Risk analysis of levee systems

Analyse de risque des systèmes d'endiguement

Introduction and general framework of the risk analysis of levee systems

Introduction et généralités sur l'analyse de risque des systèmes d'endiguement

Rémy Tourment,
INRAE

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Program of the short course

- Introduction and general framework of the risk analysis of levee systems - Rémy Tourment (INRAE, F) - 60 mn
- Functional analysis. Hydraulic functions of systems and subsystems and structural functions of levee components. Failure mode analysis: general principles and INRAE method - Bruno Beullac (INRAE, F) - 90 mn
- National and regional flood risk analysis approaches in the United Kingdom - Ben Gouldby / Jonathan Simm (HR Wallingford, UK) - 60 mn
- A practical application to Hazard Studies in France: the example of SYMADREM for the evaluation of the probabilities of levee failure and of the characteristic levels of the system (protection, safety and danger) - Thibaut Mallet (SYMADREM, F) - 60 min
- Use of the results of the risk analysis applied to the Authion levee system: decision support (design and management) of flood protection system - Sébastien Patouillard (DREAL Center, F) and Sylvain Palix (ANTEA, F) - 60 min
- Conclusion - Risk analysis of flood protection systems: contributions, current practices and development needs. Decision making support integrating Cost-Benefit Analysis and Multi Criterion Analysis - Rémy Tourment - 30 min

- Introduction et généralités sur l'analyse de risque des systèmes d'endiguement - Rémy Tourment (INRAE, F) – 60 mn
- Analyse fonctionnelle. Fonctions hydrauliques des systèmes et sous - systèmes et fonctions structurelles des composants des digues. Analyse des modes de défaillance : principes généraux et méthode INRAE - Bruno Beullac (INRAE, F) – 90 mn
- Approches nationales et régionales de l'analyse des risques d'inondation au Royaume Uni - Ben Gouldby / Jonathan Simm (HR Wallingford, UK) – 60 mn
- Une application pratique aux études de dangers réglementaires en France : l'exemple du SYMADREM pour l'évaluation des probabilités de rupture des digues et des niveaux caractéristiques du système (protection, sûreté , danger) - Thibaut Mallet (SYMADREM, F) – 60 min
- Utilisation des résultats de l'analyse de risque appliquée au système d'endiguement de l'Authion : aide à la décision (conception et gestion) des systèmes de protection contre les inondations - Sébastien Patouillard (DREAL Centre, F) et Sylvain Palix (ANTEA, F) – 60 min
- Conclusion - L'analyse de risque des systèmes de protection contre les inondations : apports, pratiques actuelles et besoins de développement. Aide à la décision intégrant Analyse Coût Bénéfice et Analyse Multi-Critères - Rémy Tourment – 30 min

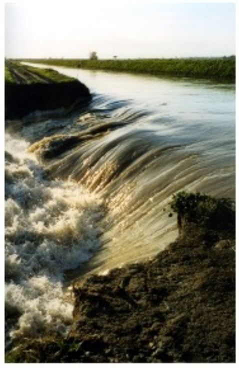
Program of this presentation

- Introduction
  - Levees, levee systems, flood protection systems
  - Risk analysis and hazard studies of levee systems : what & why ?
  - Background work & content of this source material
  - Objective of this short course
- General concepts
  - A system approach
  - Different types of flood protection systems
  - The characteristic levels
  - Flood storage vs flood protection
- Flood risk analysis of Levee systems
  - The general framework for Flood Risk Analysis of Flood Protection Systems
  - The INRAE method for Flood Risk Analysis
- Link between flood risk analysis and failure modes analysis

- All illustrations except when noted are from Bruno Beullac, Rémy Tourment and/or the International Levee Handbook

Introduction:
Levees, levee systems, flood protection systems

- Levees (also called dikes), work inside a system
- They protect an from flooding from river floods or coastal events (storm surge, tsunami, …)
  - until water reaches a certain level
  - if the system does not fail
    - by hydraulic (functional) failure
    - by structural failure



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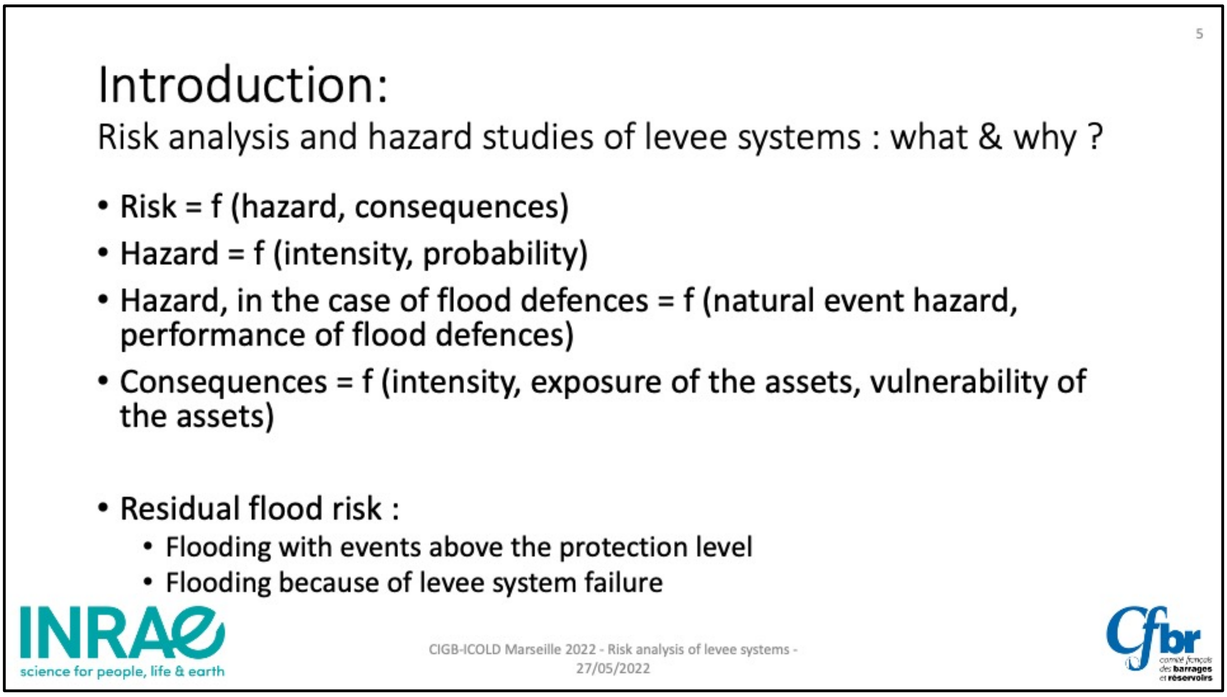
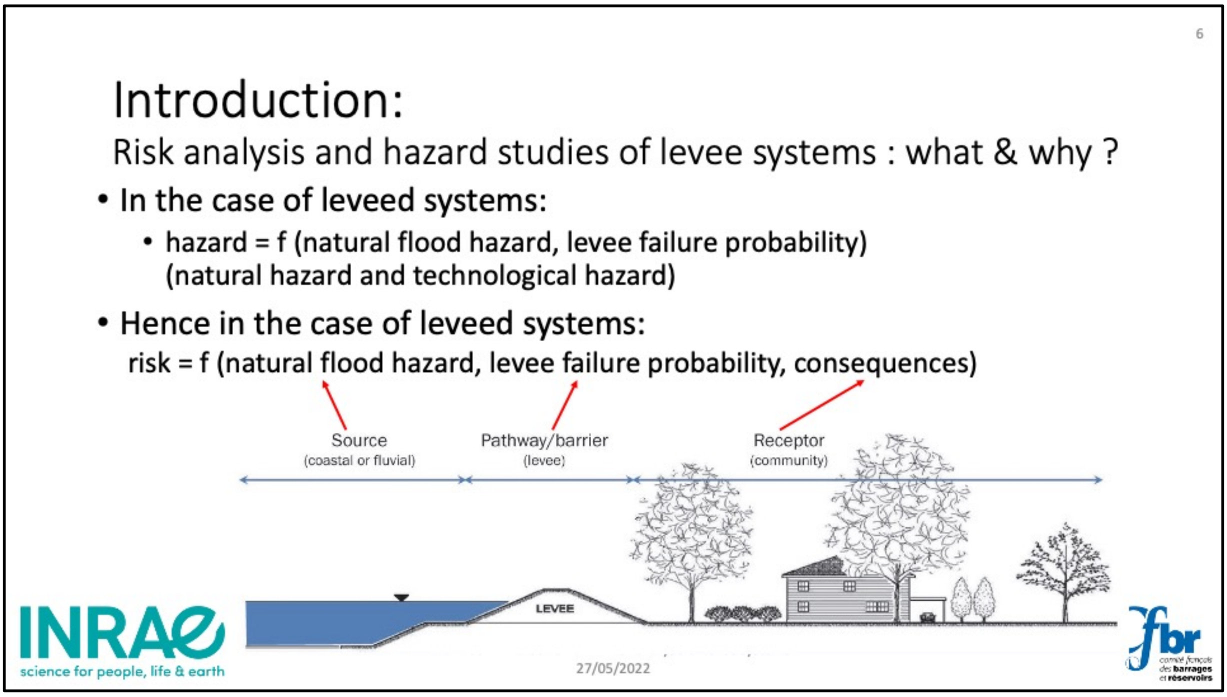
- Flood protection levees protect up to a certain level, but beyond this level flooding can occur:
  - By system bypass (for open systems)
  - By overflow without breach
  - By overflow followed by a breach
  - By breach linked to another mechanism
  - By functional failure (e.g. temporary closure, pumping station, etc.)



The main purpose of the risk analysis of a protection system is to better understand the residual flood risk (causes, quantification)

Residual flood risk :
- flooding above the protection level without failure
- AND flooding because of potential failures



Flood risk, in the presence of levee systems. In this case

- hazard will depend on both the natural hazard (water loading on the levee) and on the levee performance (or inversely, levee failure probability)
- so for the assets in the leveed area, hazard is a combination of a natural hazard and a technological hazard

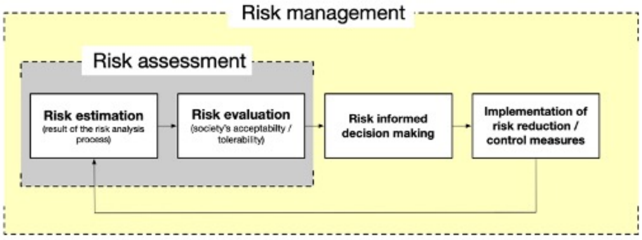
This is represented in the very useful and powerful SOURCE PATHWAY RECEPTOR model where the components of risk are :

- Natural flood hazard :which is the SOURCE
- Levee failure probability : which is in relation to the PATHWAY
- and the Consequences in the RECEPTOR area

Introduction:

Risk analysis and hazard studies of levee systems : what & why ?

- Risk analysis :
  - Understand this risk (factors influencing it)
  - Estimate and evaluate this risk (probabilities, consequences)
- Part of the larger process of RISK MANAGEMENT



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Additional definitions :

Risk management: Risk management is the identification, estimation, evaluation, assessment and prioritization of risks, followed by the application of resources to minimize, monitor, and control the probability or consequences of unfortunate events

Risk communication: The main purpose of communicating risks is to inform people and organizations in the floodprone area about hazard and consequences. It helps to prepares the community to deal with any flood event and is part of the risk management process.

Residual risk:

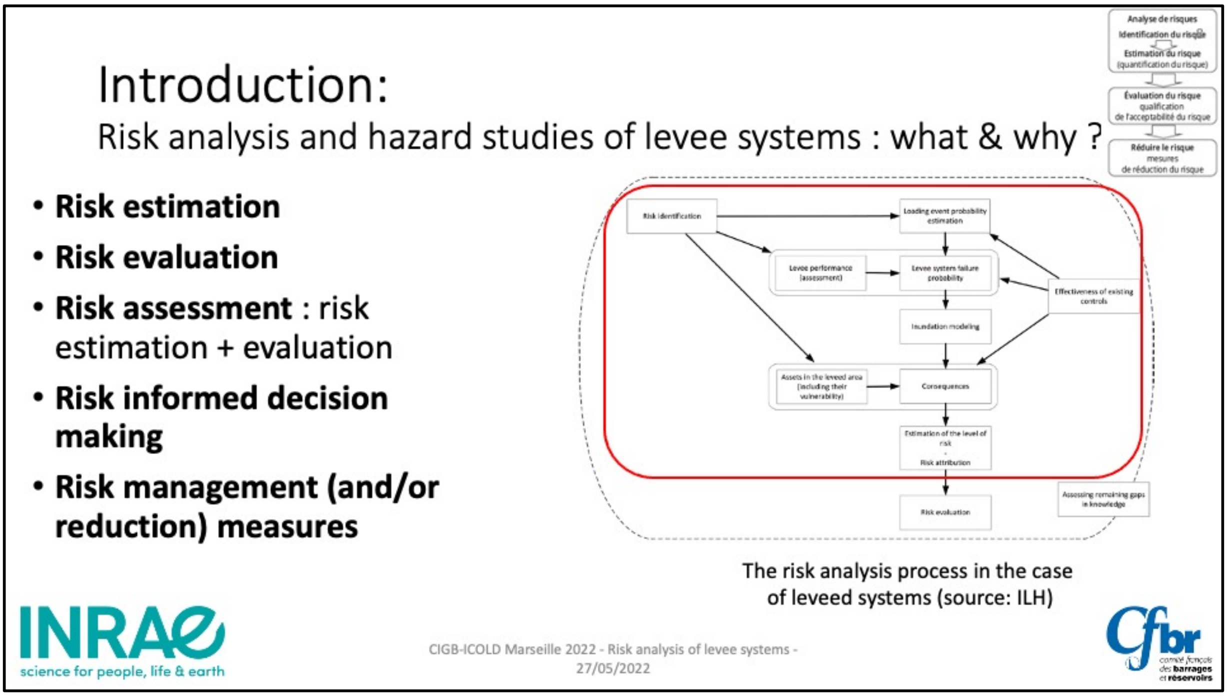
Levees provide only certain level of protection

