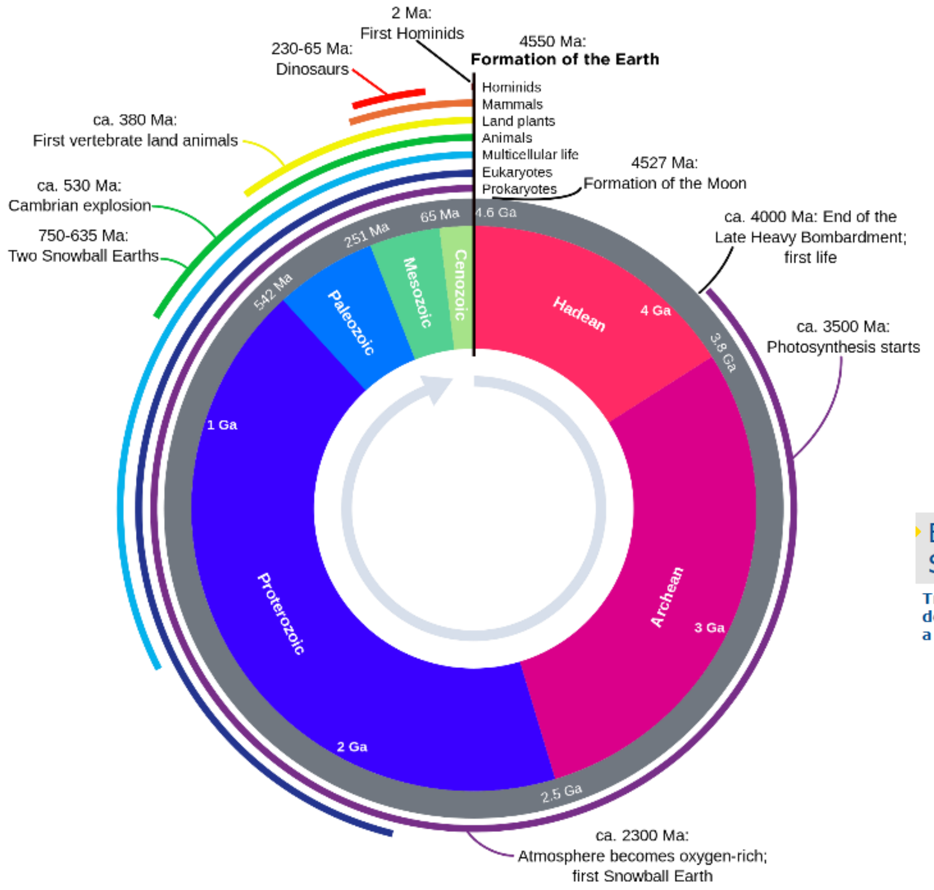



- **<u>Pluvial floods from the Urban Drainage Networks (UDNs)</u>**

  **DIRECTIVE 2007/60/EC- Article 2 -** Definition
  *1. 'flood' means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and **may exclude floods from sewerage systems**.*

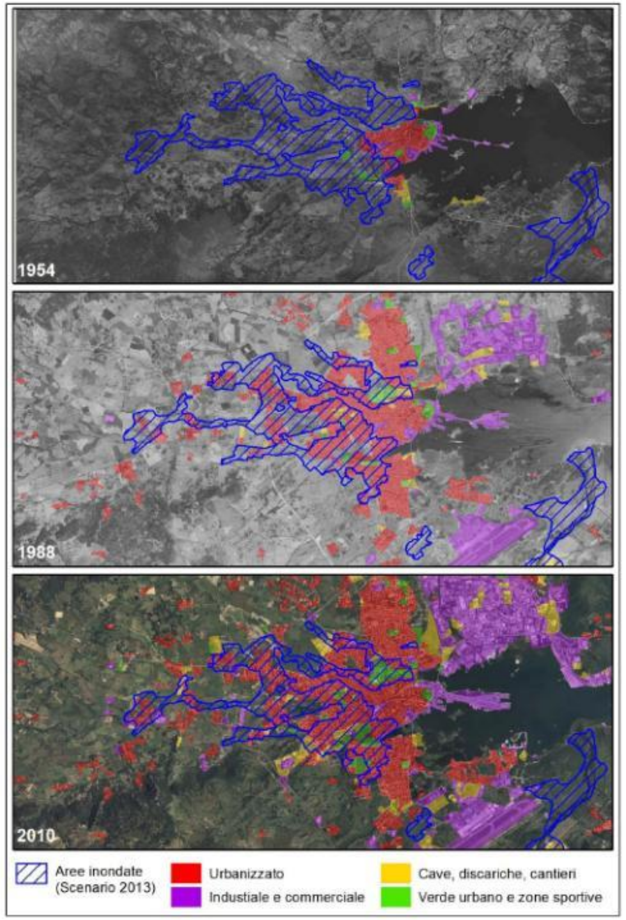
# Climate change… or … Climate evolution?

The analysis of a single set of N data with maximum annual peak flow, does not reasonably allow to predict values with a return period larger than 2·N (Benson, 1961; Committee on Techniques for Estimating Probabilities of Extreme Floods, 1988)

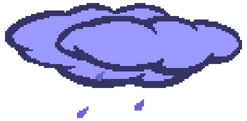




Geological time clock

# CLIMATE change?... HYDRLOGICAL change!!!




Increase of urbanized area, related to the flood event in 2013 in the city of Olbia (Sardinia, Italy).

