STRATEGIES FOR WATER
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Risk Assessment and Digitalization of Static Components at Hydro Plants: a Massive Application to Penstocks and Waterways

Luigi Papetti

STATIC COMPONENTS – THE UGLY DUCKLING OF HYDRO DIGITALIZATION

Definition: software and hardware to improve operation and maintenance of HPPs

1. What can we do when Big Data are not available?
2. Does anyone have a vague idea of what are the main causes of failure of a hydroelectric power plant?
3. Are failures due to problems with static components or problems with rotating ones prevailing?
4. Are there, or do we need, deterministic models to feed digital models of hydroelectric plants?
5. How far can we go with the digitalization of small fleets or single small hydroelectric plants?

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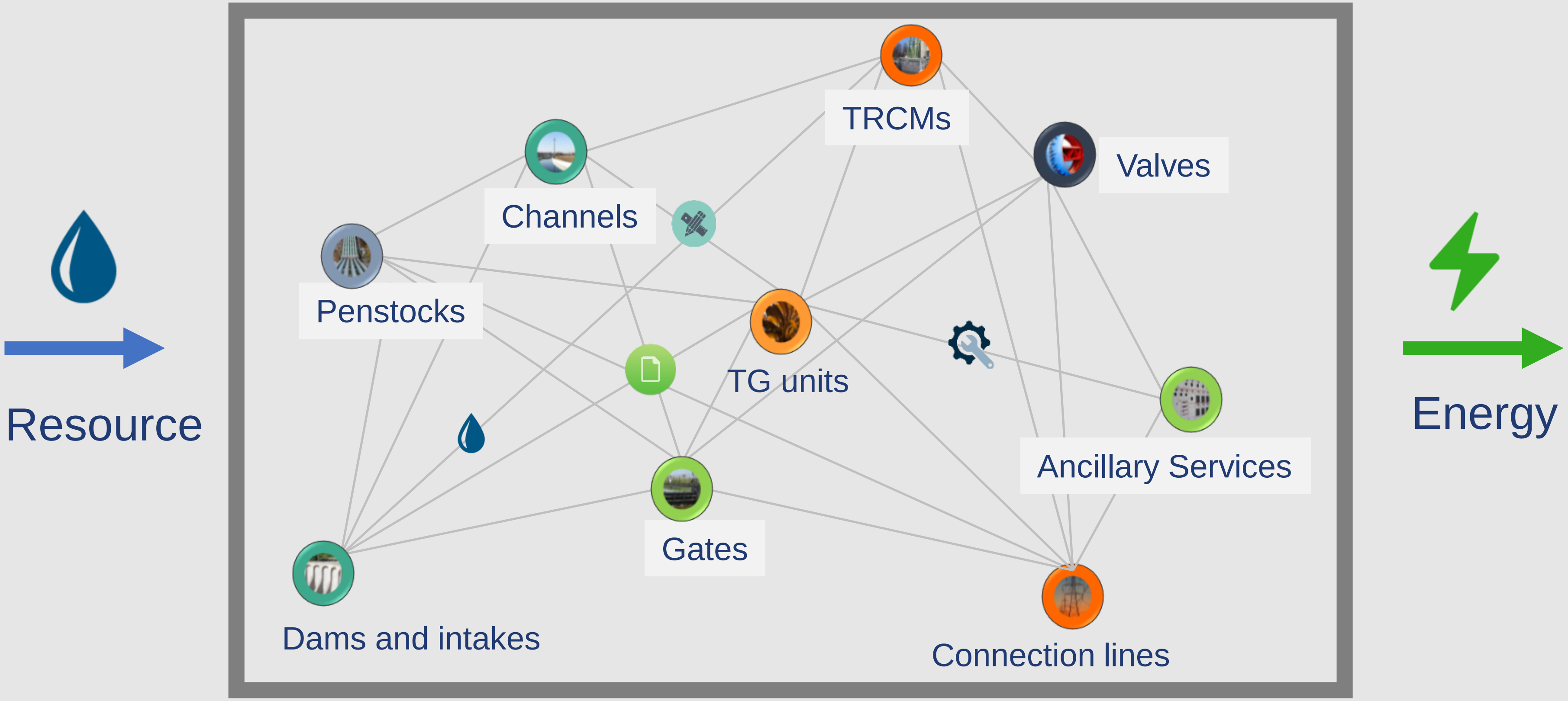
STATIC COMPONENTS – THE UGLY DUCKLING OF HYDRO DIGITALIZATION