Residual risk is caused by:

the possibility of a flood exceeding the protection level (with or even without a breach)

a failure of the levee system to perform under this level

While levee failure hazard may be low, the residual risk and the total flood risk may be quite high

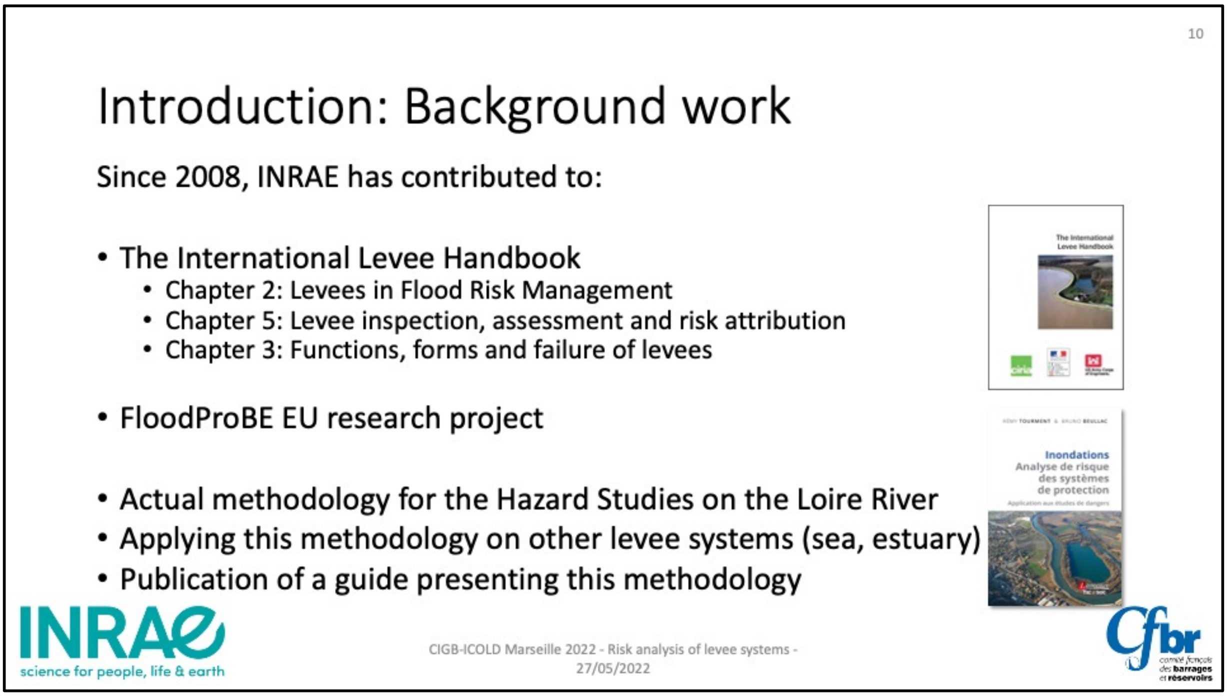


Risk estimation: the beginning of the risk assessment process leading to a knowledge of the risk factors and their association into a knowledge of the possible harmful scenarios and their consequences. Once risks have been identified, they must then be assessed as to their potential severity of impact, generally a negative impact, such as damage or loss, and to the probability of occurrence.
Risk evaluation: Risk evaluation attempts to define what the estimated risk actually means to people and communities concerned with or affected by the risk.
Risk assessment : risk estimation + evaluation
Risk informed decision making is the following step of the risk management process, in turn followed by implementation of **risk management (and/or reduction) measures**

Introduction:

Risk analysis and hazard studies of levee systems : what & why ?

- In France, the regulation on the safety of hydraulic structures introduced the concept of "Etudes de Dangers" ("Hazard Studies")
- Hazard Studies are based on a risk analysis concept, but they have to be presented in a specific format
- The first version (2007) included the definition of risk reduction measures
- The current version (2015) has to justify the consistent determination of the protection in terms of :
  - Embankment System,
  - Protected Area,
  - Protection Level
- It includes a detailed safety assessment as well as a functional analysis



INRAE (formerly Irstea, formerly Cemagref) contributed since 2009 to:

The International Levee Handbook

- Chapter 2: Levees in Flood Risk Management
- Chapter 5: Levee inspection, assessment and risk attribution
- Chapter 3: Functions, forms and failure of levees

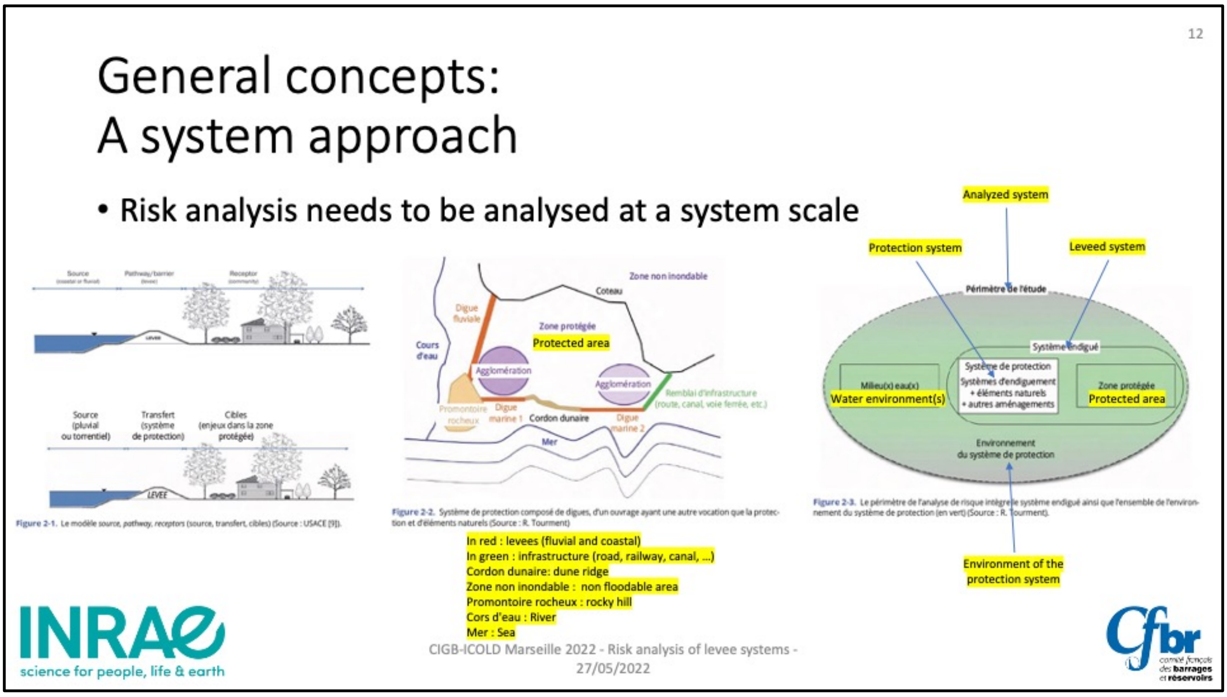
Definition of actual methodology for the Hazard Studies on the Loire River middle course (3 Class A systems, tens of Class B systems)

Applying this methodology on other levee systems

Publication of a guide presenting this methodology

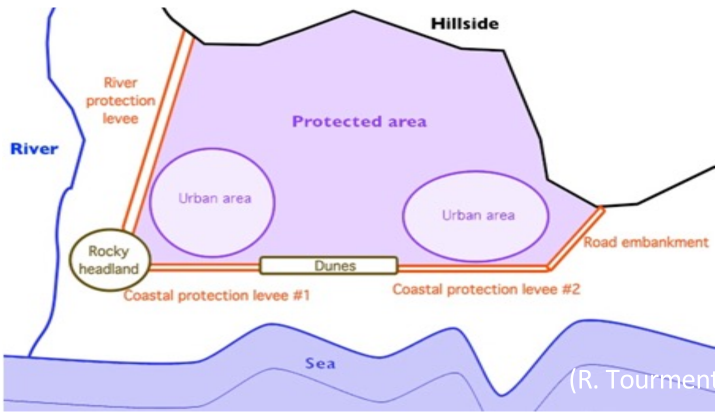
Introduction: Objective of this short course

- This course aims to help the audience to :
  - apprehend the general framework for the risk analysis of levee systems
  - understand why risk analysis is useful and essential to levee managers
  - understand how to apply existing methodologies
- by presenting :
  - the international approach to risk analysis of levee systems described in chapter 5 of the "International Levee Handbook"
  - its French version through Hazard studies
    - method for Risk analysis developed by INRAE and presented in a guide published in 2019
    - illustrated by examples (Loire River, Rhone River)
  - approaches from the UK for national and regional risk analysis



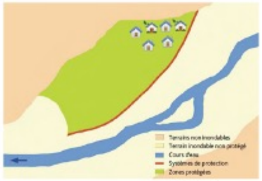
Risk analysis needs to be analysed at a system scale :

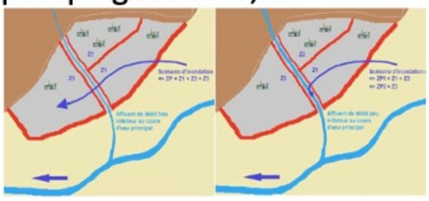
- The source pathway receptor model is a first level of analysis
- Flood protection systems are sometimes complex they need to be analysed as a complete set of elements that together protect an area (consistent hydraulic function)
- They can be composed of : levees, flood walls, other structures and natural features like dunes
- The system approach allows different levels of analysis :
    - Analysed system :
        - Water environment(s) = source
        - Protection system = pathway
            - Levee(s)
            - Other structures
            - Natural features
            - (NB : in French regulation the levee system can only include man made structures and not natural features, but the protection system (not a regulation object) may need natural features to actually provide protection)
        - Protected area = receptor



General concepts: Different types of flood protection systems

- Different types of environments : rivers, coastal, mountain streams, lakes, estuaries, …
- Very simple or very complex (multiple lines, ramifications, …), open or closed
- Specific elements like spillways, gates, pumping stations, …

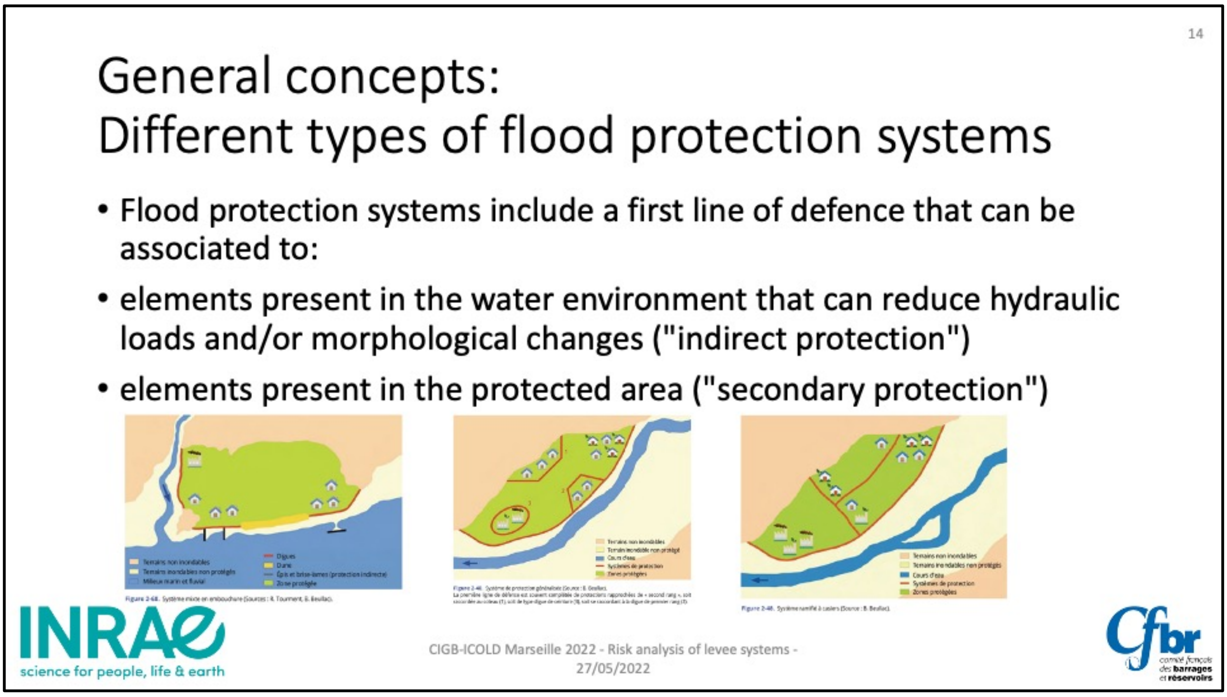




Flood protection systems can be found in different types of environments : rivers, coastal, mountain streams, lakes, estuaries, … each with specific hydraulic loadings and morphological phenomenon. For instance in coastal environment waves are a very important component of the hydraulic loading, while in mountain streams sediment transport is the major cause of problems

Flood protection systems can be very simple or very complex (multiple lines, ramifications, …), they can be open or closed

They can include specific elements like spillways, gates, pumping stations, …



Flood protection systems include :

- (always) a first line of defence that can (sometimes) be associated to:
- elements present in the water environment that can reduce hydraulic loads and/or morphological changes ("indirect protection")
- elements present in the protected area ("secondary protection")

General concepts: Different types of flood protection systems

- For risk analysis purposes, complex contiguous systems have to be analysed as a
- Although they have hydraulic interaction, systems close to one another can / have to be analysed separately (as a first approach). Scenarios involving failure of different systems are too complex.

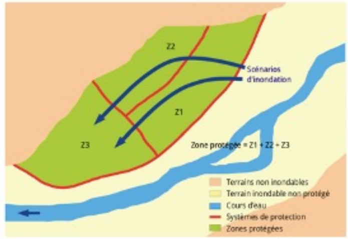


Figure 2-4. L'inondation des zones 2 et 3 dépend en partie de l'inondation de la zone 1. Les zones 1, 2 et 3 ne forment donc qu'une seule zone protégée par un unique système de protection hydrauliquement cohérent (Source : B. Beullac).