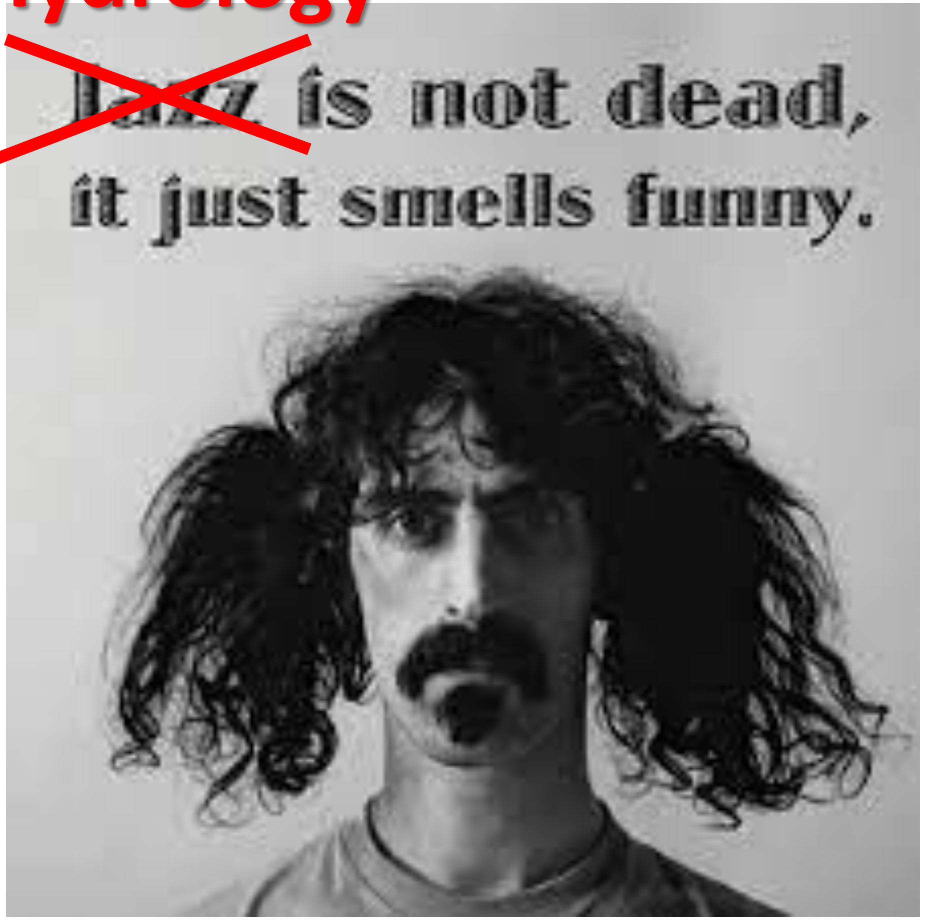


$$Q_T = \varphi \cdot i_{d,T} \cdot A$$

Il Sole 24 ORE

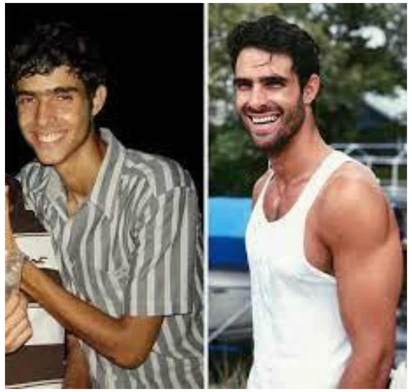
Soil consumption in Italy, only referred to 2021, was larger than 2 $m^2$ per second, about 70 $Km^2$ of new impervious surface...

