Risk analysis of dams:
French practice through Safety Review Risk Assessment

Assessment of Consequences and Criticality

Guirec PREVOT (Ministry of the Ecological Transition)
Thomas ADELINE (TA.conseils)

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Assessment of Consequences

3- Step Assessment of Consequences and Criticality

From the dam failure scenario to the assessment of level of severity

failure scenario

- flows and volumes released
- intensity, kinetics and duration of downstream wave

1

consequences (downstream issues)

- human
- material
- organizational
- environmental

2

level of severity

- from moderate … to disastrous
- criticality matrices (next chapter)

3

means implemented are adapted to the importance of the issues at stake for the safety of people and property

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3-Step Assessment of Consequences and Criticality

1 failure scenario

three types of phenomena

Dam break flood waves
- partial failure
- total failure
- overtopping wave

Elevation of the reservoir level
- water level increase
- backwater slope upstream (upstream flooding)

Unintentional releases
- mechanical
- electrical or control failures
- operational defects

Mapping the dam break flood wave

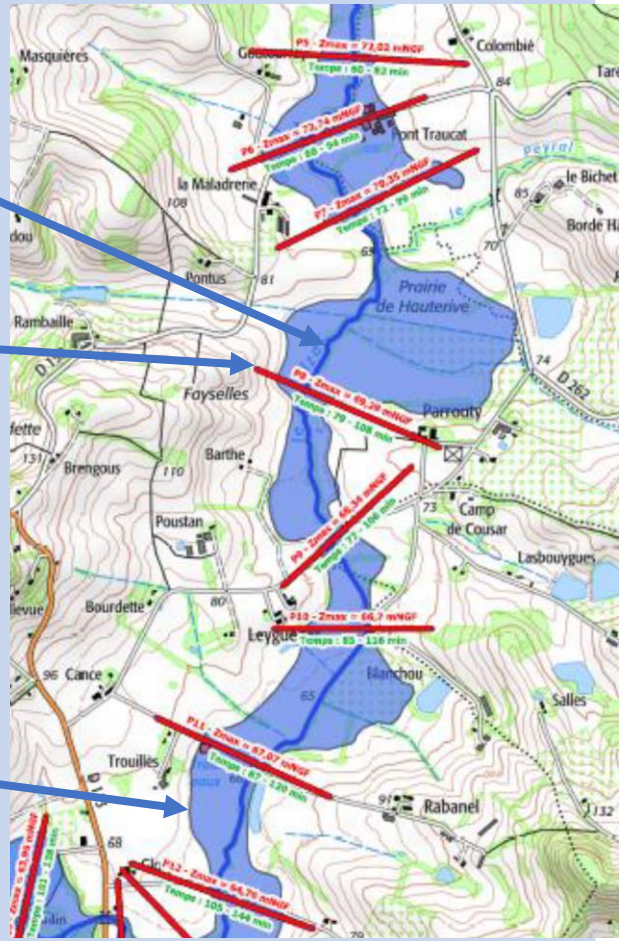
hydraulic axis

cross-sections

Kilometric Points

wave arrival time etc.

flood zone



- wave arrival times: -10 to -15%
- maximum water height: +15% with (mini. +1m if h>1m)

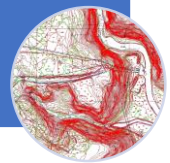
3-Step Assessment of Consequences and Criticality

Hydraulic modeling: main parameters

1 failure scenario

- bathymetric data (or topographic data when the dam is being emptied) for volume modelling

reservoir's geometry



- 1/25 000 scale maps (topographic data precise to 1 m in altitude)
- specific topographical surveys (cross-section just downstream of the structure, LIDAR survey of the analysis area, etc.)

valley's geometry

- friction coefficients of the terrain (Strickler or Manning)
- flow coefficients of any special sections are usually based on an expert's opinion

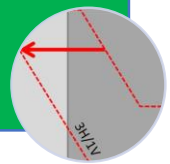
hydraulic characteristics of the area

- reservoirs at the Maximum Water Level and the valleys downstream "dry" (EPP)
- propagation on a flooded valley (i.e flood mitigation dams)

initial hydraulic state of the analysis area

- "rigid" dams (concrete, stone or other masonry): totally and instantly break or other failure diagrams (gravity dams)
- embankment dams (earth or rocks): gradually break (internal or external erosion)

dam failure mode

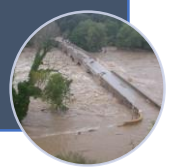


- total, instantaneous failure that releases the volume of the downstream reservoir
- modeling a weir that disappears and releases the volume of the downstream reservoir when a specific elevation is reached

behavior of downstream dams

- only resisting structures are integrated (impact on the water surface profile)
- geometry: data from local authorities or specific survey

behavior of other structures (bridges, weirs, railways and embankments)



- where maximum flow becomes lower than the 10-year flood (main case)
- where the difference between with and without failure is deemed to be negligeable (specific dams like flood mitigation dams)

wave's stopping point

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1 failure scenario

Hydraulic modeling softwares

- Hec Ras (US Army Corps of Engineers)
- Telemac 2D (France, Germany, UK)
- and many others …

Digital Terrain Model (DTM) (terrain without vegetation or buildings)

Satellite

SRTM (NASA, Endeavour 2000, radar)
- Vertical Accuracy: 16m
- Spatial resolution: 1 arc second (~30m) (ex GTOPO30)

WorldDEM Neo (ESA) hydroenforced
- Vertical Accuracy: 2.5m
- Spatial Resolution: 5m

Airborne LIDAR

specialized companies

Ground points

local surveyors
- for river cross-sections

Multiple Sources

NextMap World 10 (fully hydro enforced)
- Vertical Accuracy: 8-10m
- Spatial Resolution: 1/3 arc second (~10m)