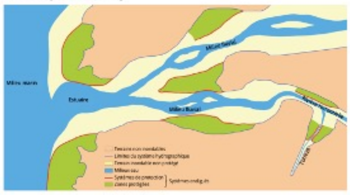


Figure 2-7. Des systèmes endigués aux milieux eau variés (Source : B. Beullac).

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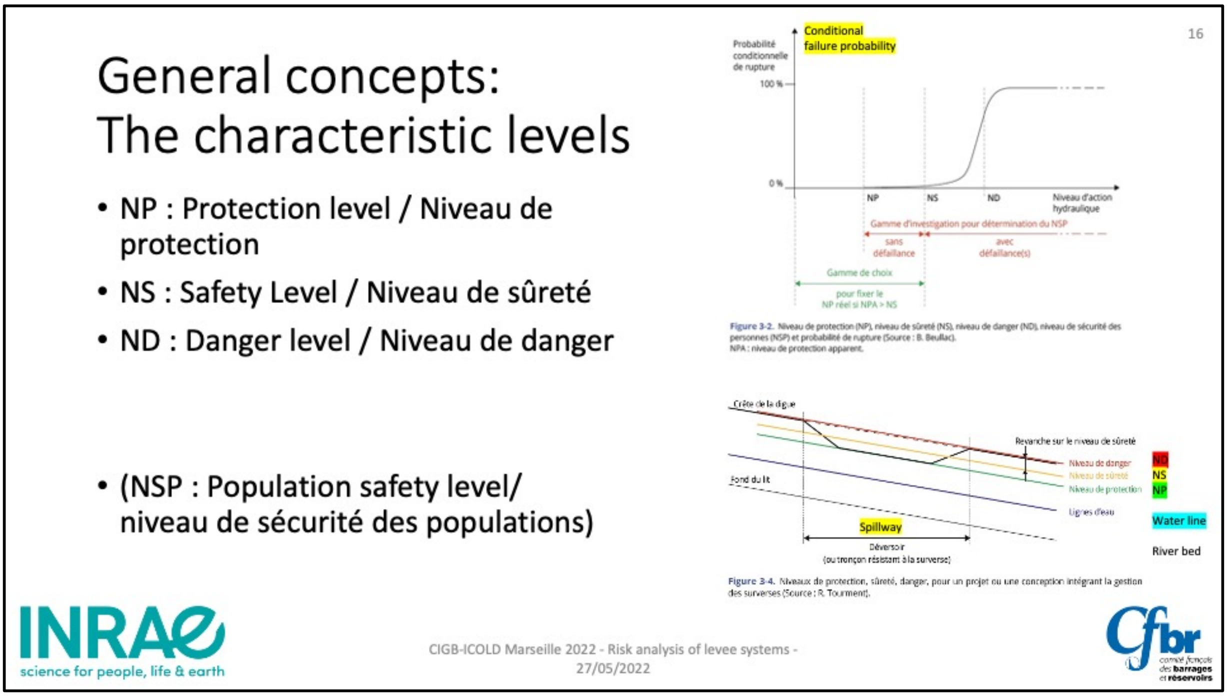
Flood protection systems include a first line of defence that can be associated to:
elements present in the water environment that can reduce hydraulic loads and/or morphological changes ("indirect protection")
elements present in the protected area ("secondary protection")



Some characteristic levels are very useful for risk analysis of levee systems, as well as their functional analysis and failure analysis

Irstea, in France, propose the use of three different loading conditions to assess the performance of a levee or levee system:

- 1 Protection level: the loading condition below which there is no flooding of the leveed area.
- 2 Safety level: the loading condition up to which there will be no major damage to the levee system (a flooding, in controlled conditions can occur between the protection level and the safety level).
- 3 Danger level: the loading condition above which the risk of breach in the levee system is probable.

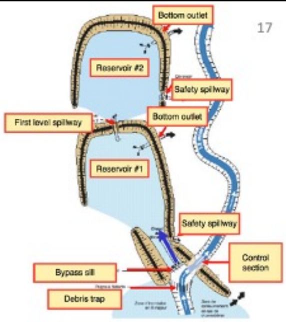
These loading conditions can be objectives, in the case of a project or when the objectives had been previously specified by the authority responsible for the levee system. They also can be findings of the assessment or risk analysis process.

These levels can be expressed either in probability of the loading event and/or in terms of altimetry. Equivalence between the altimetric levels and the probability of the loading event is a complicated matter as different events (or combination of events) can lead to the same altimetric level.

An additional level can be considered but is much more difficult to assess or to define, as it depends on the protected area topography and also of the position of protected assets

General concepts:
Flood storage vs flood protection

- Flood water storage upstream of a floodplain has the effect of reducing water level and so also flood risk in the floodplain
- This storage can be done in :
  - Online flood retention dams
  - Offline flood storage reservoirs (fed by a diversion canal)
  - Large flood retention areas protected by levees up to some level which is inferior to the protection level of downstream areas.
- Flood storage and flood protection have different hydraulic effects and limits



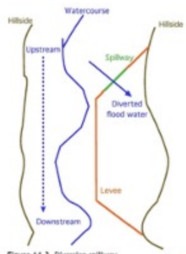


Figure A1.3. Diversion spillway.

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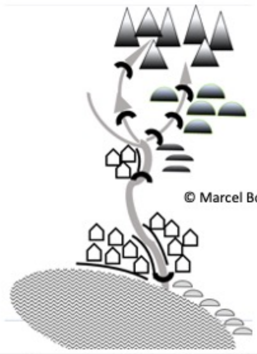
For more information on this comparison, see TOURMENT, R., BEULLAC, B., DEGOUTTE, G., PATOUILLARD, S., MAURIN, J. - 2016. Levees, Diversion Canals or Flood Expansion Areas?. 3rd European Conference on Flood Risk Management FLOODrisk 2016 17/10/2016-21/10/2016, Lyon, FRA. E3S Web Conf. Volume 7, 2016. 3rd European Conference on Flood Risk Management (FLOODrisk 2016). 7 p. https://www.e3s-conferences.org/articles/e3sconf/abs/2016/02/e3sconf_flood2016_12007/e3sconf_flood2016_12007.html

General concepts: Flood storage vs flood protection

- Flood retention lowers the flood discharge downstream, and potentially needs to be taken into account into the analysis of several flood protection systems, in terms of modification of the natural flood event.
- Analysis of this function needs to be made at a larger scale.
- The risk analysis of a flood storage structure/system is different from the risk analysis of a levee system, as their functions are different. It should combine the objectives of a dam risk analysis and of a levee system risk analysis.



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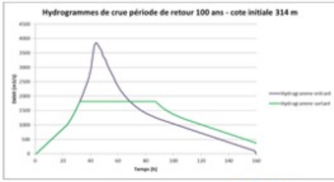

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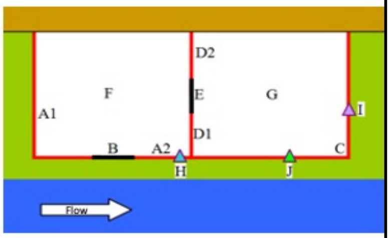
General concepts: Flood storage vs flood protection

- Some of these flood retention areas are sometimes contiguous to protection levee systems, and so part of the same local system as flood protection levees => there is a continuum between protected area and flood retention area.
- In these cases they need to be analysed (at the local scale) in the same system risk analysis, and the levee system risk analysis can be used.



Symbol	Sub-system	Sous-système
A	Levee	Digue
B	Spillway	Déversoir
C	Levee	Digue
D	Levee	Digue
E	Spillway	Déversoir
F	Flood storage area	Casier non urbanisé (stockage de crue)
G	City	Casier urbanisé
H	Flapgate	Organe de vidange (clapet)
I	Valve / gate	Organe de vidange (vanne)
J	Pump	Pompe

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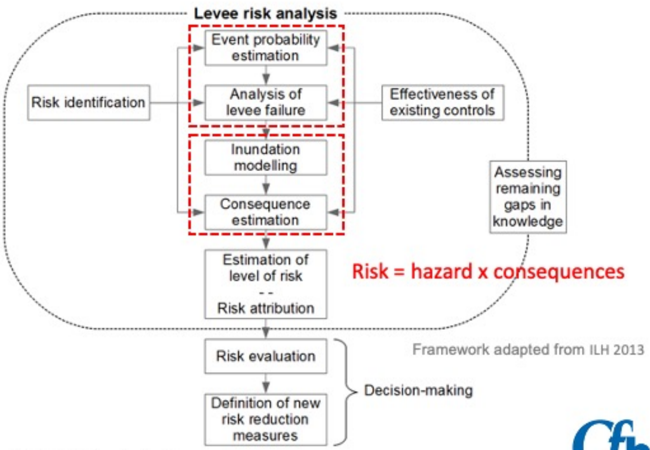
Flood risk analysis of Levee systems

The general framework for Flood Risk Analysis of Flood Protection Systems (1)

- Section 5.2 of the International Levee Handbook (2013) presents a framework with a logical approach for the risk analysis of levee systems
- La section 5.2 de l'International Levee Handbook (2013) présente un cadre pour l'analyse des risques des systèmes de digues avec une approche logique



Framework adapted from ILH 2013

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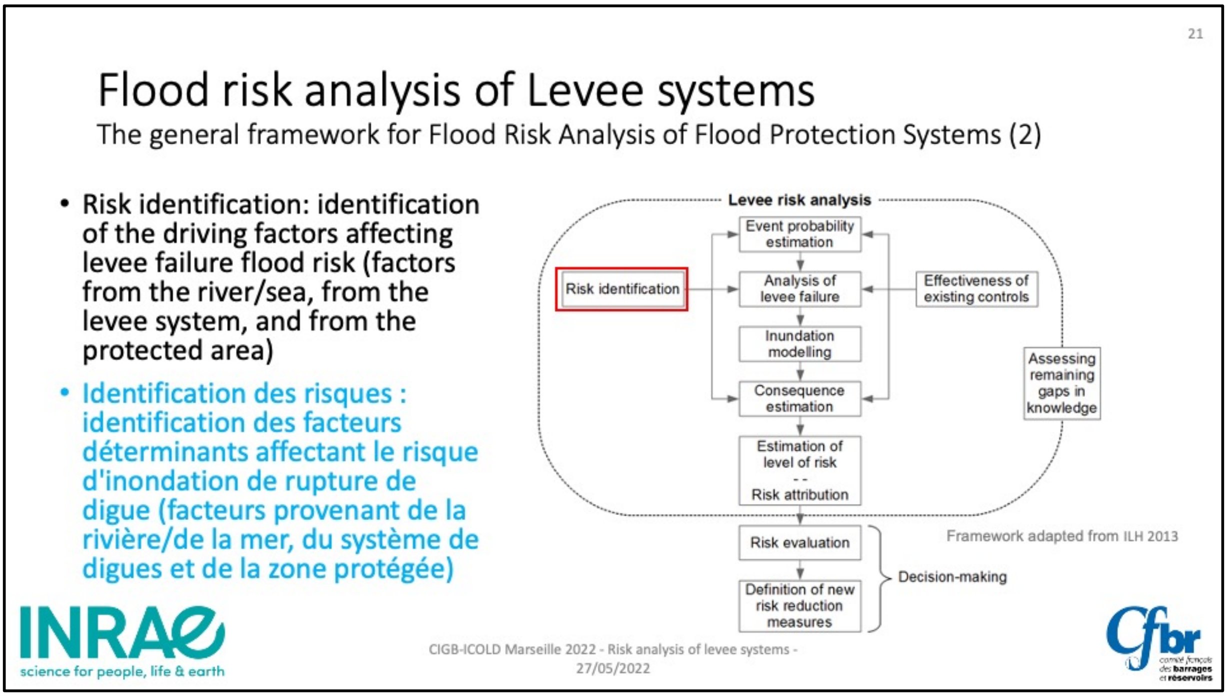
A logical approach framework for risk analysis of levee systems has been developed during the International Levee Handbook project. It is presented in its section 5.2.

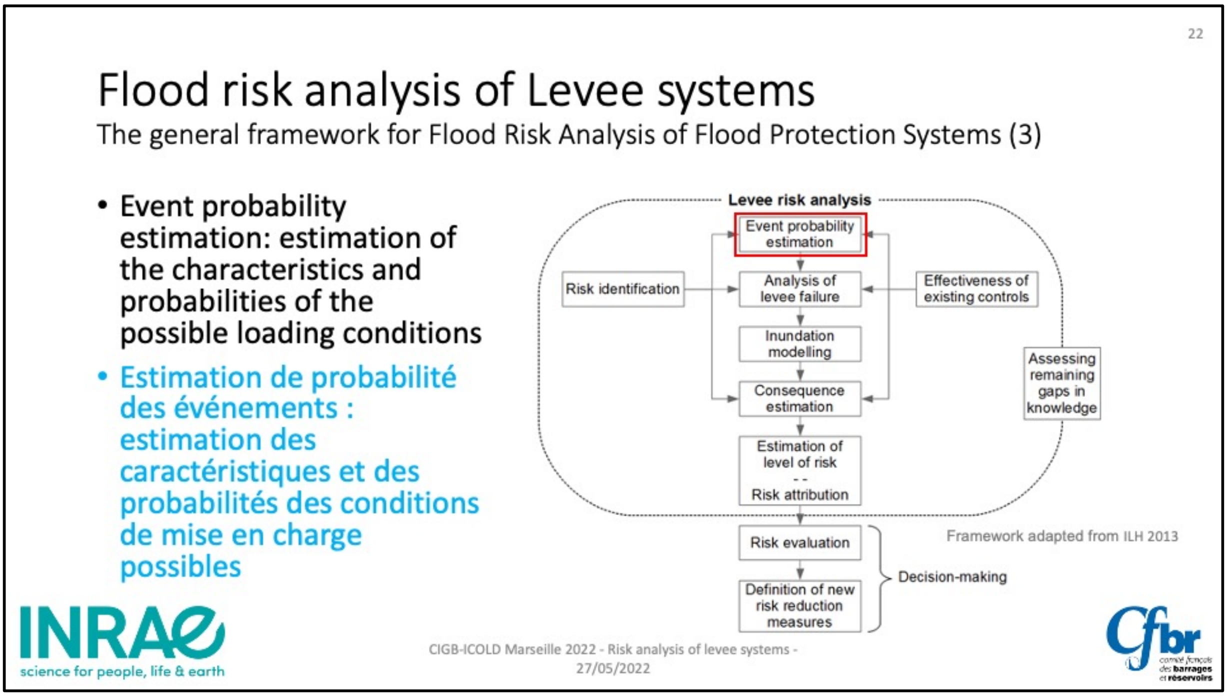
The combination of the results from its different steps leads to risk estimation and then to decision-making activities.