Hydrology



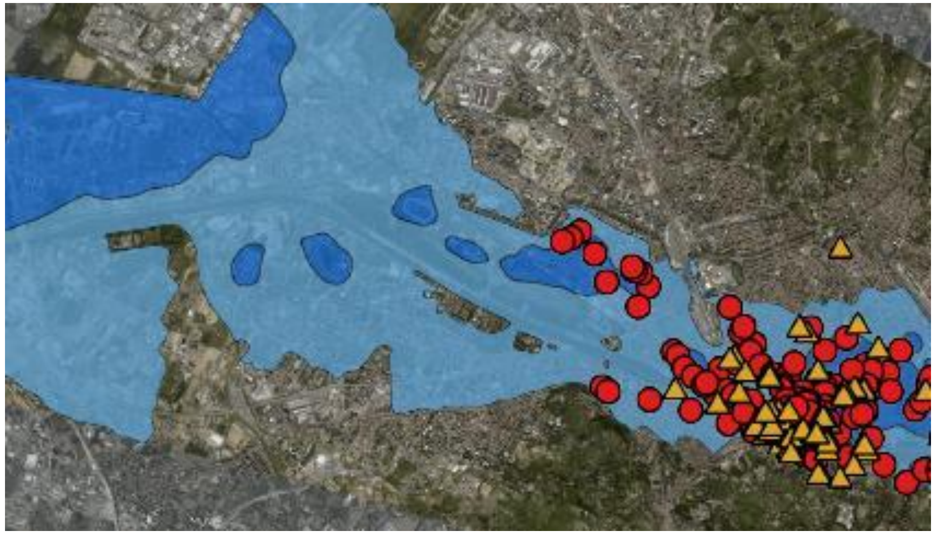

*Frank Vincent Zappa (1940 –1993)*



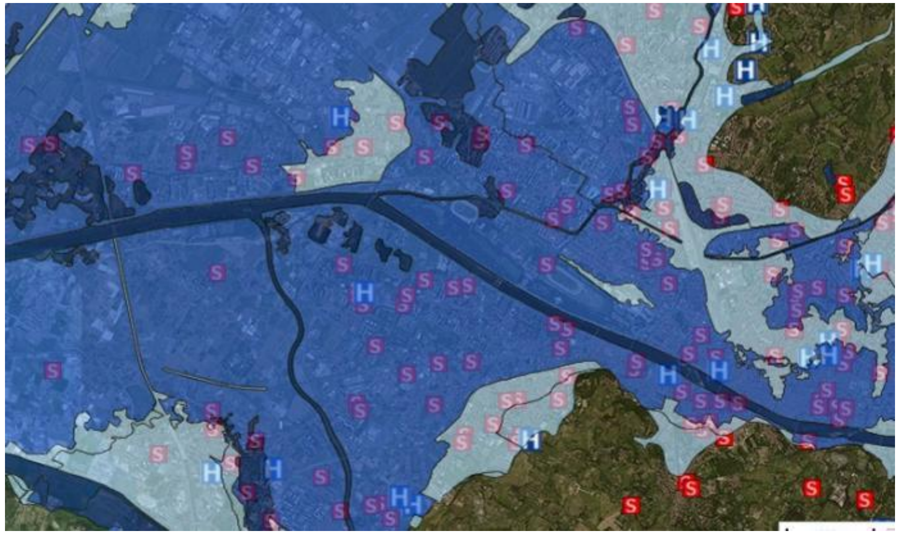


# #50Yearschallenge

Flooded areas in Florence
(November 4th, 1966)



Flood hazard map
(2025)



# Pluvial floods from UDNs

DIRECTIVE 2007/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 23 October 2007

on the assessment and management of flood risks

*Article 2*

For the purpose of this Directive, in addition to the definitions of 'river', 'river basin', 'sub-basin' and 'river basin district' as set out in Article 2 of Directive 2000/60/EC, the following definitions shall apply:

1. 'flood' means the temporary covering by water of land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems;

## D.Lgs. 49/2010

(with modifications introduces by the L. n. 97/2013)

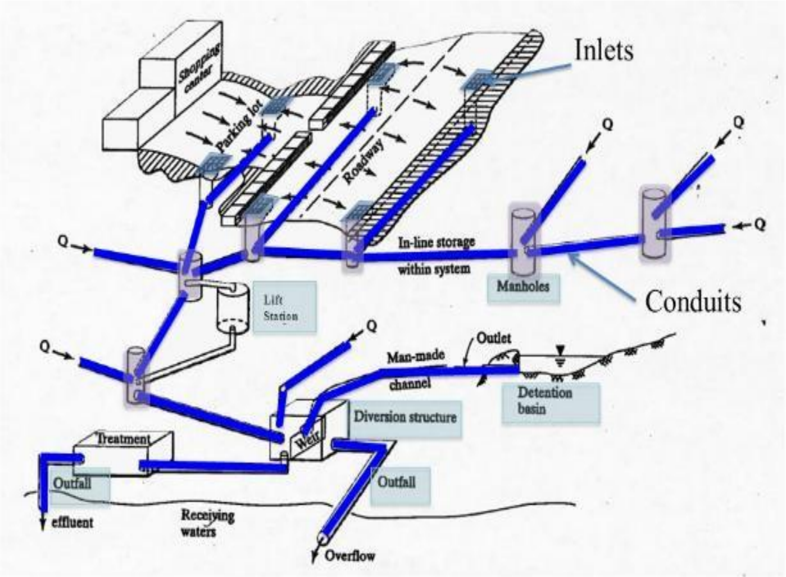
## Articolo 2 - Defintions

a) flood: Temporary flooding, also with transport or mobilization of sediment with large concentration, of land not normally covered by water. This shall include floods from *lakes*, rivers, mountain torrents, eventually artificial drainage networks, any other surface water body even if temporary, natural or artificial, and flood from sea in coastal areas, and **excludes floods** ~~*not directly provoked by weather events*~~ **provoked by sewer systems**;

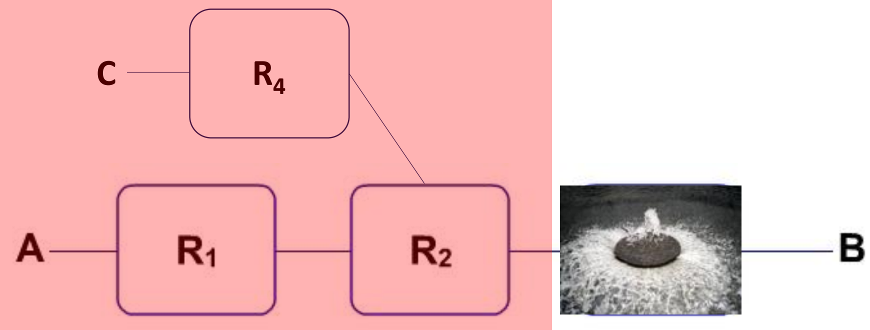
# Pluvial floods and Urban Drainage Networks

Laboratory and field investigations demonstrate that sewer systems efficiency may be affected by the inappropriate operation of singular structures, due to:

- *wrong hydraulic design*
- *construction defects*.