RGE Alti (France, IGN)
- Vertical Accuracy: 0.5-2m
- Spatial resolution: 1m/5m

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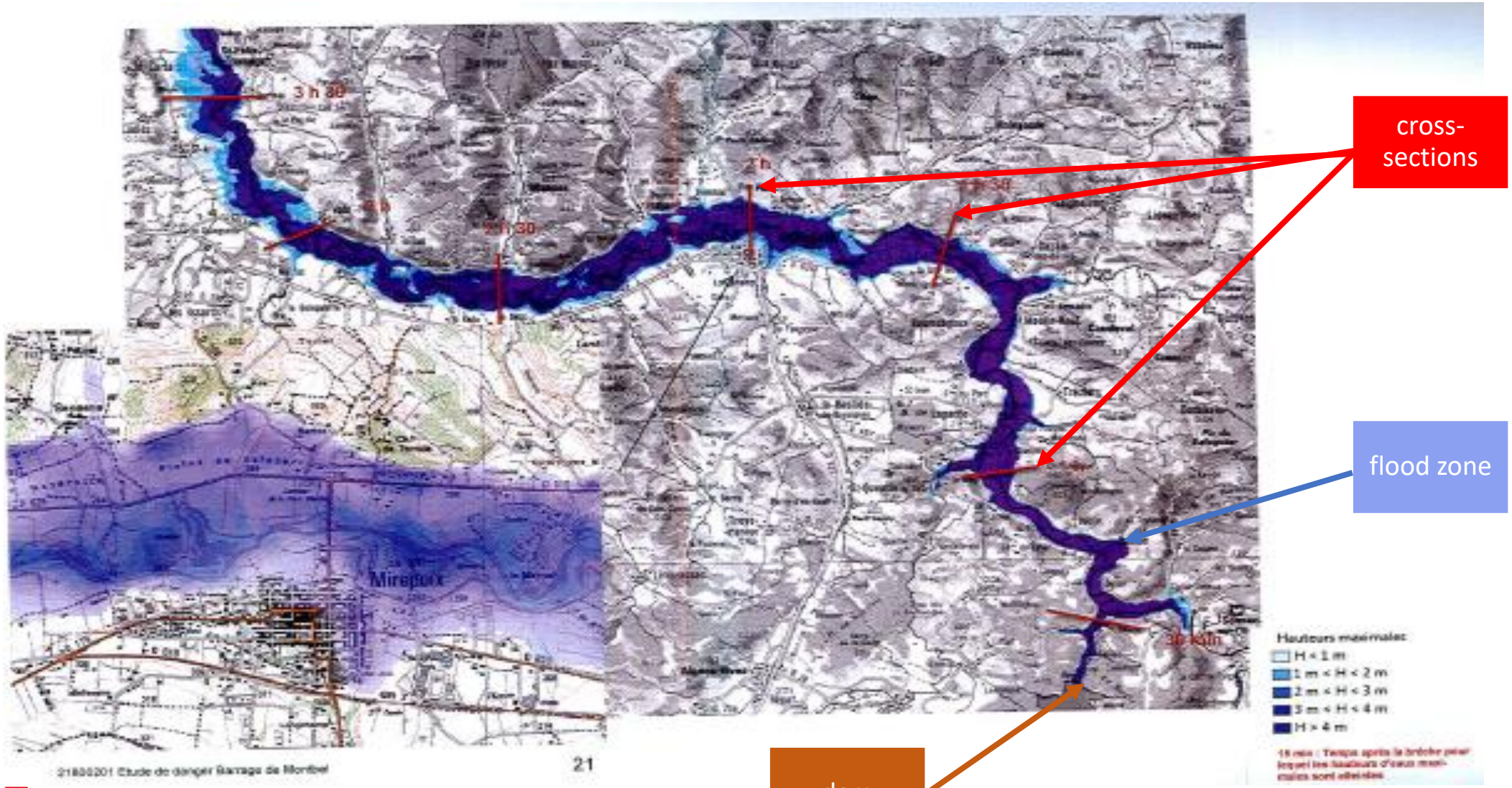
Example of map of hydraulic results



3-Step Assessment of Consequences and Criticality

2 consequences (downstream issues)

Consequences assessment: different approaches

Dam safety review	French Flood Risk Mitigation Policy : additional indicators
• **People at Risk** (PAR) = main indicator • Order of magnitude PAR rather than obtaining an exact number	• **sensitive buildings** (hospitals, old people's homes, schools, etc.) and establishments that are useful in crisis management (town halls, fire stations, etc.) • **the economic issues** (accommodation, public establishments, businesses, agriculture, networks, transport, installations and infrastructures, jobs) • **the environmental issues** (pollution of drinking water, waste, classified sites) • **the heritage issues** (sites of interest or classified sites)