Risk identification is the first step of this framework.
Its objective is to identify the driving factors affecting flood risk for the studied levee system.
These factors relate to the river or the sea (for instance the specificities of hydraulic events or morphodynamic phenomenona), to the levee system (for instance the structural characteristics of levees or the organisation of their management), and to the protected area (with for instance the nature of the assets located in the protected area).
Accidentology is a part of Risk identification, but Risk identification also involves analysis of the whole system and imagination to identify any possible factor of risk

Risk identification (Section 5.2.4): to analyse risk, first the factors affecting risk must be recognised and recorded to identify what might happen and what situations might arise. These factors include those sources-pathways-receptors of the flood system.
To analyse risk, the source, pathway and receptor components affecting risk must first be recognised and recorded to identify what might happen and what situations might arise. The actual risk can be analysed by identifying a chain of causes and effects such as:

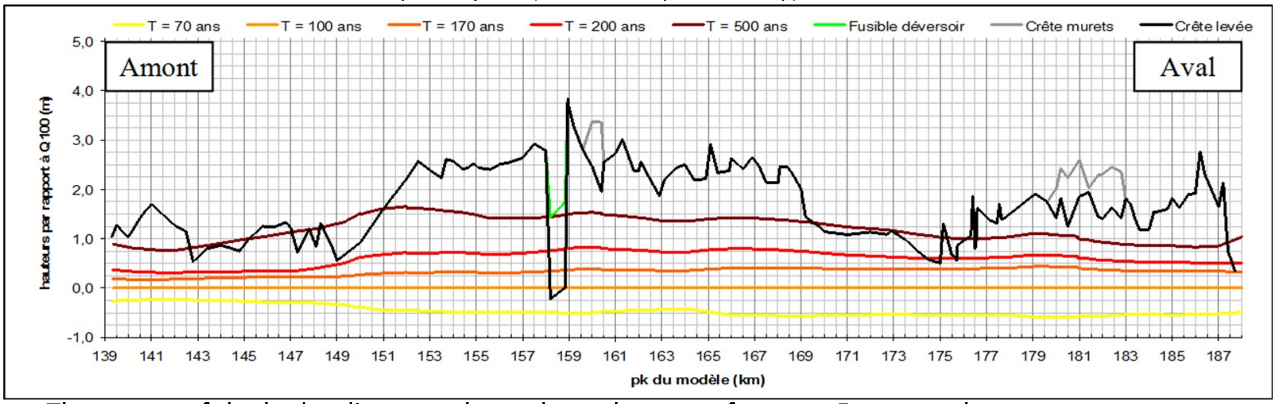
- rainfall or storms causing high water levels that in turn either increase the load on levees or inundate the floodplain
- the increased loads on the defences may cause failure of a levee (see Section 3.5.2),
- which may result in breach growth/progression
- and inundation of the leveed area
- the inundation may lead to casualties (loss of life, serious injury etc) and devastation of property.



Event probability estimation aims to characterize and estimate the probabilities of the possible water loading conditions.

This activity is generally conducted through the analysis of a range of loading scenarios and not for the all possible events which could impact the studied levee system.

Event probability estimation (Section 5.2.5): floods are episodic events. Large floods are rarer than medium sized or small floods. The probability of each size of event can be characterised as the chance that it will occur in any one year (its annual probability).

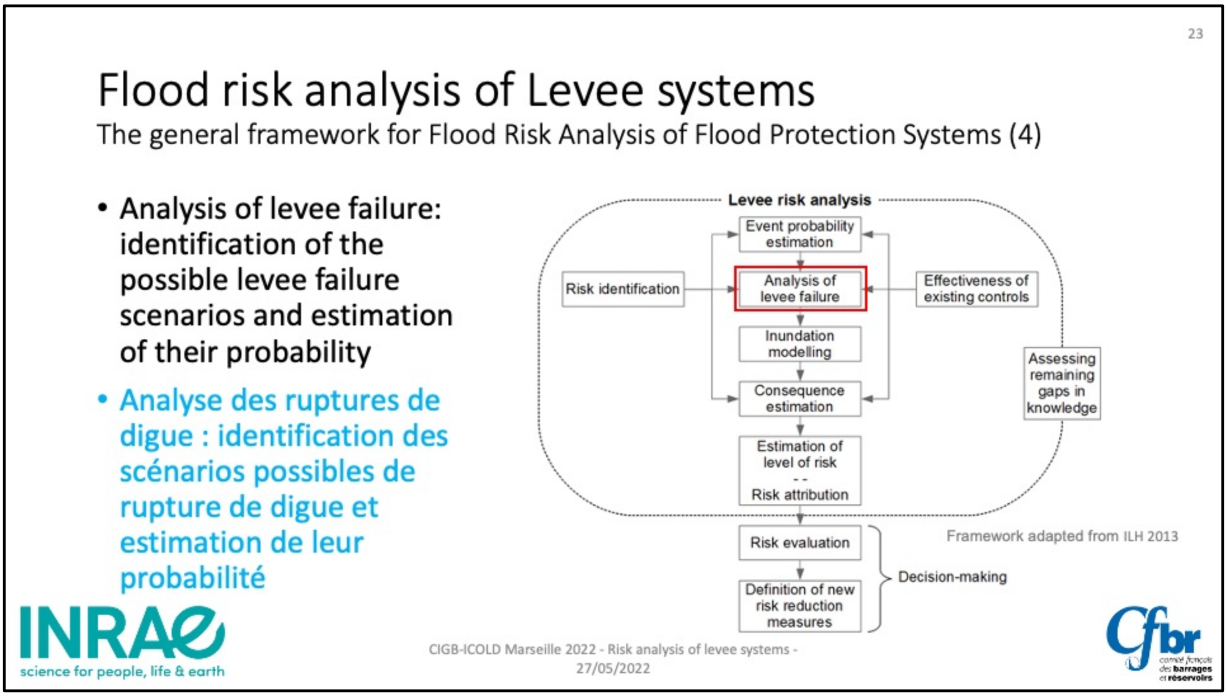


The nature of the hydraulic event depends on the type of source. For example :

- for a watercourse: excess rainfall and/or dam failures caused by floods,
- for the sea: storms or earthquakes cause coastal flooding or tsunamis.

The load on the levees can be increased or decreased by other random events such as:

- failure of other dyke or dam systems,
- jams (ice, driftwood, etc.).



Two steps : assessment of levee failures (including identification of possible failure modes) using different possiblemethods then estimation of the probabilities of these different failure scenarios

The levee failure analysis aims to identify the possible failure scenarios for the levee system and to estimate their occurrence probability. This activity is mainly linked to diagnosis and structural assessment of levee segments performance but is also linked to the characterization of the hydraulic effect of the all levee system.

The subject of the analysis of the failure of levees is detailed in Section 5.3 of the ILH. The purpose of this section is to show how the result of a levee assessment is used as an input into a wider flood risk analysis of a levee system, particularly as this result then needs to be expressed as a probability.
Levees are rarely uniform in materials, methods of construction, geometry, reliability etc (Section 3.3) and this variability influences the probability of failure. So, the likelihood/probability of failure for a levee system must be evaluated for each levee segment using a functional analysis of the levee (as shown in Figure 5.10) including the levee components, the components' functions, and the functionally homogenous parts of the levee length.

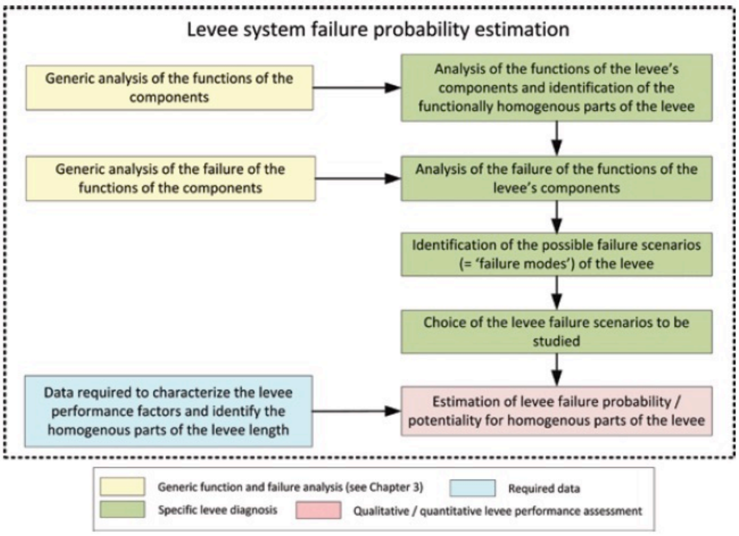
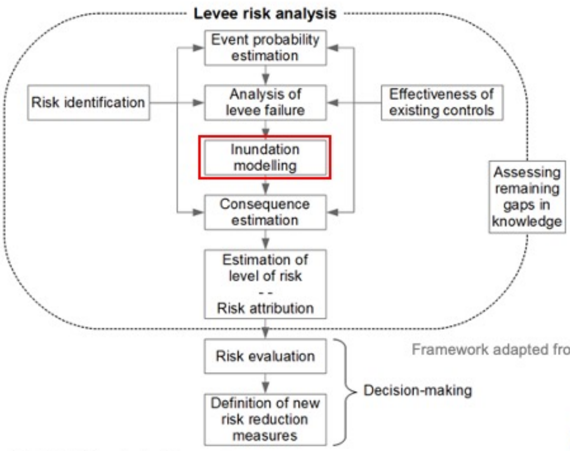


Figure 5.10 Levee system failure probability estimation (courtesy B Beullac and R Tourment, Irstea)

Flood risk analysis of Levee systems

The general framework for Flood Risk Analysis of Flood Protection Systems (5)

- Inundation modelling: identification and characterization of inundation routes and flood spreading (flood duration, flow velocity, water level and elevation speed, and reach time)
- Modélisation des inondations : identification et caractérisation des chemins d'inondation et de propagation des inondations (durée de l'inondation, vitesse d'écoulement, niveau et vitesse d'élévation de l'eau, temps d'atteinte)



Framework adapted from ILH 2013

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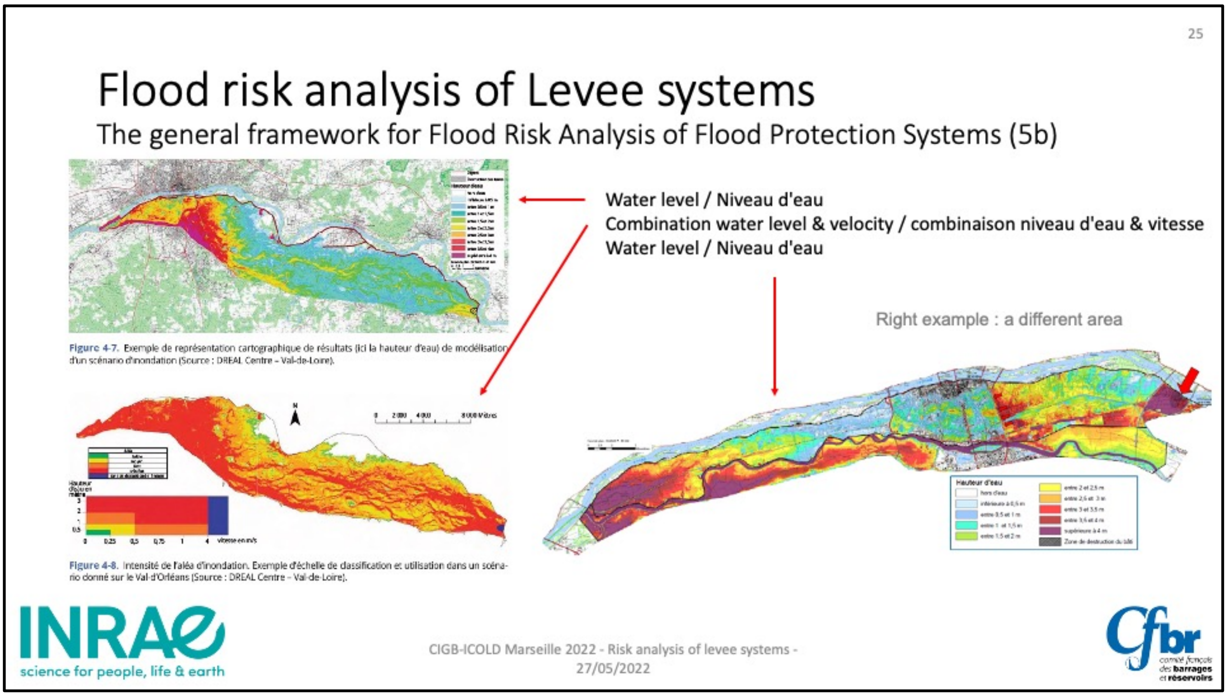
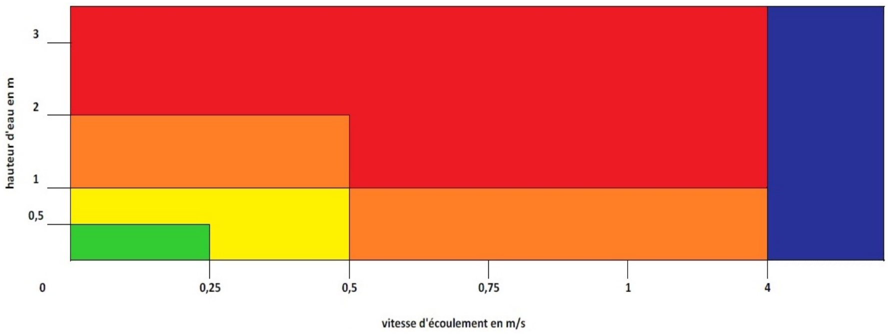
Inundation modelling deals with the identification and characterization of inundation routes and flood spreading in protected area.
This characterization is made for a range of significant inundation scenarios, and in terms of flood duration, reach time, flow velocity, water level and elevation speed.