A sewer network is configured as a Chain System whose components are connected in Series: pipes, manholes, overflow structures, drop structures and pumping stations, etc..




**System failure is caused by the failure of a single component!**

# Pluvial floods from the Urban Drainage Networks

Urban Drainage Networks belong to the "***out of sight, out of mind***" *family*, until an unexpected rainy day occurs...

*Sewer geyser in uscita da un pozzetto lungo Wolfe Street, Montreal 18.07.2011*

*... the road swallowed a garbage truck... (Casalnuovo, Naples - August 10, 2011)*

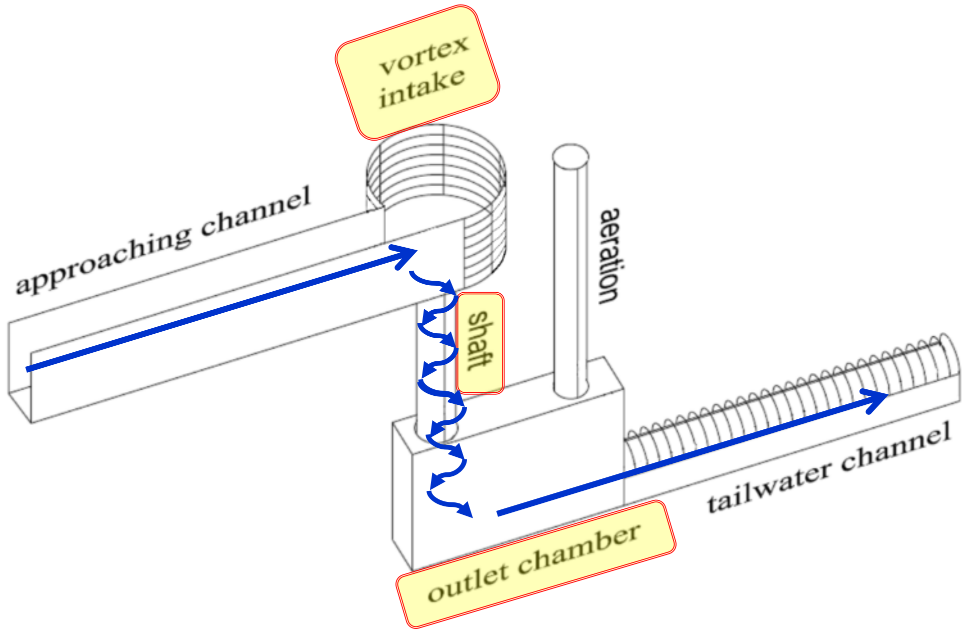
Mis-design?...

Climate change?...


# Vortex Dropshaft Scheme

The vortex shaft is essentially constituted by three elements:

1. **INTAKE STRUCTURE:**
   - Horizontal flow is transformed into helicoidal flow
   - The air flow through the **“vortex core”**
2. **VERTICAL SHAFT:**
   - Centrifugal force ensures that the flow adheres to the shaft walls
   - The air flow is preserved by the presence of the “vortex core”
3. **OUTLET STRUCTURE**
   - The flow is forced to return from vertical to horizontal direction
   - Control of flow patterns toward the tailwater channel
   - Enhancement of air detrainment

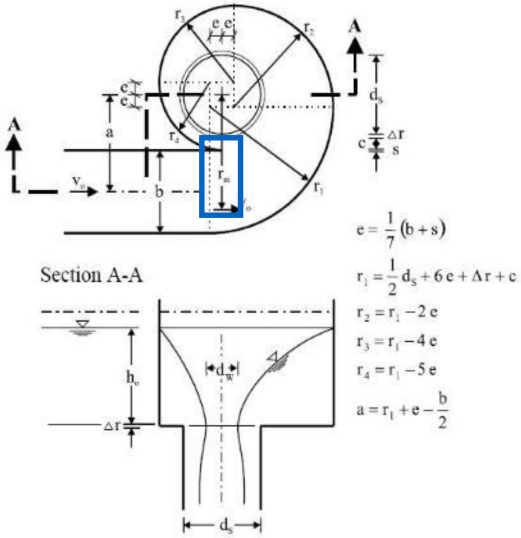


# Design criteria

The purpose of the **intake structure** is to guide the rectilinear approach flow toward a vertical shaft flow; the tangential intake must thus have an *adequate geometry*.

## *Subcritical* approach flow

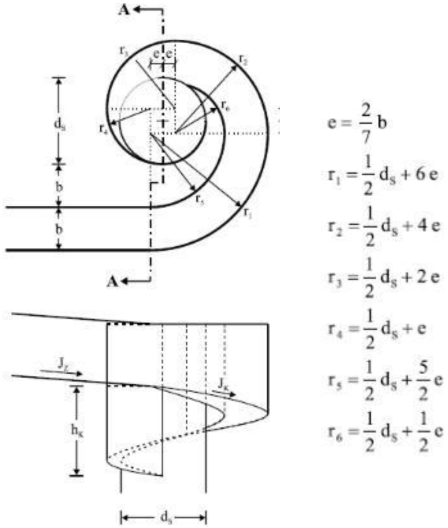
- ❑ Horizontal bottom of the vortex intake
- ❑ Smooth spiral flow at the shaft intake




Geometrical conditions to be respected:
$0.8 < D_s/a < 1$ , $a\text{-}b/2 > 0.65\ D_s$ , $\Delta R > D_s/6$ .