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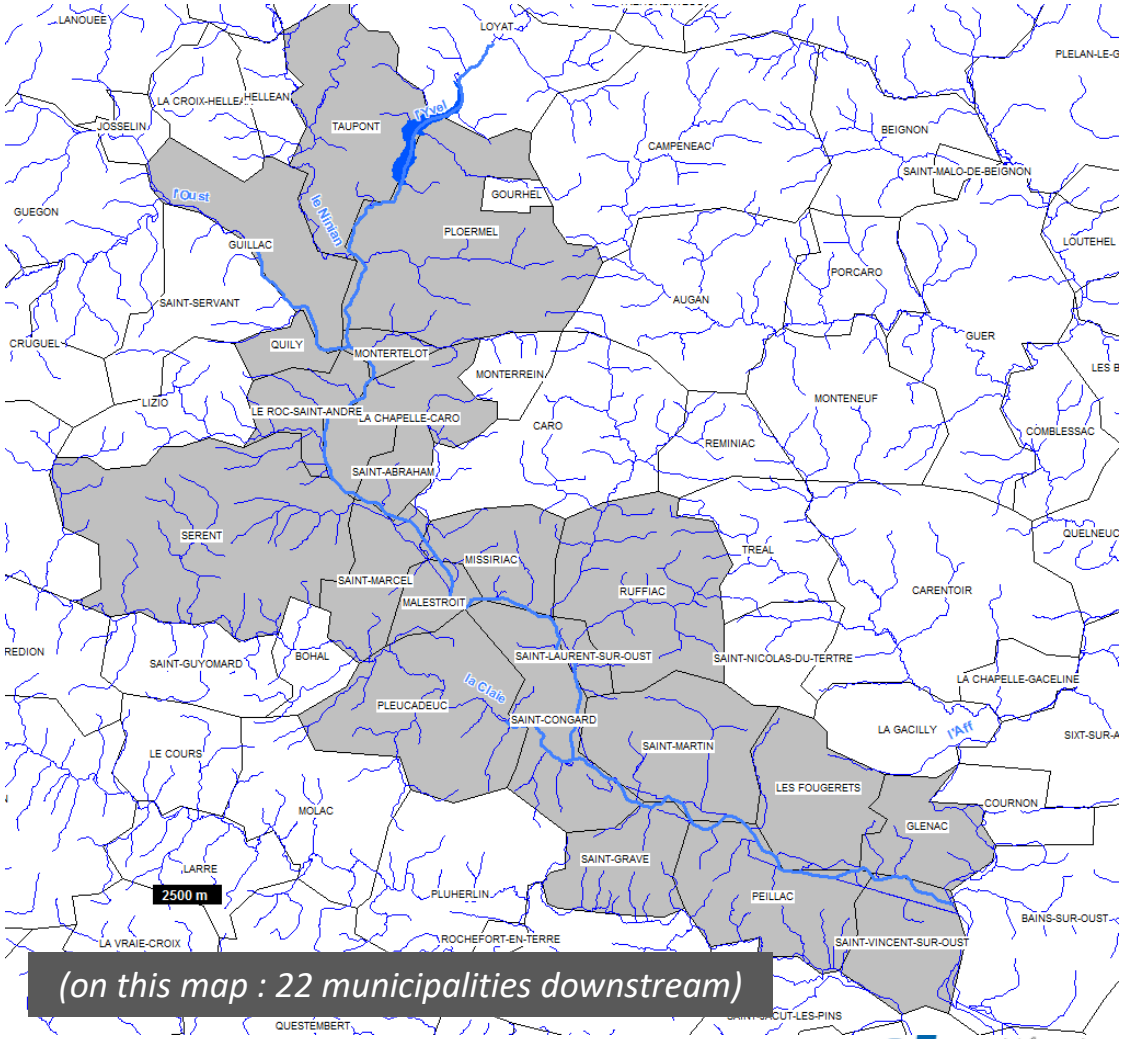
3-Step Assessment of Consequences and Criticality

2 consequences (downstream issues)

Mapping the PAR: upstream and dowstream limits

banks of the reservoir	• risk of landslide • risk of the reservoir rising
valleys downstream	• risk of release through failure • risk of unintentional operation



(on this map : 22 municipalities downstream)

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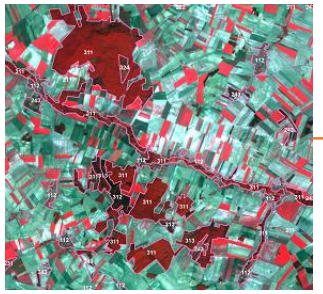
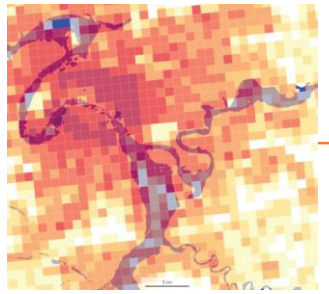
3-Step Assessment of Consequences and Criticality

2 consequences (downstream issues)

Mapping the PAR: methods and source of data



Method 1: breakdown of the space into homogeneous units → Number of people per hectare → Source in EUROPE: Corine Land Cover (CLC) (satellite imagery: Landsat, SPOT, IRS,…)



Method 2: population grid → Number of people per square (distributed) → In France: INSEE data (national Official Statistics Authority) geolocalized population data by 200 m square tiles

Method 3: individual buildings/dwellings mapping → Number of people per building → Source in France: IGN (National Institute of Geographic Information) buildings vectorial databases and INSEE statistics

Method 3: individual buildings/dwellings mapping → Number of people per floor (when relevant) → Source in France: Treasury Department cadastral database

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2 consequences (downstream issues)