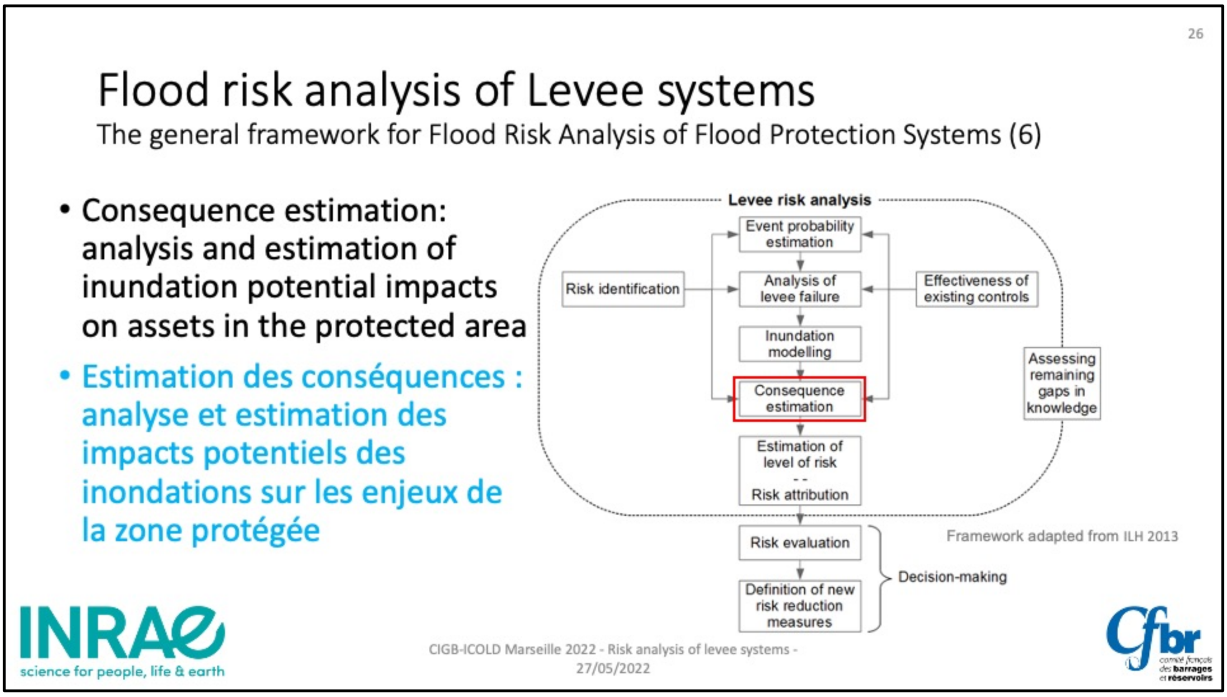


Left example : same flood event, presented with two different types of results : water level (above) and (below) combination (based on the following diagram) of levels (vertical axis) with water velocity (horizontal axis) representing the flood "hazard level"

	aléa
	faible
	moyen
	fort
	très fort
	zone de destruction du bâti



Right example : different area, water levels



Consequence estimation analyses and estimates the potential impacts of inundations on the assets located in the protected area.

This activity consists in the combination of the results of inundation modelling with the estimated vulnerability of the different assets which have been identified and located inside the protected area.

Evaluating the consequences of inundation in the leveed area (see Figure 5.13) requires combing the net results of hydraulic modelling of potential inundations (see Box 5.4) and the estimated vulnerability of the different assets identified and located in the leveed area.

A leveed area can contain many different types of assets, including:

- people
- buildings
- natural/undeveloped areas
- agriculture
- factories/business
- critical infrastructure: transport, utility and communications networks
- recreational areas
- nature conservation areas.

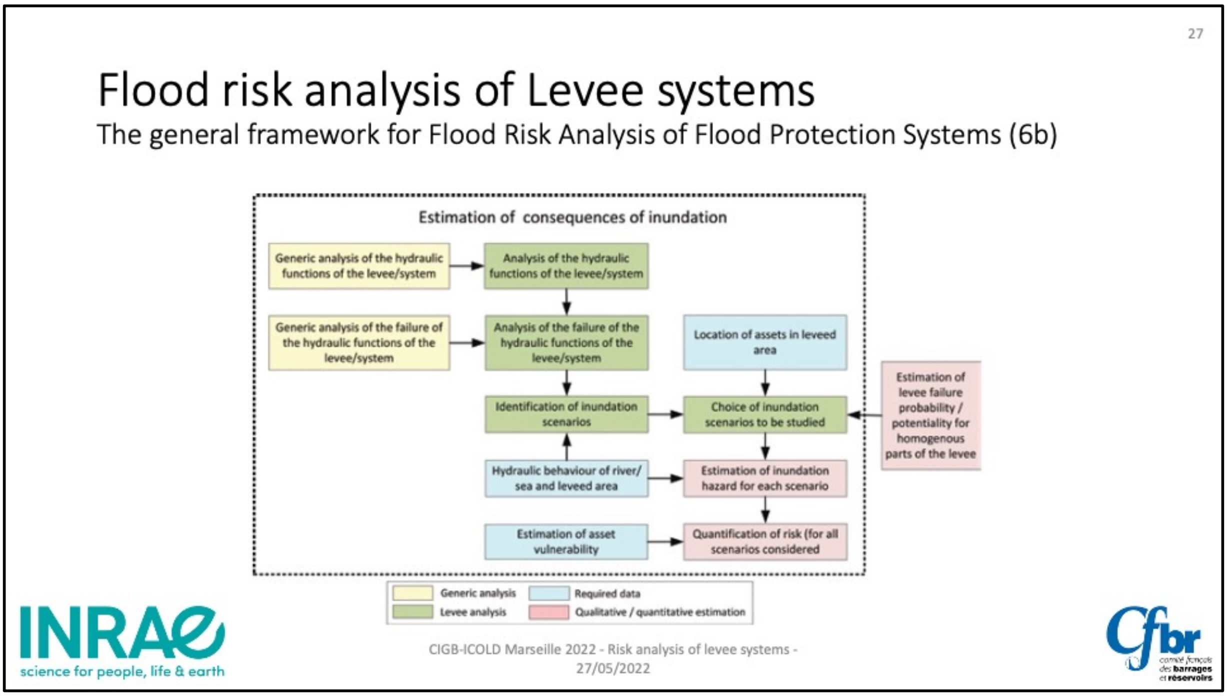
The extent of the impact on these receptors of flooding in the leveed area depends on key inundation characteristics such as:

- depth of the floodwater
- flow velocity of the floodwater
- duration of the inundation
- speed of rise of the water levels
- the time from breach to impact.

The impacts are also dependent on and interact with the characteristics and quality of the water (salt/fresh, temperature, turbidity, pollutants etc).

To evaluate impacts, the people and assets in the leveed area should be identified and geographically referenced. Their vulnerability also needs to be assessed. Vulnerability of an asset is a function characterising its damage according to the hydraulic characteristics of the inundation (ie water level, flow, duration).

Control measures taken to limit the consequences of an inundation, like f lood warning, organisation of evacuation, shelters, including an estimation of their efficiency, should be taken into account in this analysis.



On the right : an example of an identification of different types of assets inside a protected area

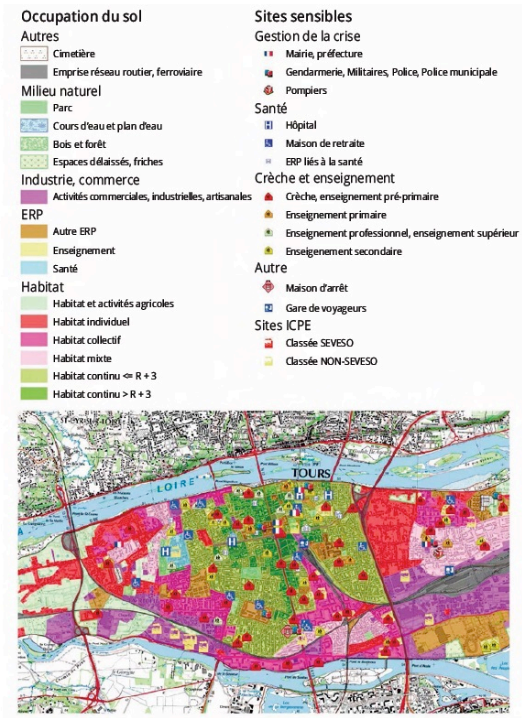
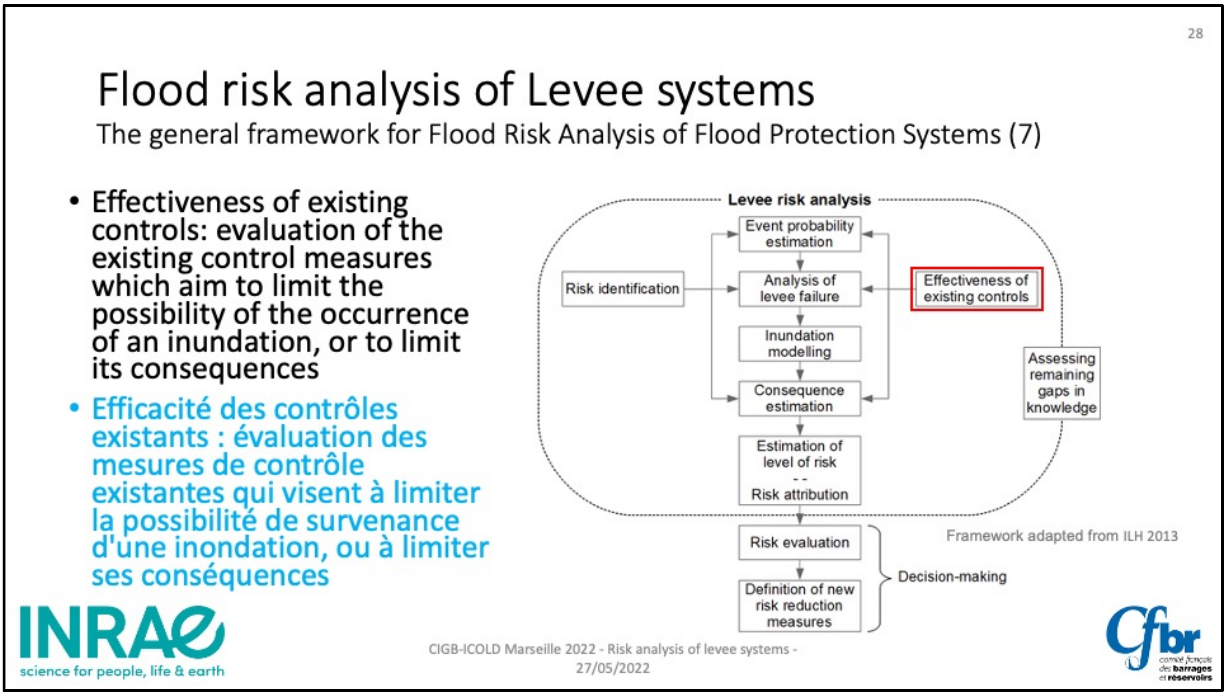


Figure 4-9. Recensement et localisation cartographique des enjeux sur le Val-de-Tours (Source : DREAL Centre – Val-de-Loire).



The evaluation of the effectiveness of existing controls aims to characterize the existing measures which aim to limit the probability of inundations, or to limit their consequences.
For instance, these measures can be a flood alert system about the water environment, a levee maintenance organization about the levee system or a population evacuation plan about the protected area.

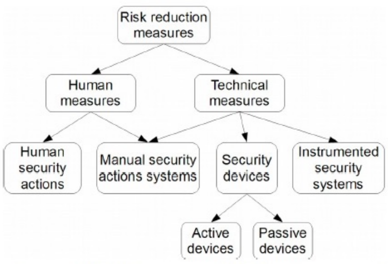


Figure 2. The different types of risk reduction measures in industrial context [6]

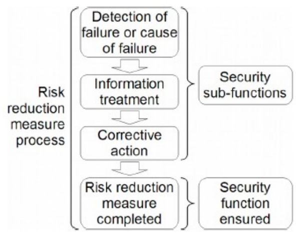
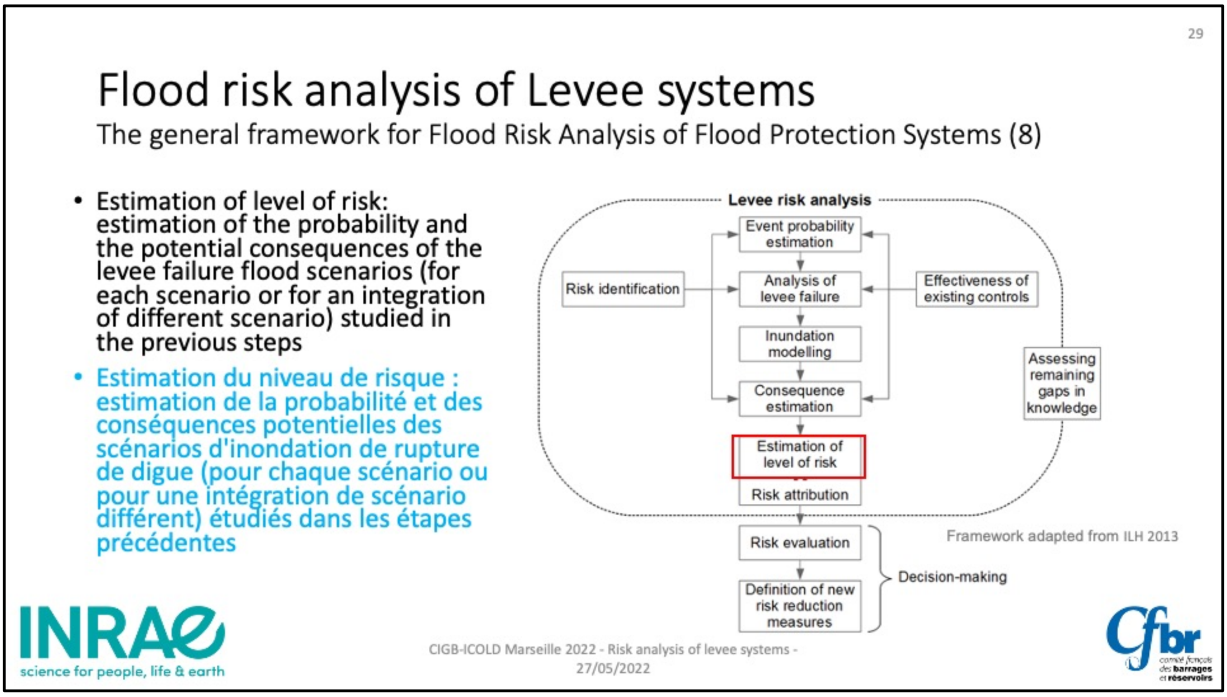


Figure 3. The risk reduction measure process and the security sub-functions sequence to ensure security functions

Effectiveness of existing controls: controls are measures, either structural or non-structural, taken in order to limit the possibility of occurrence of an inundation, or its consequences. They can apply either to the source (eg breakwaters, and upstream flood management including dams), pathway (eg levee maintenance, monitoring, and emergency management) or receptor (eg flood warning, population evacuation, and resilient buildings) parts of the system. Existing controls can and should be taken into account in the estimations of the event probability, of the levee failure, and of the consequences of the inundation.