## *Supercritical* approach flow

- ❑ Steep helical ramp to direct the flow toward the vertical shaft
- ❑ Occurrence of shockwave at the outer wall of the intake structure



Geometrical conditions to be respected:
$0.4D_s \le b \le D_s$ $0.4D_s \le d \le D_s$

# Design criteria

***Subcritical* approach flow**

The maximum discharge $Q_M$ can be estimated as

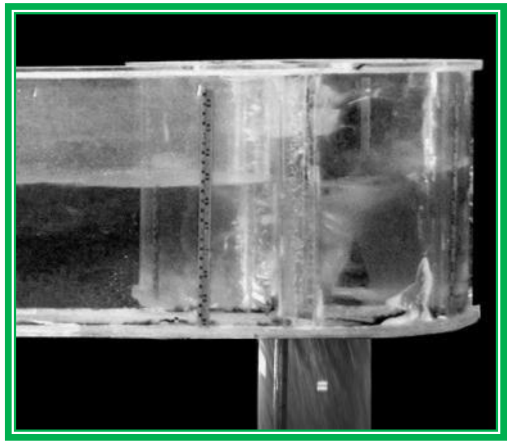
$$Q_M = (1/2)\, D_s^3 (5g/b)^{1/2}$$

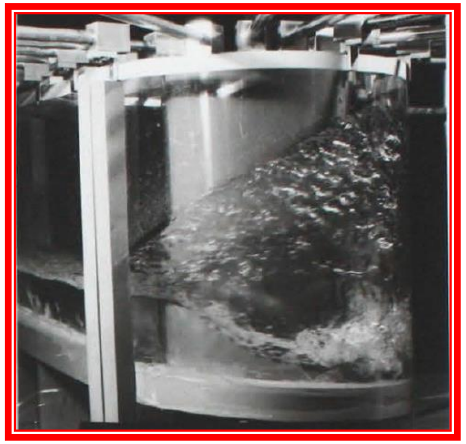
***Supercritical* approach flow**

The maximum discharge $Q_M$ can be estimated as

$$Q_M = [g\,(D_s/1.25)^5]^{1/2}$$

The shaft diameter $D_s$ can be calculated, once the design discharge is given (i.e. from hydrological models).





Vortex intake subcritical and supercritical approach flow

# Problems & Countermeasures

$Q > Q_M$ → dropshaft *choking*; possible structural damages

Insufficient ventilation →

# Vortex dropshafts in Naples (IT)

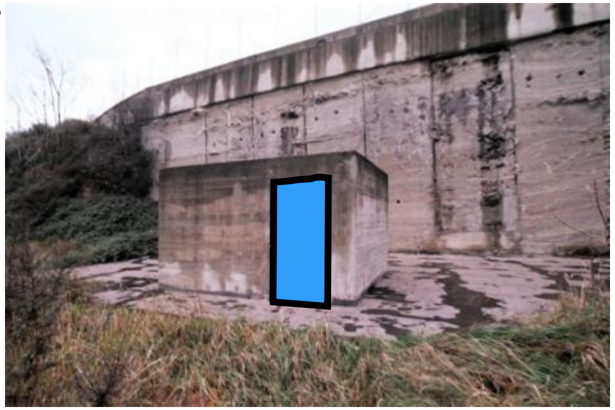
Due to the hilly context and the large elevation gaps within the city of Naples, the modern sewer system includes several vortex dropshafts, mostly designed during the 70’s and 80’s.


Digital Terrain Model (DTM) of the municipality of Naples

***The Pizza analogy***

# Choking effects

*<u>Naples (Italy),14-15.09.2001</u>*: **181** mm in *three* hours (**T>100 y**).



| Vortex shaft | D | $L_s$ | $Q_{max}$ | $F_o$ |
|---|---|---|---|---|
| | m | m | $m^3/s$ | |
| 1 | 2.5 | 27.80 | 18.00 | 1.27 |
| 2 | 2.5 | 27.80 | 18.00 | 1.27 |