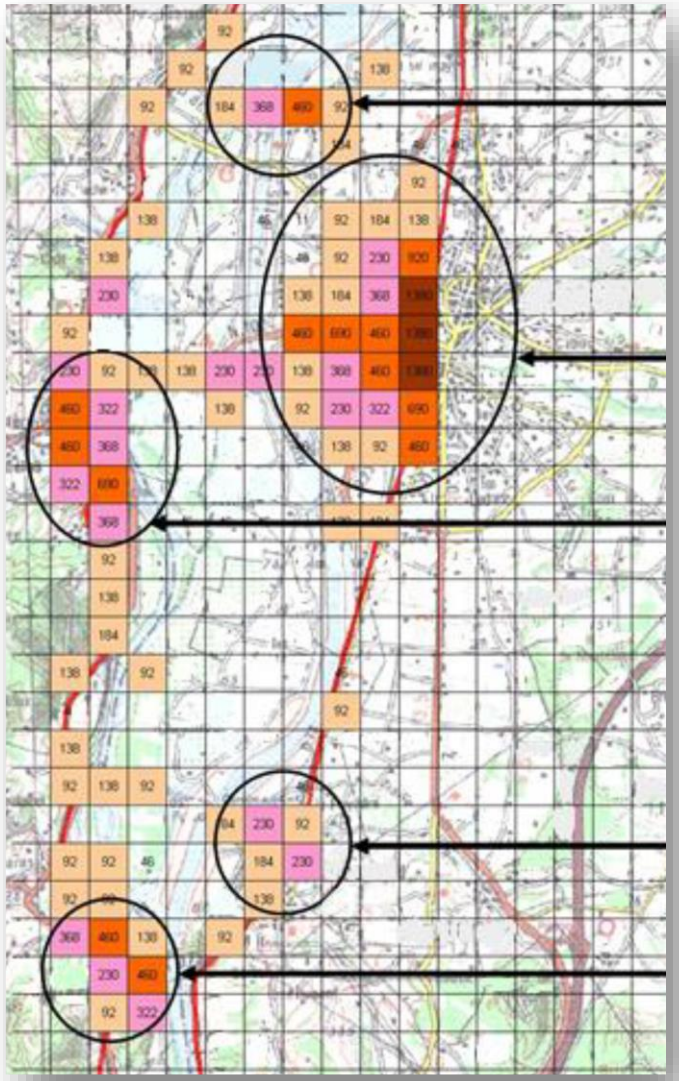
Other situations taken into account

assessment per accident based on the most realistic scenario	when greater precision is required: special issues
• possibility of sheltering people is sometimes taken into account • day/night, holidays, rush-hour scenarios are sometimes assessed	• Campsites, fishing and hiking sites; • Shopping centers; • Other establishments that receive the public (ERP) like stations and airports, hospitals, schools, stadiums, etc. The local authorities (town hall, prefecture) can offer information on capacity, or it can be found on site

3-Step Assessment of Consequences and Criticality

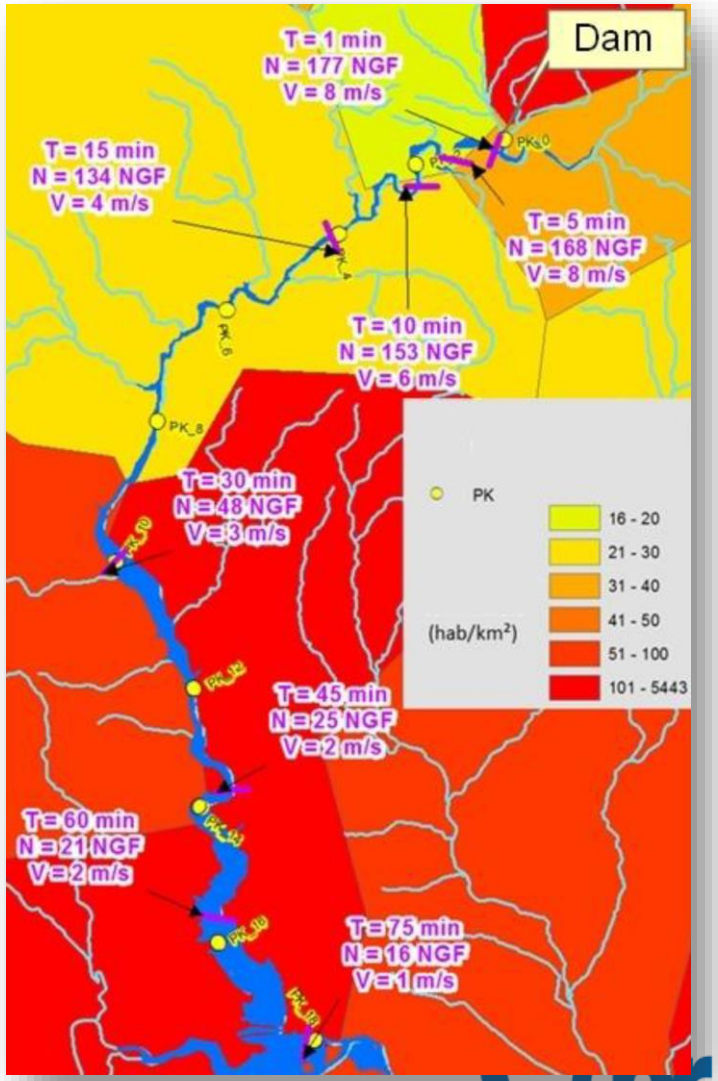
2 consequences (downstream issues)

Mapping the PAR: examples



200mx200m grid of population data

municipalities
population density



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3-Step Assessment of Consequences and Criticality

2 consequences (downstream issues)

Critical analysis of the results

- complexity of the failure modes
- uncertainty on the behavior of floating elements
- sediment transport
- structures downstream (bridges, weirs,dams, etc.) behavior

=> overall count of the people likely to be impacted is sufficient

3-Step Assessment of Consequences and Criticality

3 level of severity

Class of severity
Rapid/slow kinetics (example below)

CLASSES OF SEVERITY OF CONSEQUENCES (in decreasing order)		NUMBER OF PEOPLE exposed in a zone with **rapid** kinetics	NUMBER OF PEOPLE exposed in a zone with **slow** kinetics
5	Disastrous	over 1 000	over 10 000
4	Catastrophic	100 to 999	1 000 to 9 999
3	Important	10 to 99	100 to 999
2	Serious	1 to 9	10 to 99
1	Moderate		1 to 9