Risk estimation is the final step of risk analysis. It consists in a mechanical step which aims to combine the probability and the potential consequences of the inundation scenarios whose characteristics have been estimated during the previous steps of risk analysis. It concludes on the level of risk for each studied inundation scenario.

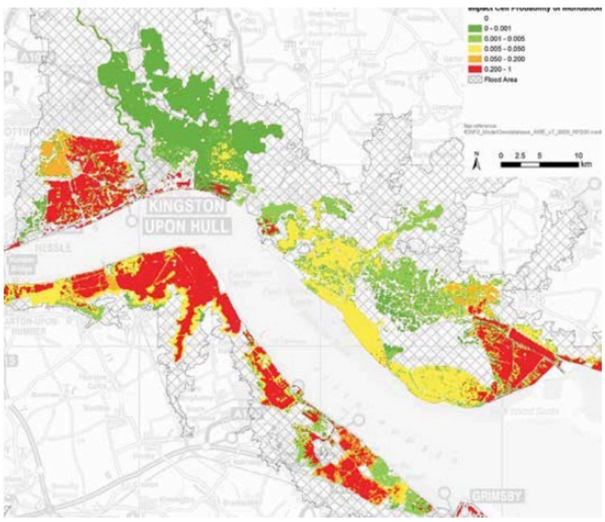


Figure 5.15 Example of a probability of inundation map in the UK (courtesy Environment Agency)

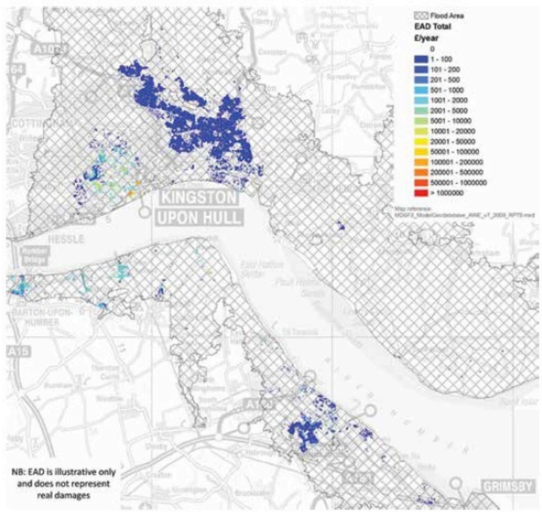
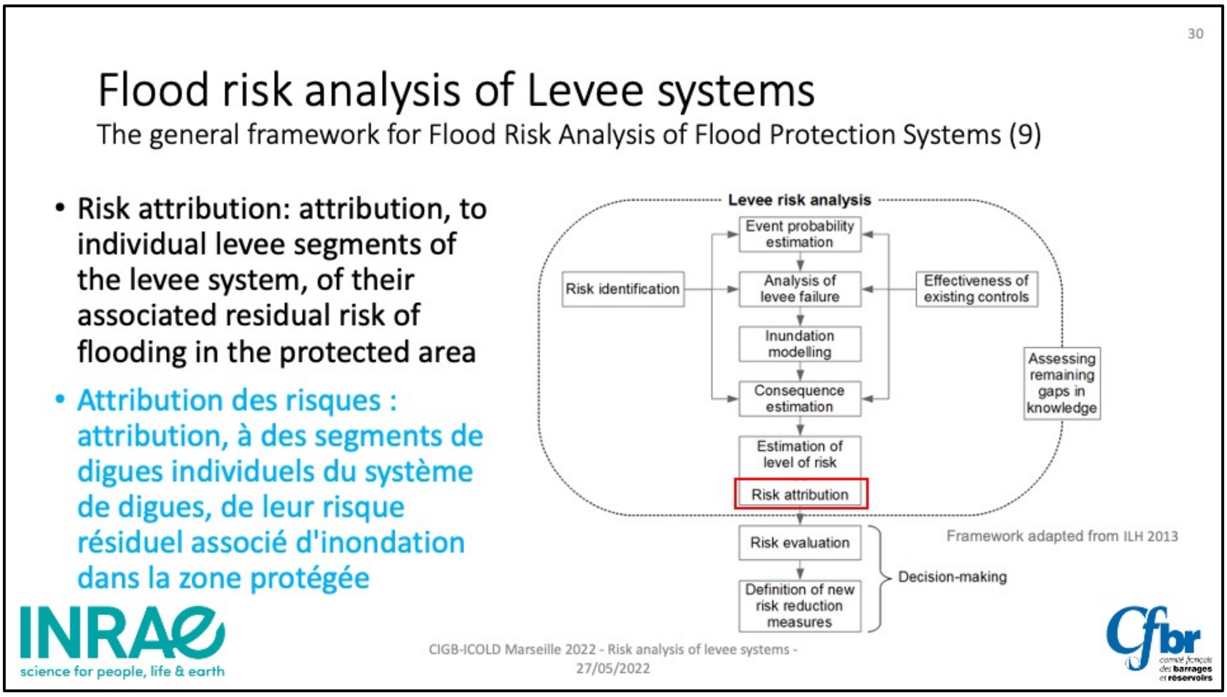


Figure 5.16 Example of an expected annual damage map in the UK (courtesy Environment Agency)



Risk estimation can optionally be completed by a risk attribution step. Its objective is to attribute to individual levee segments of the levee system, the residual risk of flooding they represent for the protected area. This activity can be especially tricky and resource consuming.

Even though levee segments work together in a levee system, they are not all equally reliable and so do not contribute the same level of risk reduction to the whole. This is because:

- some levee segments may have lower or more variable crest levels than others, so may overtop more readily
- some levee segments may be weaker structurally than others, so may breach more readily
- some levee segments may have less efficient maintenance, monitoring, or emergency management.

The attributed flood risk associated with a particular levee segment is the residual risk arising from inundation of the leveed area (in terms of flooded area, water levels, time, flow velocities and depth etc) as a result of the probability of overtopping or breach of that particular levee segment. So, risk attribution is the process of quantifying the level of this residual risk associated with different levee segments.

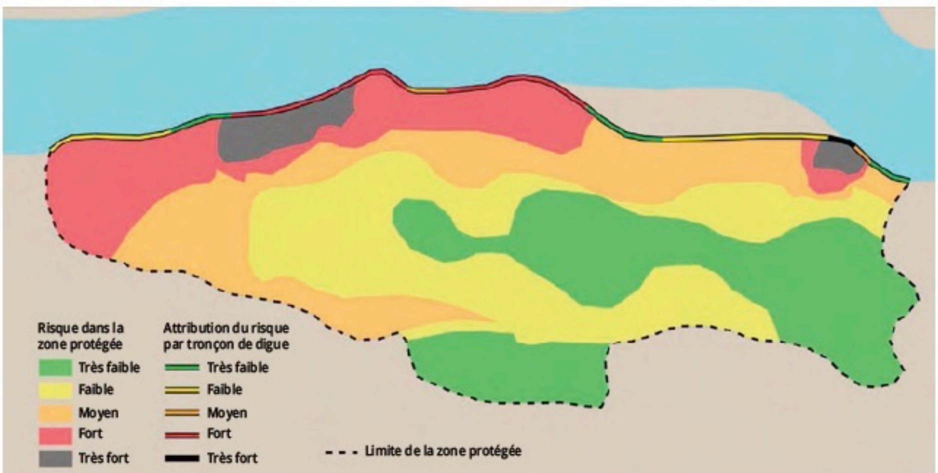
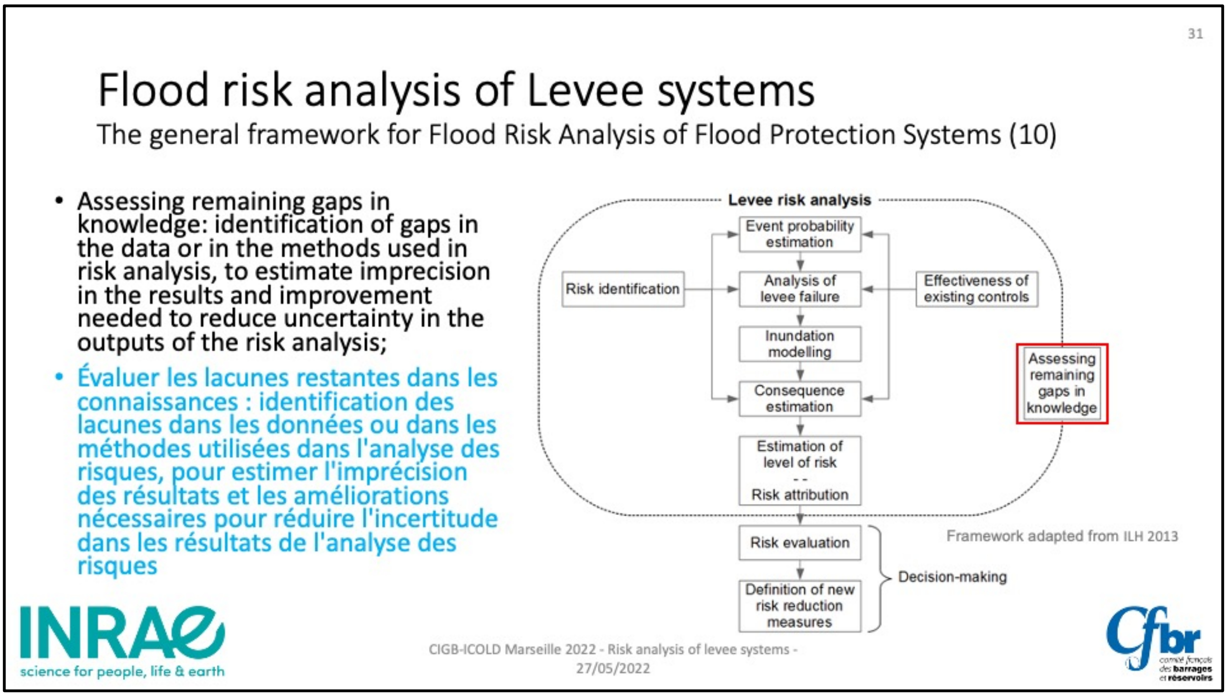


Figure 4-11. Exemple d'attribution du risque (Source : B. Beullac).

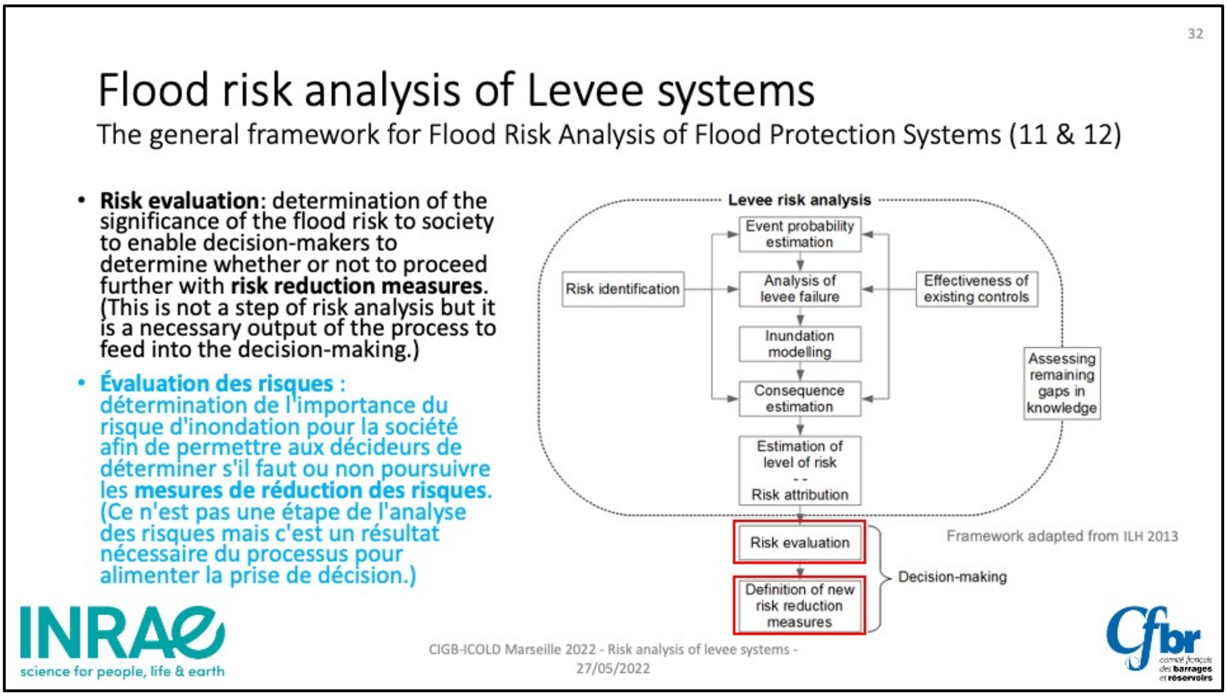


Assessing remaining gaps in knowledge consists in the identification of :

- gaps in the data or
- in the methods used to perform risk analysis.