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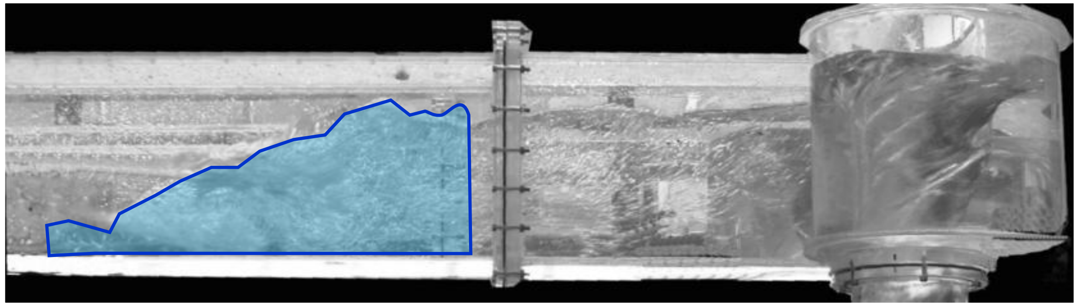
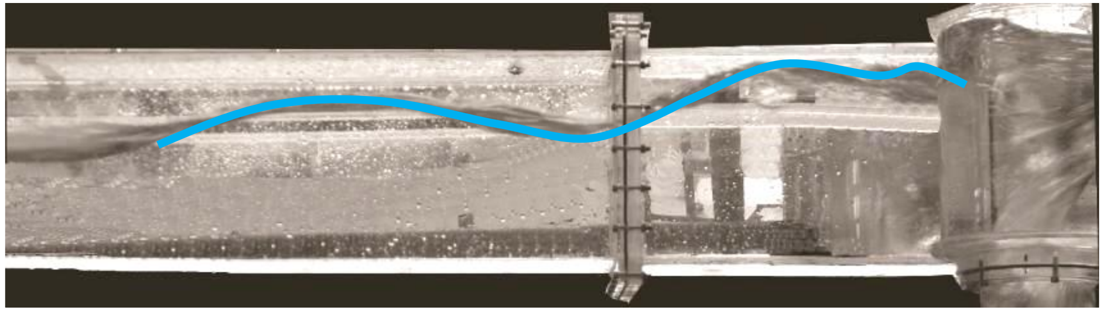
# Performance of subcritical intake for supercritical flow

- For low discharges a shock wave develops along the intake wall. The shock wave height increases with the discharge until a **hydraulic jump** occurs causing a transition from supercritical to subcritical flow upstream of the vortex intake



- The hydraulic jump causes free surface fluctuations, resulting in an irregular shaft operation with a possible **choking** of the air vortex core

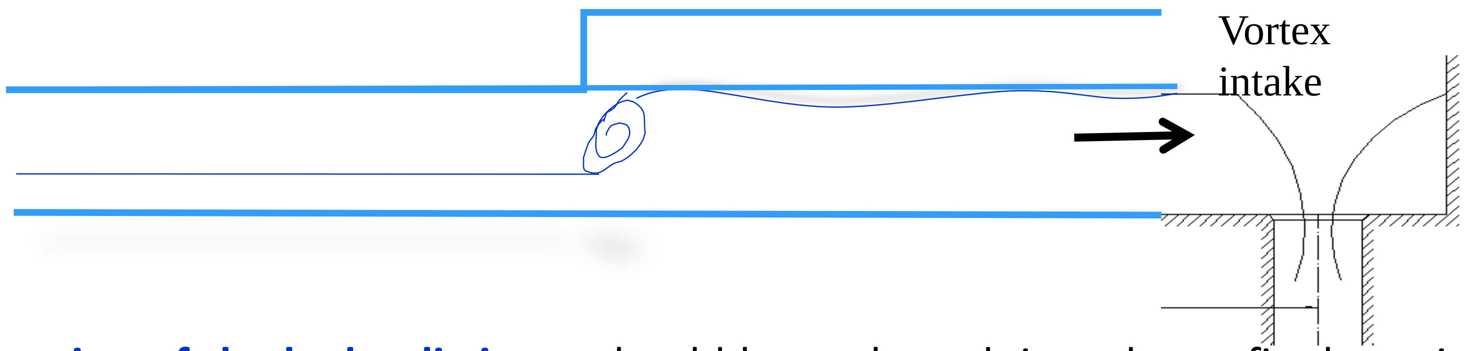


# Practical Issues

Can we adapt the subcritical intake for supercritical approach flow in order to reduce construction costs or to retrofit existing structures?