Hydroelectric plant: a set of components functionally connected to transform the water resource into energy



STATIC COMPONENTS – THE UGLY DUCKLING OF HYDRO DIGITALIZATION

Old method

50% success

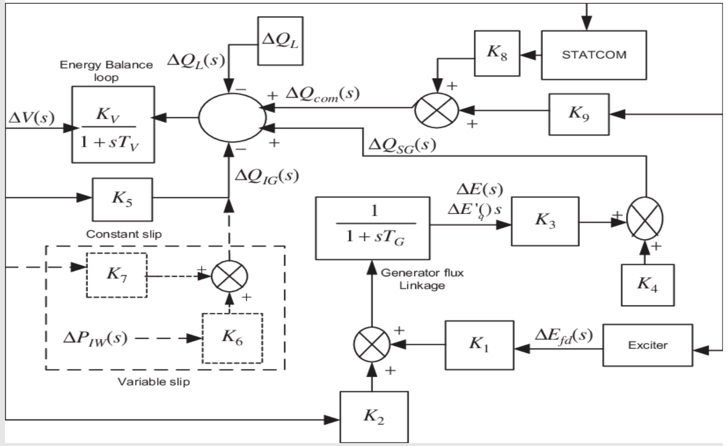
No control on rivets and penstock shell in 70 years

No need for complex systems: common sense is enough

New method

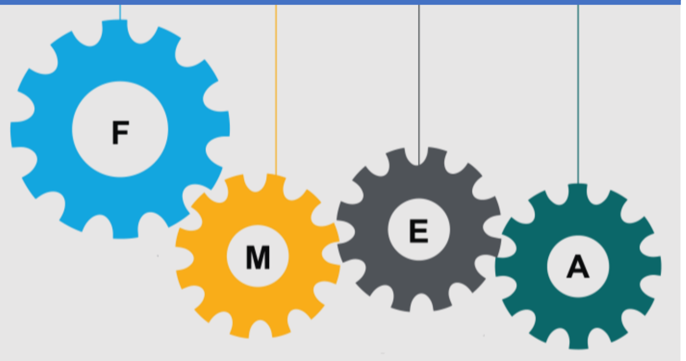
$$\frac{\partial u_i^+}{\partial t^+} + u_j^+ \frac{\partial u_i^+}{\partial x_j^+} + Re^{-1} = -\frac{\partial p^+}{\partial x_i^+} + Re^{-1}\frac{\partial^2 u_i^+}{\partial x_j^+ \partial x_j^+}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{N} \frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j} u(x_i, x_j) = \sum_{i=1}^{N}\left(\frac{\partial f}{\partial x_i}\right)^2 u^2(x_i) + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} \frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j} u(x_i, x_j)$$



50% failure

THE METHOD



- Identifies the ways in which a product can fail (failure modes)
- Estimates the risk associated to a specific cause
- Prioritize the failure mode (and actions)

Severity x **Occurrence** x **Detection** = **RPN**

RPN VALUE	RISK LEVEL	ACTIONS
up to12	Negligible	None
from 13 to 25	Low	To be considered on a case by case basis
from 26 to 50	Medium	Action aimed to reduce the risk
over 50	High	Urgent action aimed to reduce the risk

REAL CASES

October’19

17 PLANTS, 17 STRUCTURES:
- 17 penstocks

October’20

25 PLANTS, 58 STRUCTURES:
- 35 penstocks,
- 15 tunnels,
- 8 channels.

December’20

30 PLANTS, 130 STRUCTURES:
- 58 penstocks,
- 52 tunnels,
- 21 channels.





FAILURE MODES & CAUSES

PENSTOCKS

Failure mode	Cause
Pipe hole	Stray current
Partial failure	Human error
	Damage or pull-out of joint
	Failure of connections
	Failure of constraints
	Wear of constraints
	Failure of pipe shell
	Wear of pipe shell
Total failure	Impacts and other environmental factors
	Attacks and vandalism