This activity aims to estimate imprecision in the results and improvement needed to reduce uncertainty in the outputs of all the different steps of the risk analysis framework.

The level of uncertainty that is acceptable will depend upon the application of the risk analysis and on the perceived receptors at risk. So, the determination of the appropriate level of analysis will need to be ascertained through a tiered approach to risk assessment as described in Sections 2.1.3.3 and 5.2.1. This review should include determining the requirements of the risk assessment and setting the risk criteria. The process should question basic assumptions as to the applicability of the data used (age, resolution, original purpose of use etc), how expert review and judgement should be used, and how the proposed approach compares to other risk assessments.



Finally, risk evaluation determines the significance of flood risk to society by evaluating if the estimated risk is acceptable, tolerable, or unacceptable.

Risk evaluation enables decision-makers to determine if new risk reduction measures are needed to reduce flood risk in the protected area.

Decision-making is not a step of risk analysis but it is a necessary complement to the process to feed into the general risk management process.

Likelihood of failure/ inundation	Consequence of failure/inundation				
	Insignificant	Minor	Moderate	Major	Severe
Almost certain	M	H	H	E	E
Likely	M	M	H	H	E
Possible	L	M	M	H	E
Unlikely	L	M	M	M	H
Rare	L	L	M	M	H

Rating risk level

E	Extreme risk
H	High risk
M	Moderate risk
L	Low risk

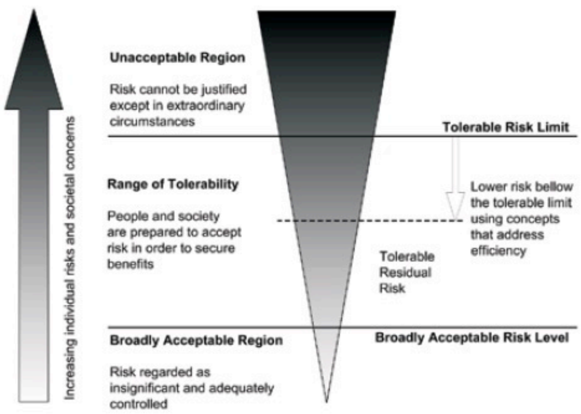
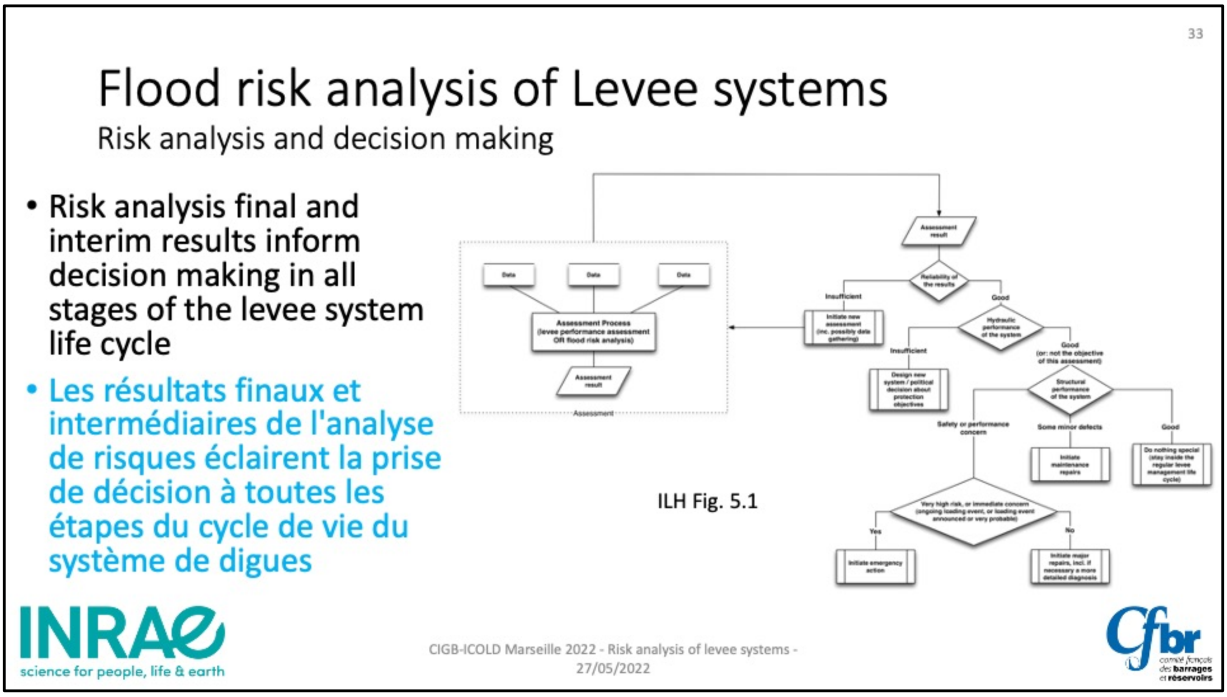


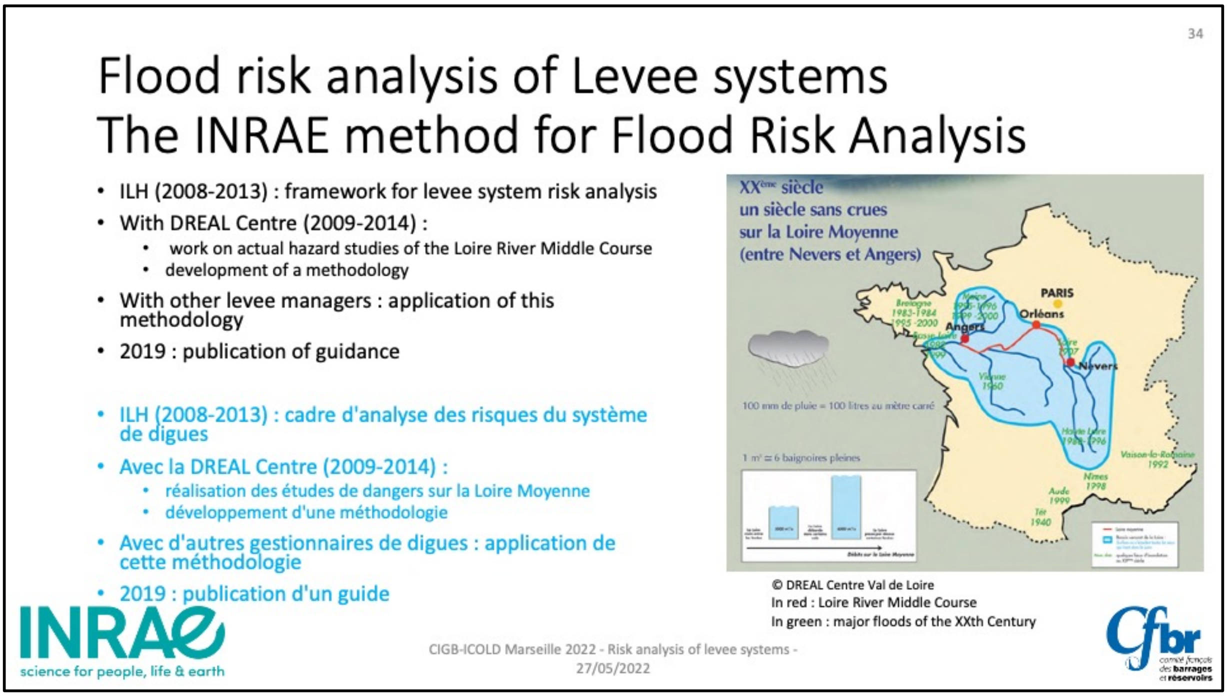
Figure 5.18 Acceptability of risk (adapted from HSE (2001) by Munger et al (2009))



Risk analysis results (final and interim, as well as some data gathered during the process) help to inform decision makers to better manage flood risk behind levees, either to maintain the current level of risk if it's acceptable or to lower this level if it's not. By looking at all the different components of risk that have been analysed (and that we have presented in the general framework and in the INRAE method) and their influence in the final risk level, it's possible to identify the leading factors on how to maintain or improve this level.

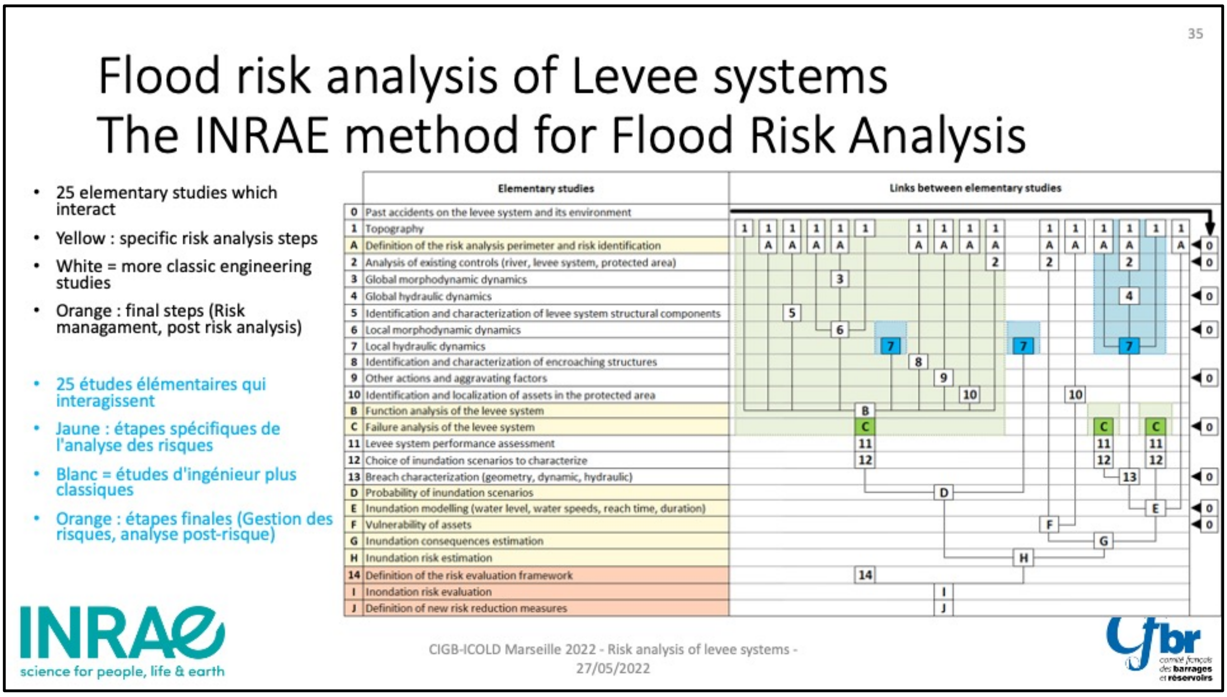
A risk analysis of the levee system, taking into account the levee performance assessment and the people and physical assets in the leveed area, helps levee system managers prioritise the actions that need to be taken after the assessment process (and hence optimise their investment strategy). These actions can include, for example:

- carrying out an emergency response or procedure
- conducting a complete diagnosis of some part of the system (most likely based on differentiation of levee segments according to their performance) in order to design and implement remediation of structural problems
- undertaking some ‘routine’ maintenance repairs
- doing nothing special but keep on inspecting and assessing the levee system.



In parallel of the work on the International Levee Handbook, INRAE worked with DREAL Centre (Levee Manager of the levee systems of the Loire River Middle Course) to prepare the hazard studies of its 3 major levee systems (Class A).

No actual method for conducting these studies existed, and this work was the occasion to develop one, since then applied on tens of other systems, and formalized in a handbook describing this methodology.



The INRAE risk analysis method for levee systems identifies 25 elementary studies which interact to finally produce a risk estimation, a risk evaluation and help the definition of risk reduction measures. This structured and integrative method helps to organize the risk analysis process to produce consistent results.

Objective of the method: to formalize an integrative approach to improve:
- the overall consistency of the risk analysis
- its completeness
- and the quality of its results

Proposal: break down and structure the risk analysis into thematic **elementary studies**
The structuring of the method: a framework for carrying out the risk analysis:
- to guide the identification and characterization of all risk components
- to describe how to analyse and combine risk components to obtain risk estimation