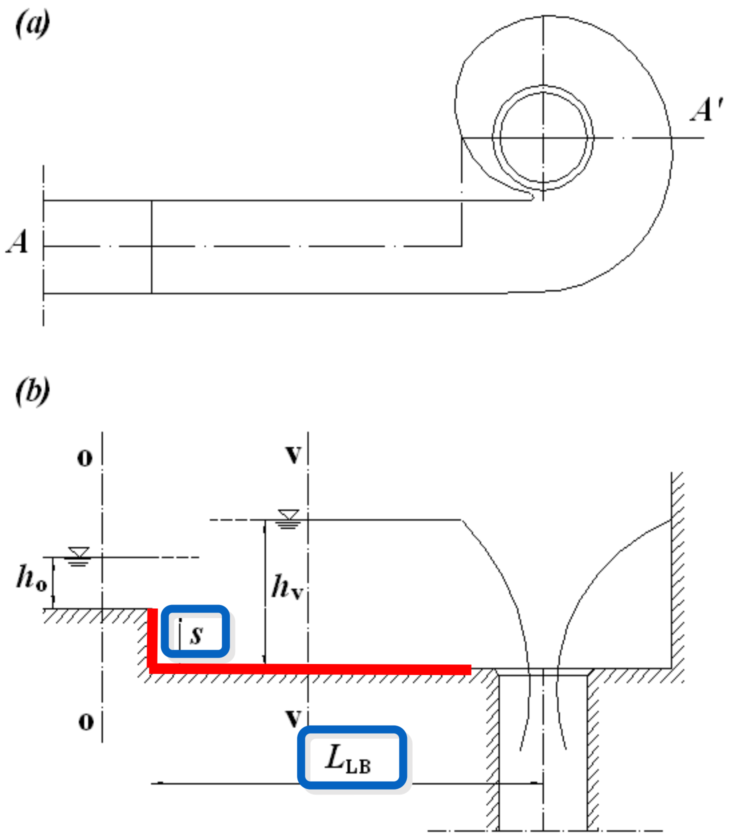
**Important shortcomings:**

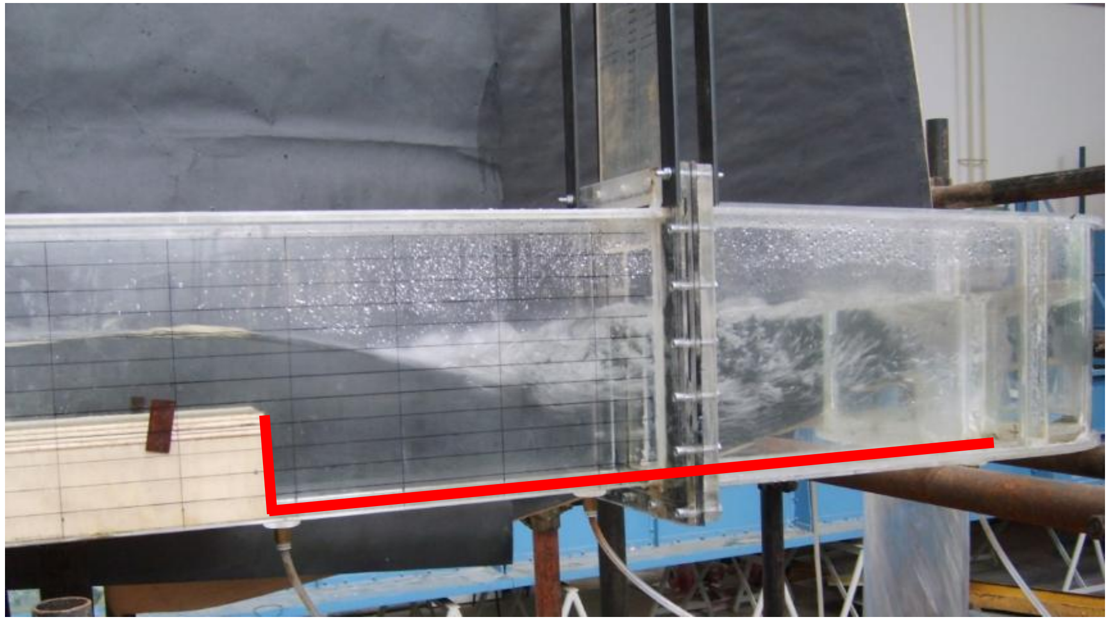
- **Hydraulic jump** along the approaching channel; consequently **the height of the approach channel could be increased** in order to prevent pressurized flow (often not feasible)

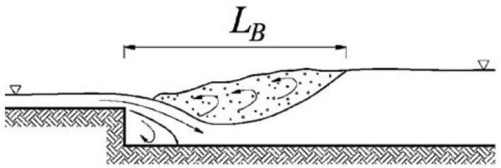



- the exact **location of the hydraulic jump** should be evaluated, in order to fix the point where the height of the approach channel has to be increased;
- the hydraulic jump may still cause **water depth fluctuations** that disturb the **intake structure**, with unfavorable effects in terms of irregular operation of the shaft (**choking**)

# Proposed solution





B-jump

- partial lowering of the bottom (***negative step***) along the approach channel, so that the hydraulic jump shall occur stably downstream of the step.
- the ***length*** of lower-bottomed channel shall be long enough as to prevent water depth fluctuations due to the effects of the macro-turbulence caused by the hydraulic jump.

Climate change?...


Mis-design!...