Assessment of Criticality

Assessing the criticality of scenarios and displaying risks

Probability Scale	E	D	C	B	A
Qualitative (if number of installations and feedback are sufficient)	"Possible event, but extremely improbables : *is not impossible considering current knowledge, but not experienced worldwide during a large number of installation.years*	"very improbables event": *already occured in the industry sector, but corrective actions were taken which significantly reduced the probability of occurrence*	"improbables event": *similar event already occured in the industry sector or in this type or organization worldwide, but no corrective actions were taken which significantly reduced the probability of occurrence*	"probables event": *already occured or can occur during life duration of the installation*	"current event": *already occured or can occur several times during life duration of the installation, in spite of risk reduction measures*
Semi-quantitative	This scale is intermediate between qualitative and quantitative scales, and enables to take into account risk reduction measures				
Quantitative (by unit and by year)		10^{-5}	10^{-4}	10^{-3}	10^{-2}

Probability

CLASSES OF SEVERITY OF CONSEQUENCES (in decreasing order)		NUMBER OF PEOPLE exposed in a zone with **rapid** kinetics	NUMBER OF PEOPLE exposed in a zone with **slow** kinetics
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Severity

Criticality

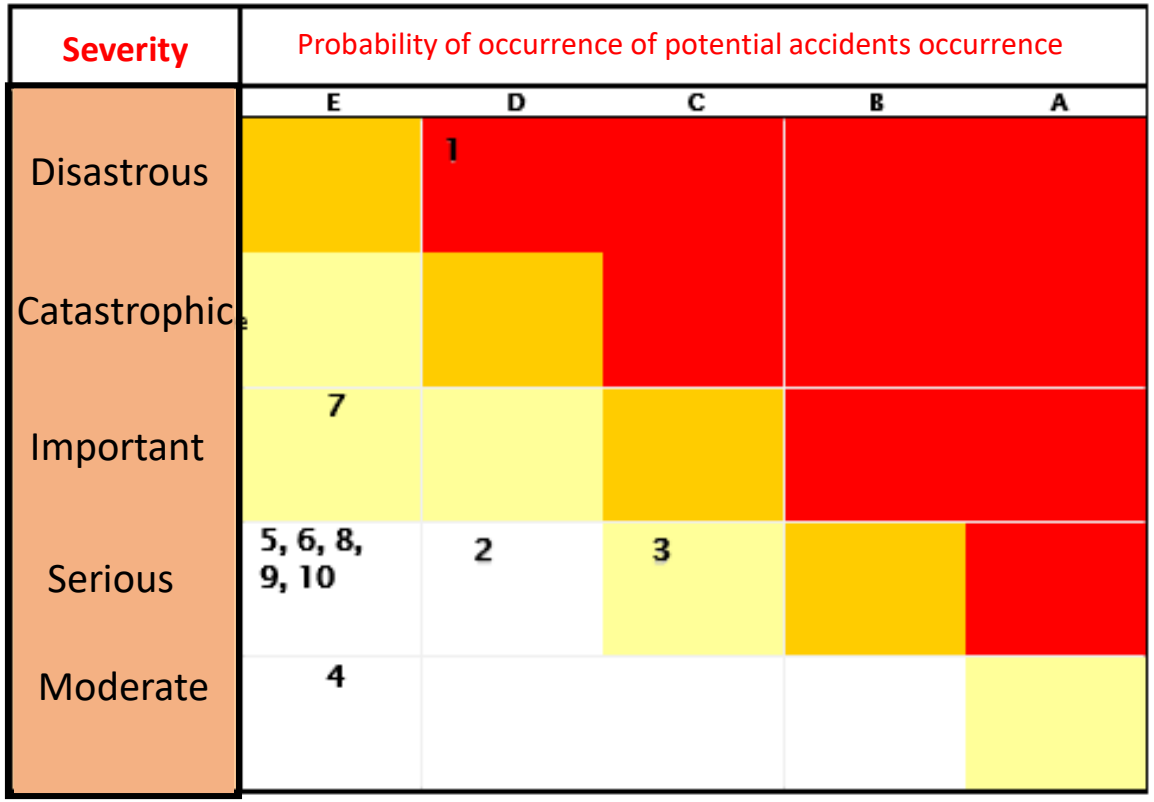
Assessing the criticality of scenarios and displaying risks

French practice uses criticality matrices

Severity	Probability of occurrence of potential accidents occurrence				
	E	D	C	B	A
Disastrous		1			
Catastrophic					
Important	7				
Serious	5, 6, 8, 9, 10	2	3		
Moderate	4				

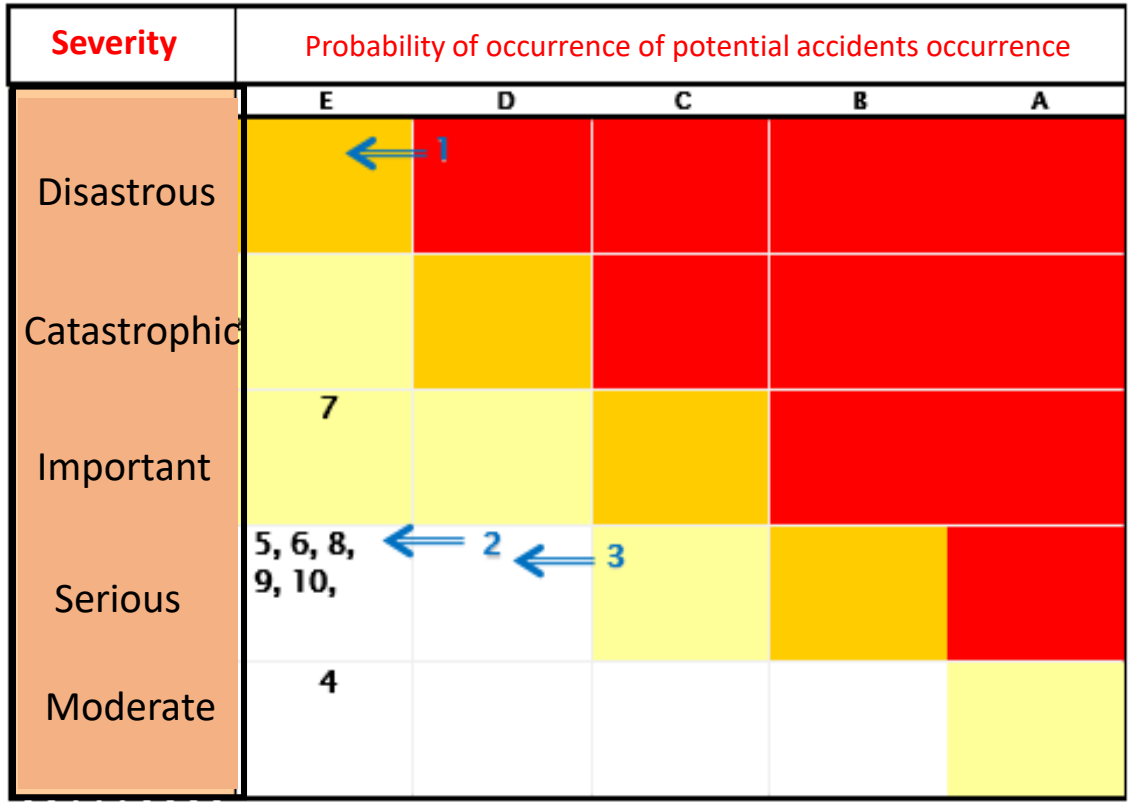
Assessing the criticality of scenarios and displaying risks