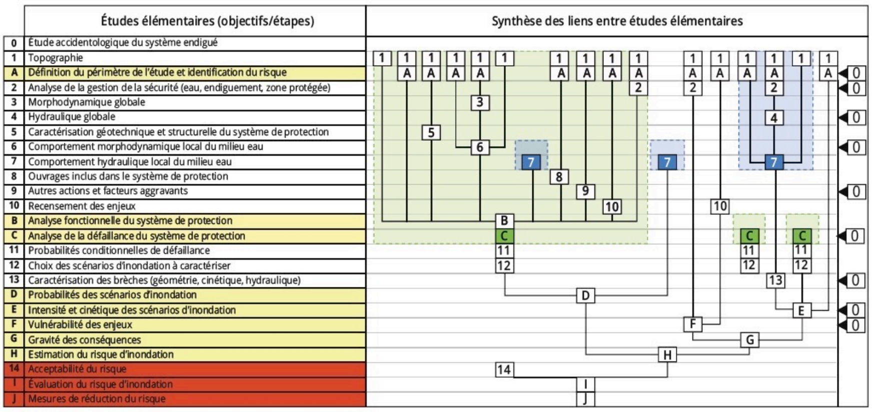
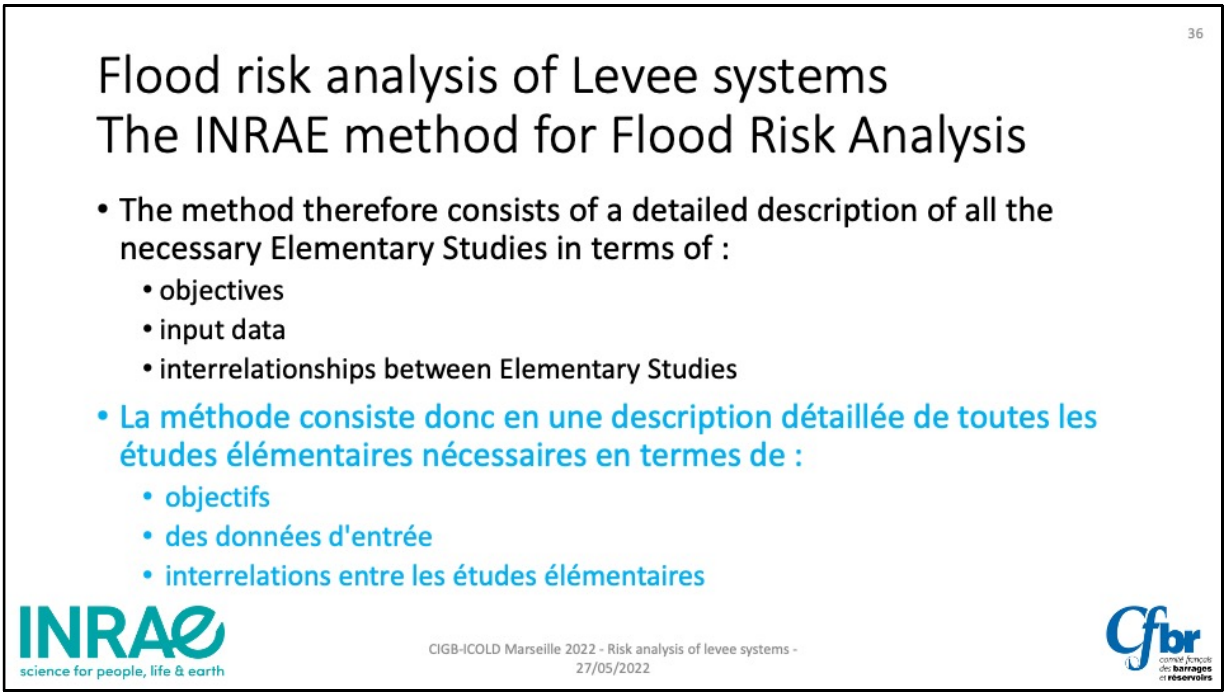


Figure 5-3. Décomposition de l'analyse de risque en études élémentaires (Source : B. Beullac).
En blanc : les données d'entrée nécessaires ; en jaune : les étapes de l'analyse de risque ; en rouge : l'utilisation des résultats de l'analyse de risque.



The method therefore consists of a detailed description of all the necessary Elementary Studies in terms of :

- objectives
- input data
- interrelationships between Elementary Studies

Objectives (results to be produced) and process

Including description of any specificities related to river, marine and torrential environments

Required input data:

Results of other elementary studies,

Manager data,

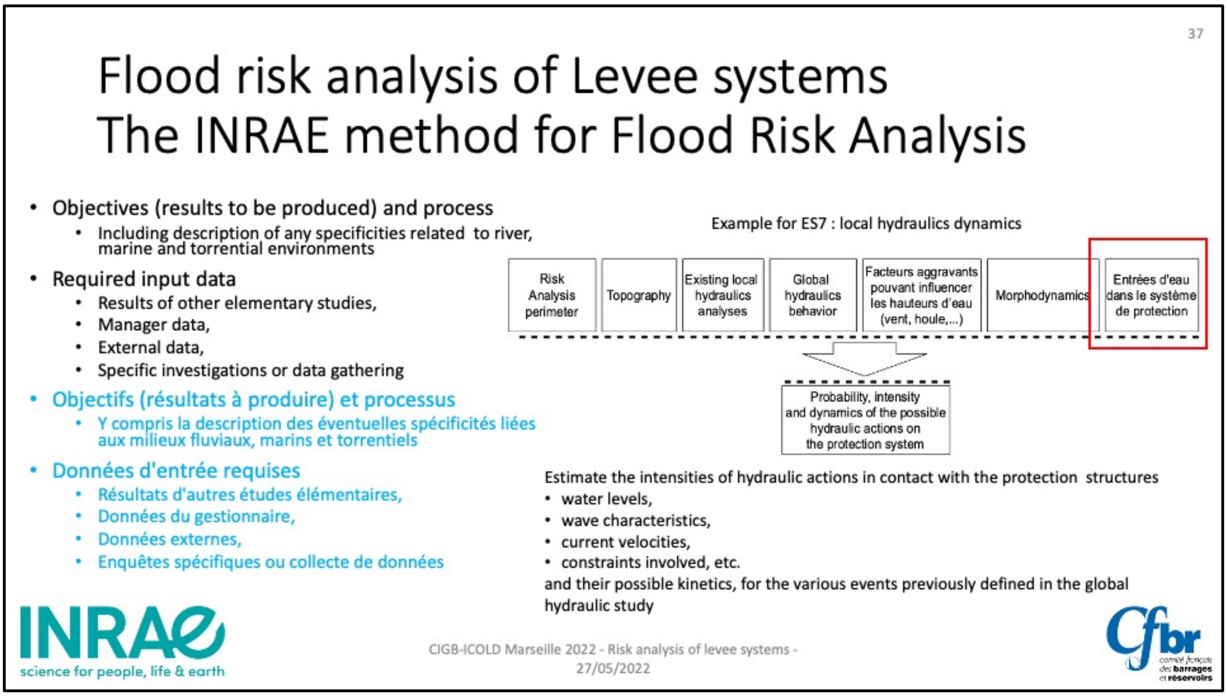
External data,

Specific investigations or data

Interrelations (data exchanges) with other elementary studies

Simple interrelationships: the result of one study is used as input for another (simple arrows),

Complex interrelationships: need to go back and forth when carrying out the two studies (double arrows).



Objectives (results to be produced) and process

Including description of any specificities related to river, marine and torrential environments

Required input data:

Results of other elementary studies,

Manager data,

External data,

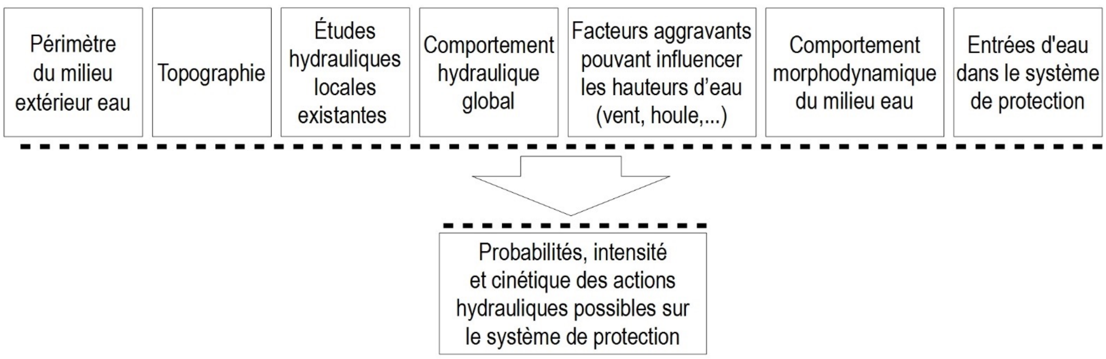
Specific investigations or data gathering

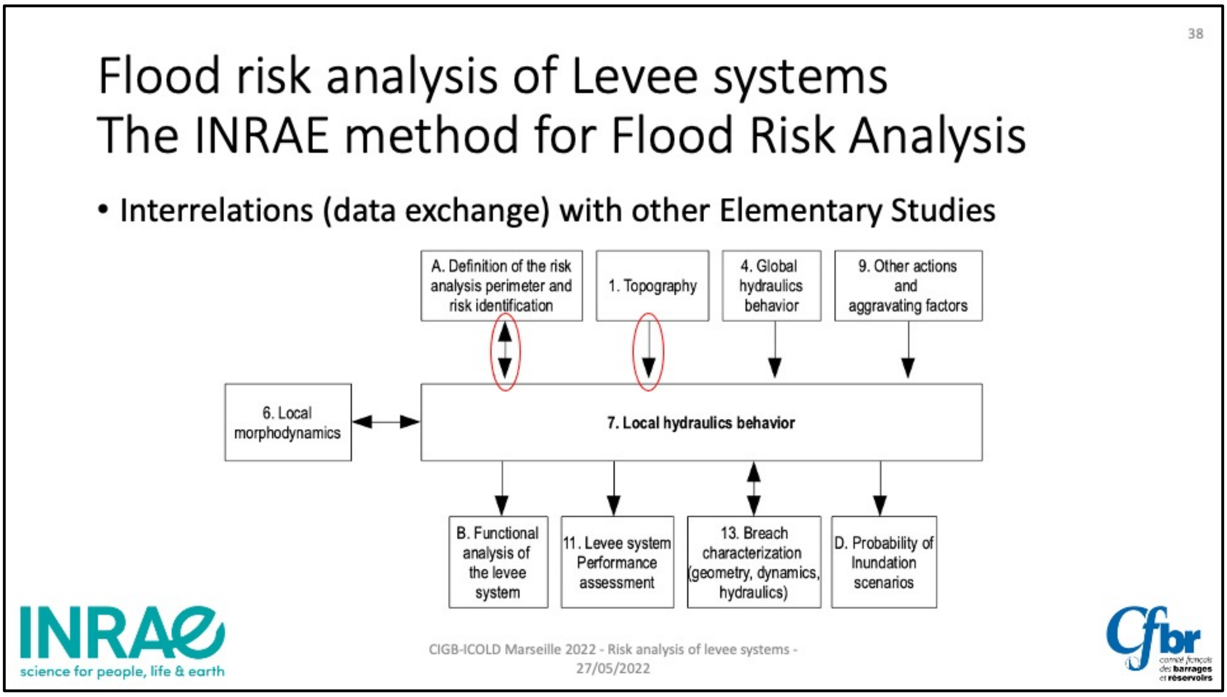
Example for ES7 "Local Hydraulics dynamics" :

Estimate the intensities of hydraulic actions in contact with the protection structures

- water levels,
- wave characteristics,
- current velocities,
- constraints involved, etc.

and their possible kinetics, for the various events previously defined in the global hydraulic study





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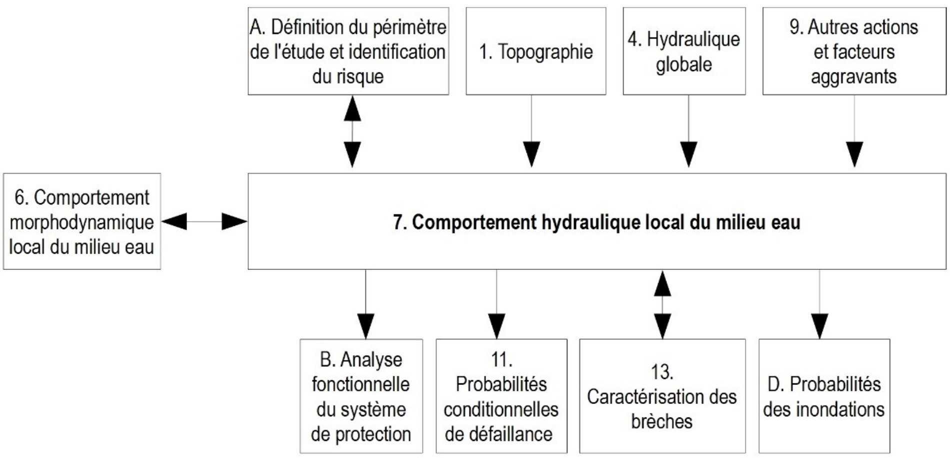


Flood risk analysis of Levee systems
The INRAE method for Flood Risk Analysis

- Advantages of this integrative method
  - Generic, it is applicable in all type of environment
  - More logical and modular than if it had remained centered on the EdD layout from the regulation, it makes it possible to overcome any regulatory changes,
  - The structure in elementary studies facilitates:
    - the reuse and updating of the results of previous analyses,
    - the reassessment of the performance of the structures and the risk they represent (as part of their daily management, and during regulatory updates of the hazard study).
- Detailed methods for the elementary studies are not defined. So up-to date methods can be used, and the risk analysis can easily be updated and/or improved when new methods are developed or new data gathered

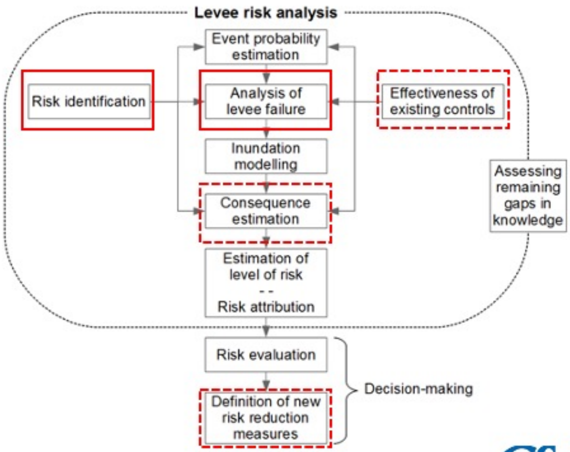
Flood risk analysis of Levee systems
Link between flood risk analysis and failure modes analysis

- Failure analysis (that can be based on a functional analysis) of a levee system is an important part of a levee system risk analysis
- Failure mode analysis (that can be based on a functional analysis) of a levee (eventually a levee segment) is an important part of a levee safety assessment (or diagnosis). A recent report of ISSMGE TC201 on "Failure paths for levees" presents the importance of considering chains of mechanisms (failure scenarios)
- These analyses can be conducted by a "simple" expert judgement based on individual and/or collective experience or by using a more structured method

Flood risk analysis of Levee systems

Link between flood risk analysis and failure modes analysis

- In the general framework for levee system risk analysis, this important activity is not detailed as a specific step, as it may be used at different steps of the process
- In the INRAE methodology we detail functional analysis and failure mode analysis of levees and of the levee system as important
- A specific method for these analyses has been developed and it is the topic of the next presentation by Bruno Beullac



INRAE science for people, life & earth

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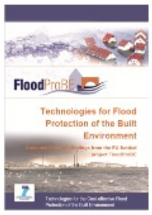
Main References
(more in the binder)

- http://www.ciria.org/ILH
- http://floodprobe.eu



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