TUNNELS

Failure mode	Cause
Partial failure	Instability and/or decay of the rock mass structural conditions
	Presence of active/inactive tectonic lines and seismology
	Critical hydrogeological conditions
	Absence or damage of the lining
	Failure of the watertight doors in the manholes
	Presence of irrigation valves
	Human error
Total failure	Slopes instability
	Critical sections
	Attacks and vandalism

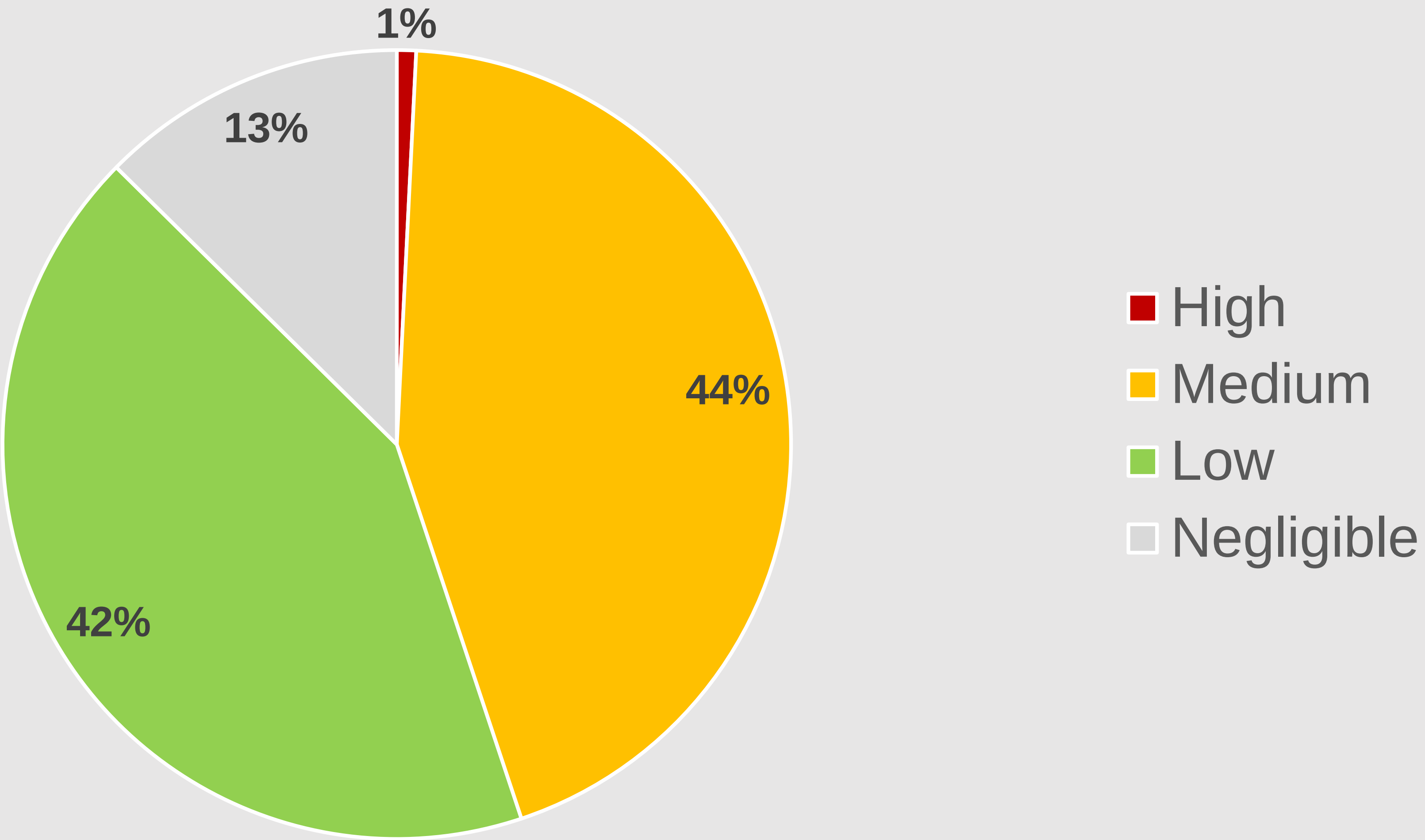
CHANNELS

Failure mode	Cause
Banks overflow	Flood hazard
	Unsuitable freeboard
Partial failure	Seismology
	Structural failure of the work
	Human error
Total failure	Slopes instability
	Attacks and vandalism