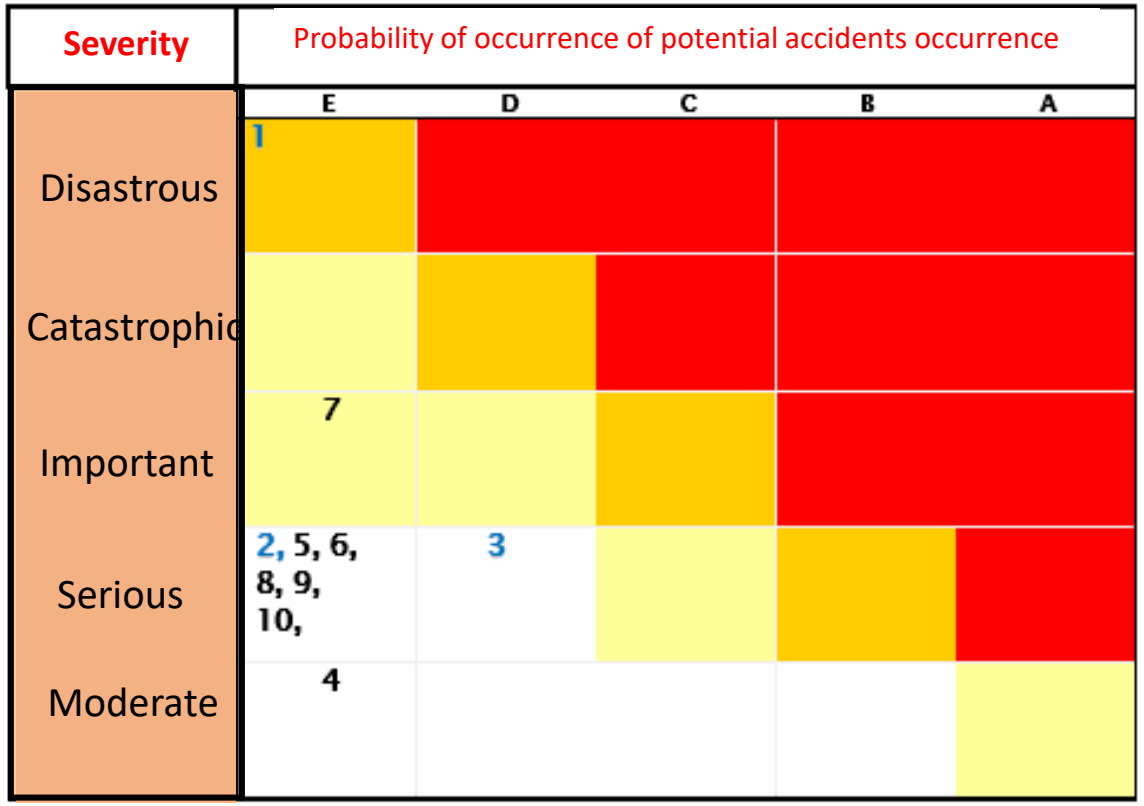
The criticality matrix is completed with the limits of tolerability (colors)



Assessing the criticality of scenarios and displaying risks

Proposing measures to control and/or reduce the risks as reasonably as possible





Probabilité							
	Fréquent	A					
	Probable	B				ERC 1	
	Peu probable	C			ERC 2 ERC 3		
	Rare	D			ERC 4		
	Extrêmement rare	E					
			Mineure	Significative	Sévère	Critique	Catastrophique
			Gravité				

	Risque inacceptable
	Risque à surveiller
	Risque acceptable

Vertically: Probability*; top to bottom*: Ordinary; Unlikely; Very Unlikely; Rare; Extremely Rare Horizontally: Severity; *left to right* : Minor; Significant; Severe, Critical, Catastrophic/ ERC = feared event