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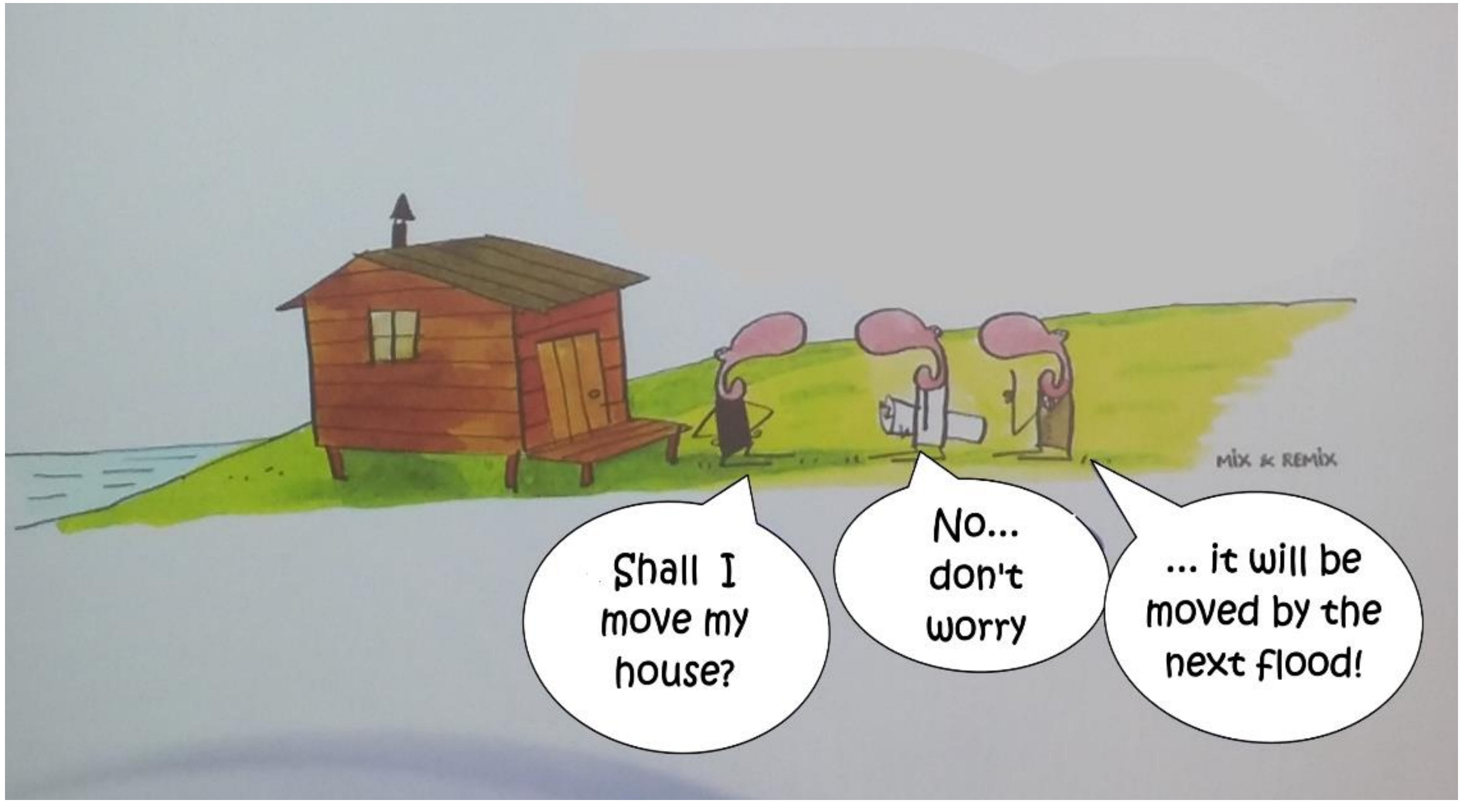
- Introduction
- The situation in Europe
- Risk assessment criteria
- Open issues
- Final comments



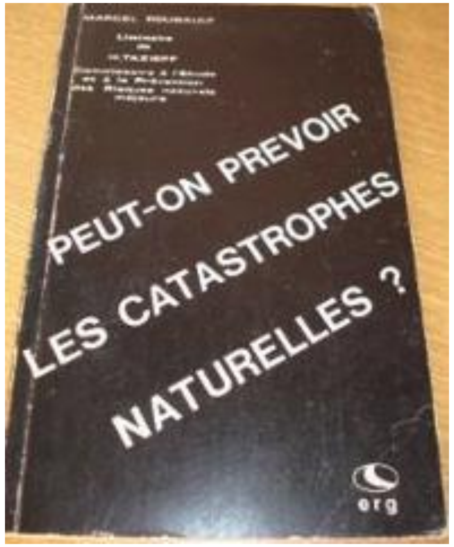
# Conclusions

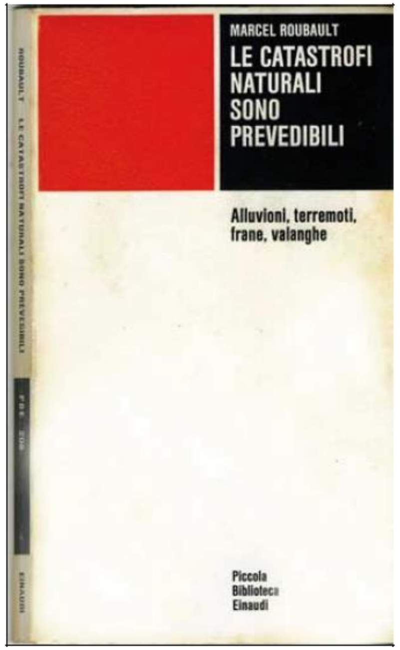
- Urban areas in EUROPE suffer from widespread **Flood Hazards**.
- The **involvement of all stakeholders** (population, institutions, competent authorities, etc.) is essential to mitigate the effects of these phenomena.
- The **EU Legislation** needs to provide more detailed and geographically homogeneous criteria for Flood Hazard / Risk assessment.
- The escalation of these phenomena is *probably* determined by the **climate evolution**, but it *certainly* depends on **anthropogenic factors** directly or indirectly linked to the use of land and water.
- The **climate issue** cannot be discussed as *stadium cheering*, but must be addressed in a reasoned and scientifically based way.

For decades, a recurring question has been put to researchers and scientists, whenever a calamitous event occurs:

## Is it possible to predict hydrogeological disasters?

Roubault M. (1970). *Peut-on prévoir les catastrophes naturelles?* Presses Universitaires de France, Paris.
The Italian translated title sounds very different: *Natural disasters are predictable.*




Even today, in most cases, **we cannot predict** natural/hydrogeological disasters, but we can certainly do MUCH MORE to **mitigate** their consequences, through **adaptation strategies** to the possible occurrence of extreme events!



Università degli Studi della Campania Luigi Vanvitelli

# Thank you for your attention!

...questions?


*Corrado Gisonni*
*corrado.gisonni@unicampania.it*