STATISTICAL ANALYSIS

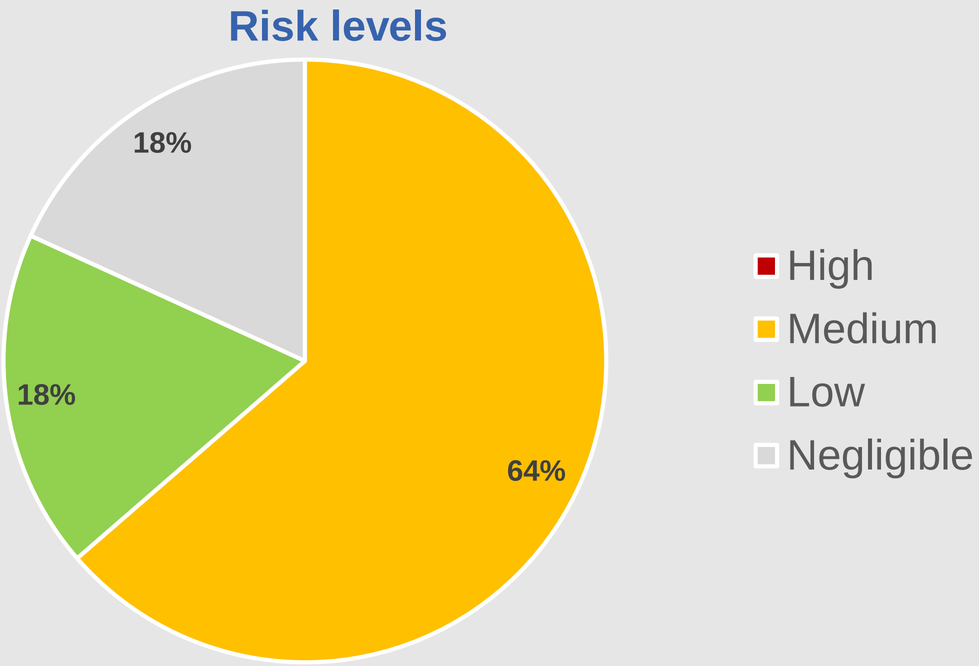
General Overview Penstocks Tunnels Channels

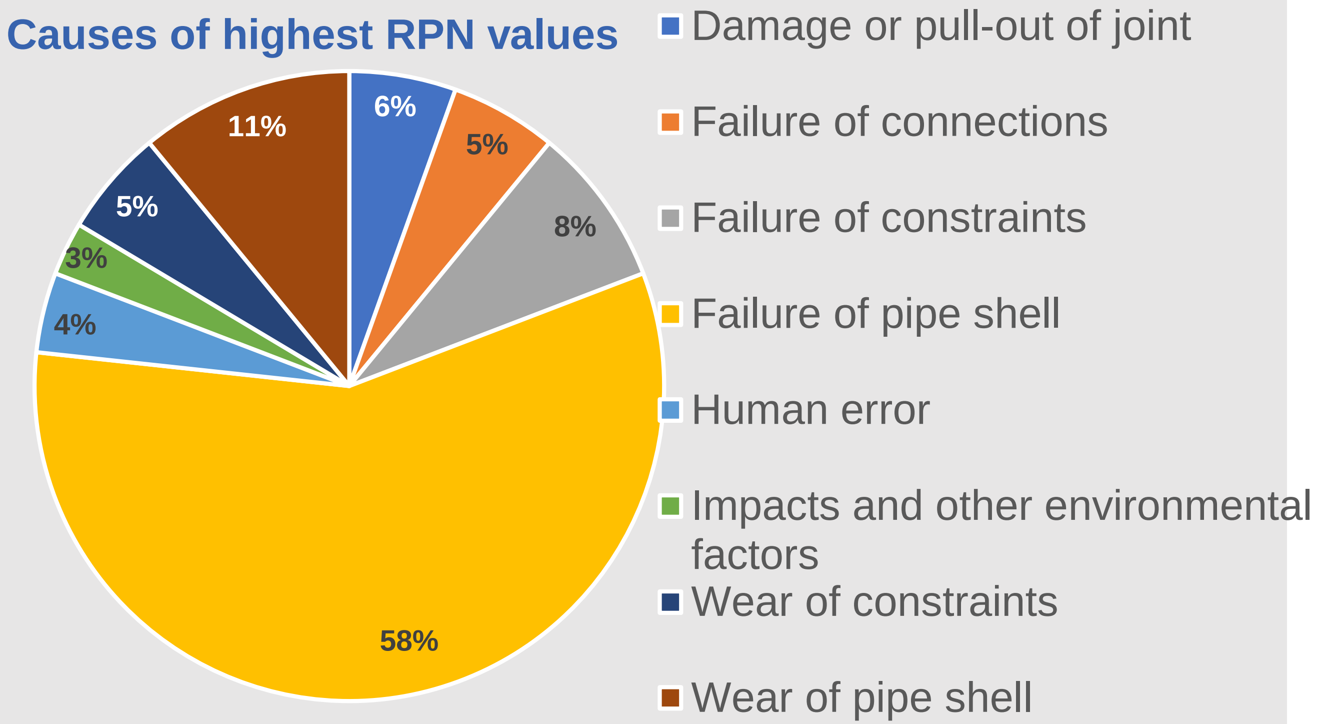
Global risk levels of all the assessed works