Legend : red = unacceptable Risk/Yellow = Risk to watch/ Green = Acceptable Risk

Risk Reduction

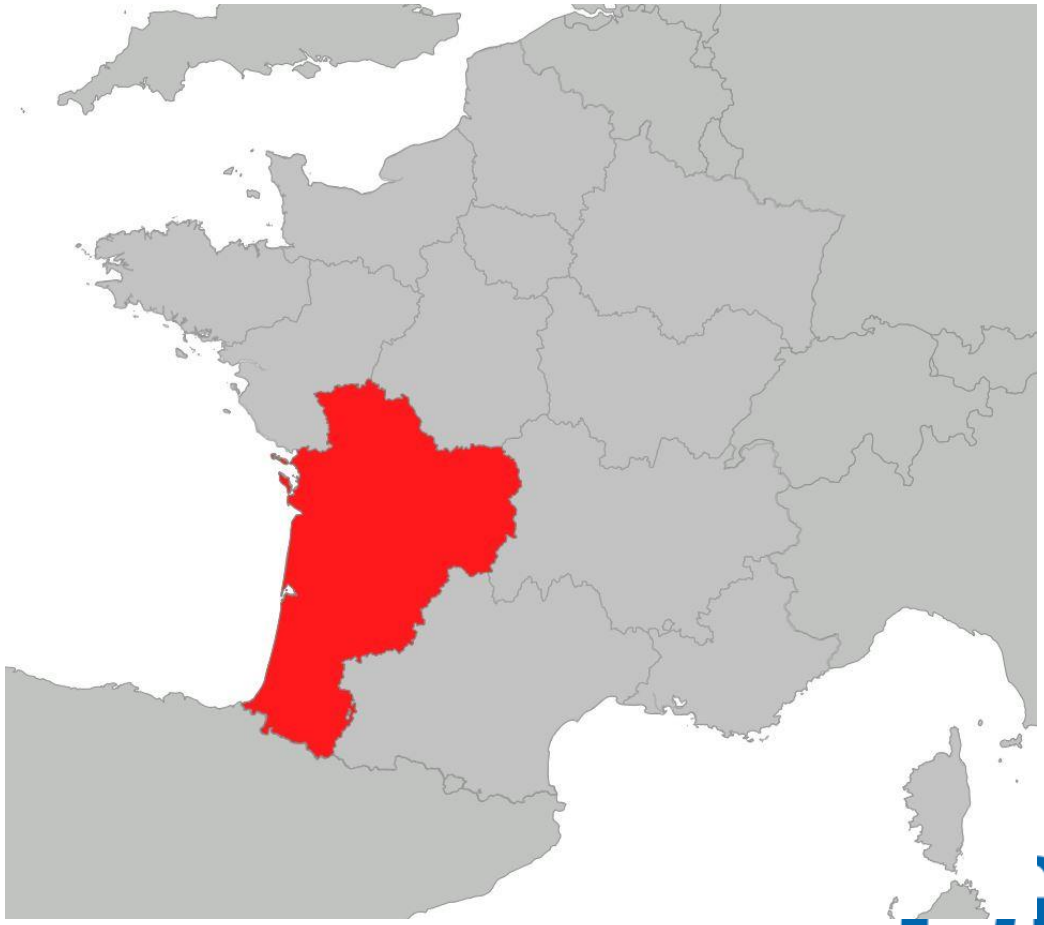
Risk control and reduction measures

- **<u>Risk control measures (RCM)</u>**
  - maintain a satisfactory level of safety
  - do not modify the criticality of the scenario identified
- **<u>Risk reduction measures (RRM)</u>**
  - reduce the level of risks
  - induce a revision of the criticality of the scenario on which the measure will focus

Risk control and reduction measures

Summary of the risk reduction measures produced on Safety Review Risk Assessments in one region of France (Nouvelle Aquitaine)

- for 111 dams with different uses and a wide range of operators, 298 risk reduction measures were proposed