STATISTICAL ANALYSIS

General Overview | **Penstocks** | Tunnels | Channels



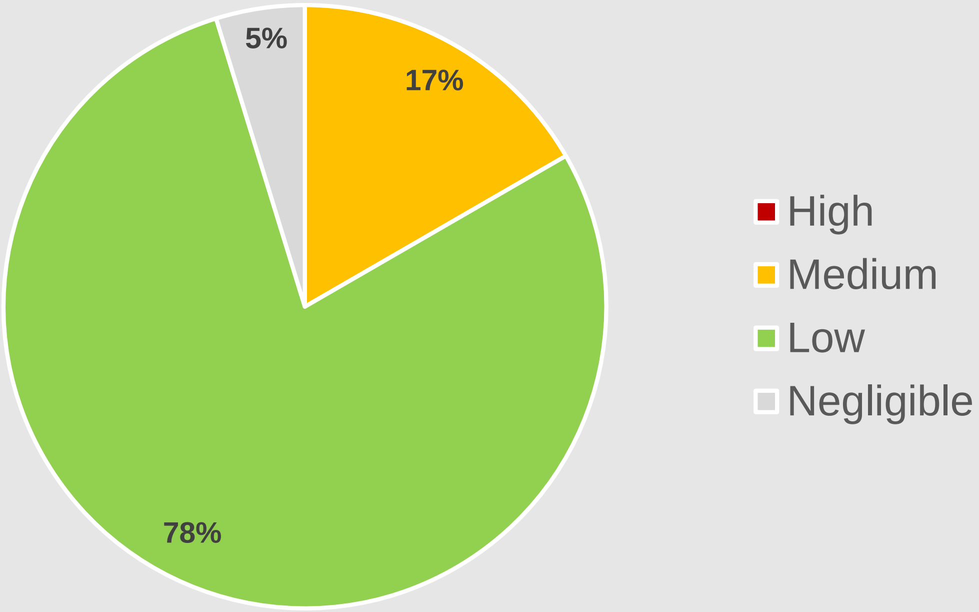


Cause: Failure of pipe shell					
Range of Occurrence	**No.**	**Range of Detection**	**No.**	**Range of Severity**	**No.**
0-1	3	**0-1**	5	**0-1**	4
1-2	5	**1-2**	6	**1-2**	49
2-3	13	**2-3**	1	**2-3**	2
3-4	34	**3-4**	2	**3-4**	0
		4-5	41	**4-5**	0

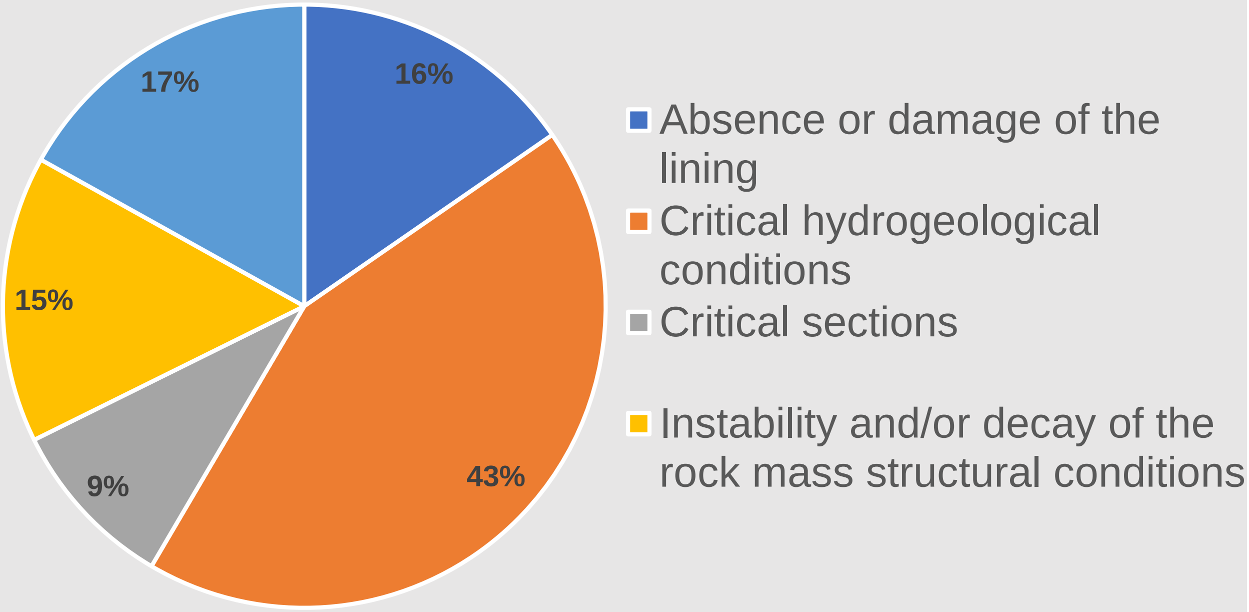
STATISTICAL ANALYSIS

General Overview Penstocks **Tunnels** Channels

Risk levels



Causes of highest RPN values



Cause: Critical hydrogeological conditions					
Range of Occurrence	**No.**	**Range of Detection**	**No.**	**Range of Severity**	**No.**
0-1	0	**0-1**	0	**0-1**	2
1-2	2	**1-2**	14	**1-2**	40
2-3	3	**2-3**	28	**2-3**	0
3-4	37	**3-4**	0	**3-4**	0
		4-5	0	**4-5**	0