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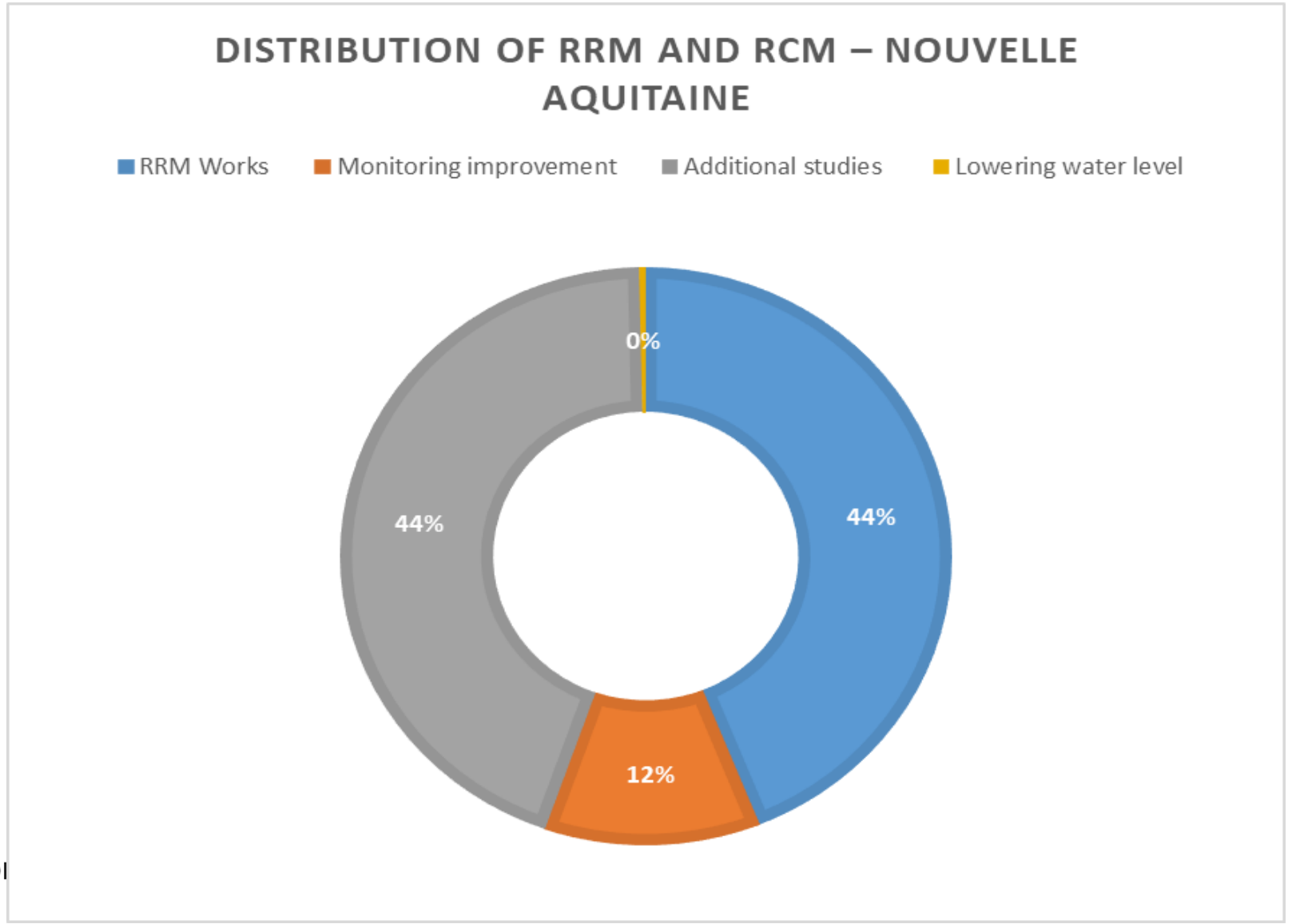
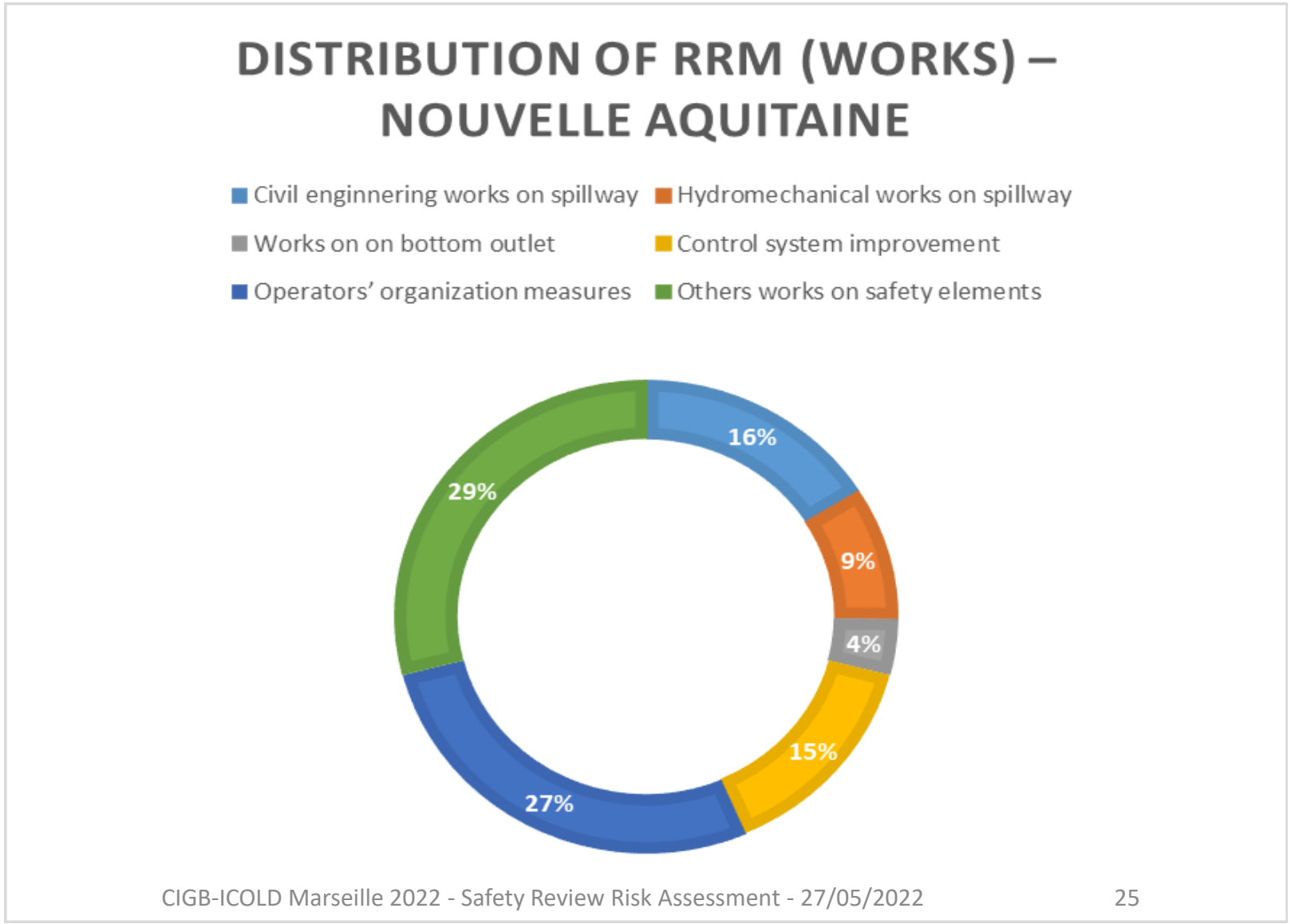
Risk control and reduction measures



Risk control and reduction measures



Type of RRM	Examples
Civil work on spillway	Work to recalibrate the spillway for the design flood
Work on spillway gates	Treatment of spillway gates (sandblasting and repainting)
Work on bottom outlet	Neutralizing an old bottom outlet no longer required
Improvement of the control system	Work to ensure reliability of back-up engine of spillways
Organizational measures	Organizing formalized follow-up of agent training in monitoring and in gate operation during a flood
Work on the dam	Repairs to the deteriorated zone on the upstream facing