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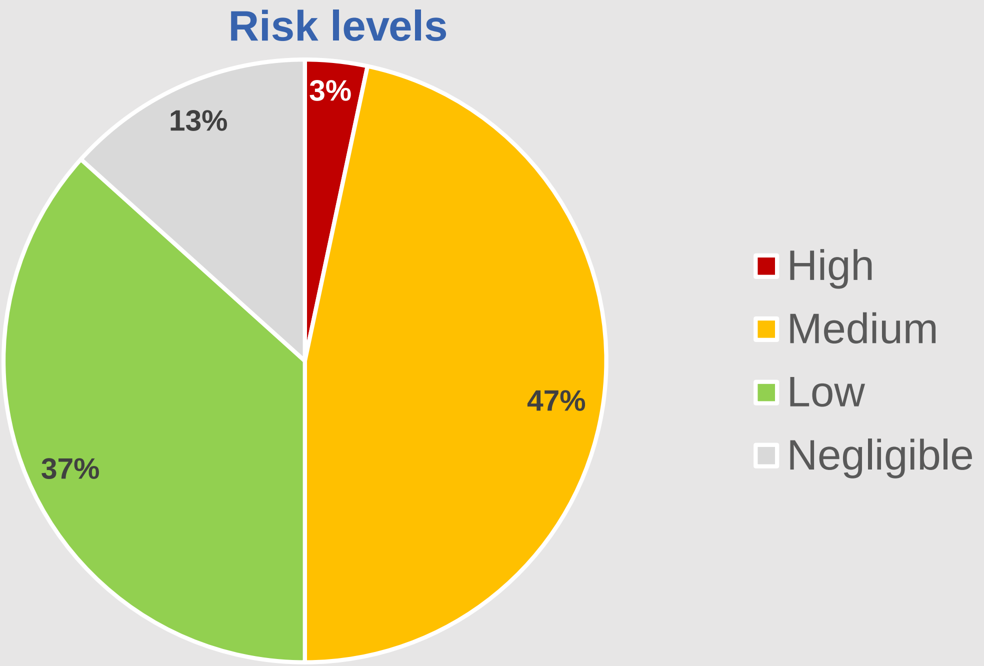
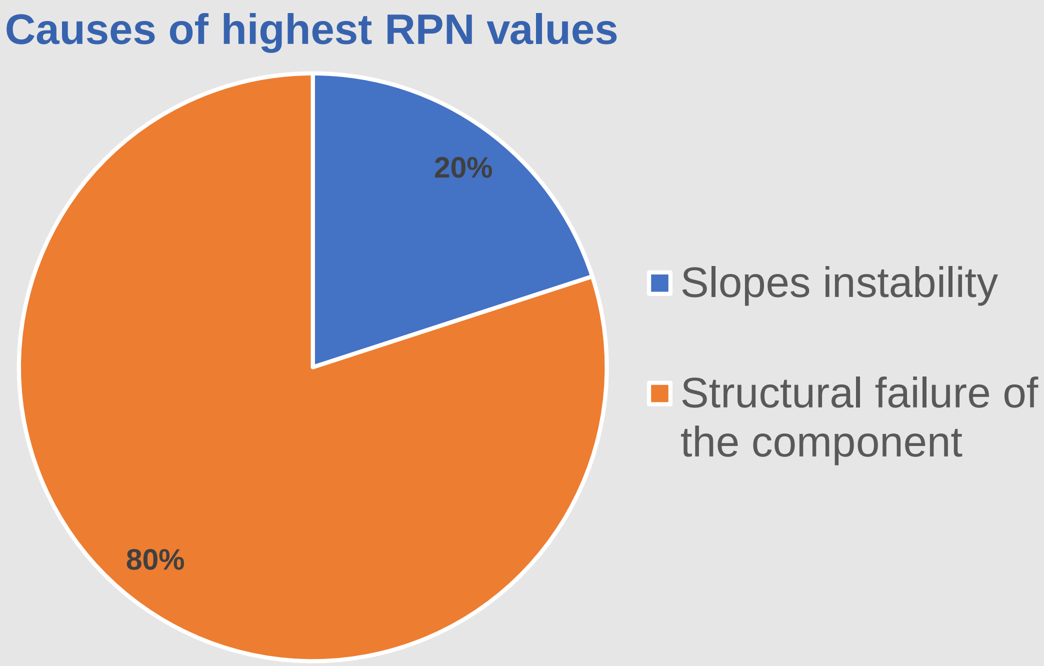
STATISTICAL ANALYSIS

General Overview Penstocks Tunnels **Channels**





Cause: Structural failure of the component					
Range of Occurrence	No.	Range of Detection	No.	Range of Severity	No.
0-1	0	**0-1**	1	**0-1**	10
1-2	1	**1-2**	0	**1-2**	19
2-3	0	**2-3**	6	**2-3**	0
3-4	28	**3-4**	0	**3-4**	0
		4-5	22	**4-5**	0

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CRITICAL REVIEW

- Easy implementation even specific information lacking
- Positive reduction of the time
- Objective, consistent
- DECISION-MAKING tool

CONCLUSIONS

1. The ability of a hydroelectric plant to produce energy or supply power depends on the efficiency and reliability of **all** its components
2. Static components deserve the same attention than rotating ones
3. A preliminary analysis (e.g. FMEA) of the functional links between the different components of a HPP can help in prioritizing the (expensive) monitoring efforts of digitalization
4. Sharing data about plants failures in the hydro community could help the creation of statistically significant conclusions
5. Site-specificity of hydropower requires a great preliminary effort in adapting general methods to peculiar situations

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THANK YOU FOR YOUR ATTENTION

Luigi Papetti