Thibaut Mallet

Thibaut Mallet is a hydraulic engineer having 24 years of experience. After working in Sri Lanka and Mali from 1995 to 1998, he joined the Agricultural Ministry as a civil engineer. Following the 2002 flood in the Gard province and the Rhône flood of 2003, he became Project Director for the construction of small dams and reconstruction of levees (Aramon, Comps...). In 2006, he became Deputy General Manager of SYMADREM, a public institution in charge of the management of river and sea levees in the Rhône Delta River (240 km). He is now implementing a 400M Euros program to reinforce the Rhône levees. As part of the French regulation related to levees, he developed a model to evaluate breach probability following the guidelines of ICOLD bulletin 164. He presented his work at ICOLD annual meetings in 2014, 2016 and 2018.

Quantitative Risk Assessment for flood protection embankments using ICOLD Bulletin 164: the Symadrem experience

Internal erosion workshop

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ICOLD Ottawa, Friday 14 June 2019

Presentation of SYMADREM

A public institution responsible (25 people) for :

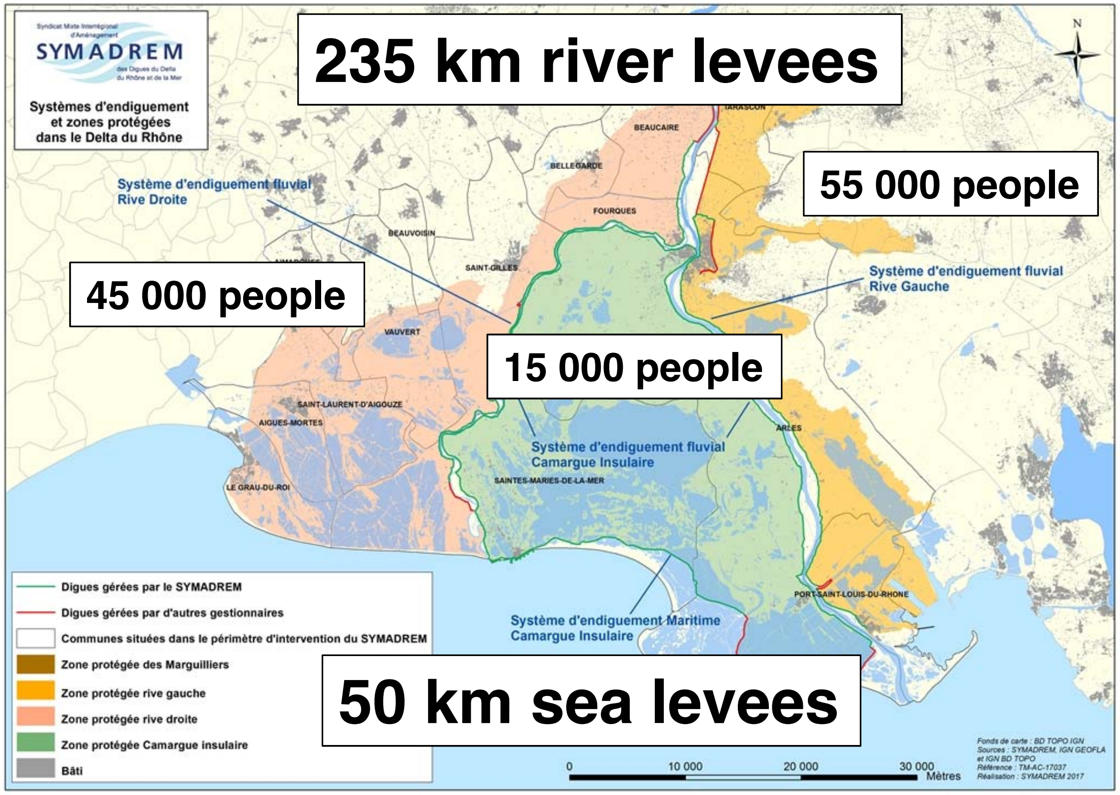
- operations and maintenance of levees in all circumstances
- levees improvement works (400 millions euros over 20 years)

$Q_{10} = 8\,500\ m^3/s$

$Q_{100} = 11\,500\ m^3/s$

$Q_{1000} = 14\,500\ m^3/s$

3 river levees systems and 1 sea levees system



210 km embankment levees

25 km infrastructures

30 closing gates

350 crossing hydraulic structures

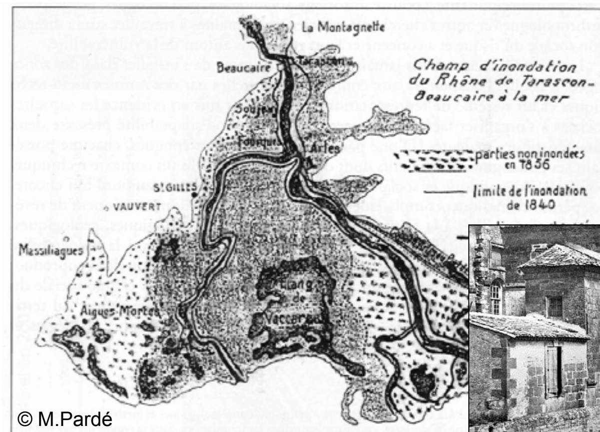
Inundations by breaches

in 1840, 1841, 1843, 1846, 1856, 1993, 1994, 2002, 2003

December 2003 **Q = 11 500 m³/s** **T = 100 years**

4 breaches
Spilling volume ≅ 230 million m³
Cost of damages ≅ 700 million €

November 1840 & May 1856



Q ≅ 12 500 m³/s

T >> 100 years

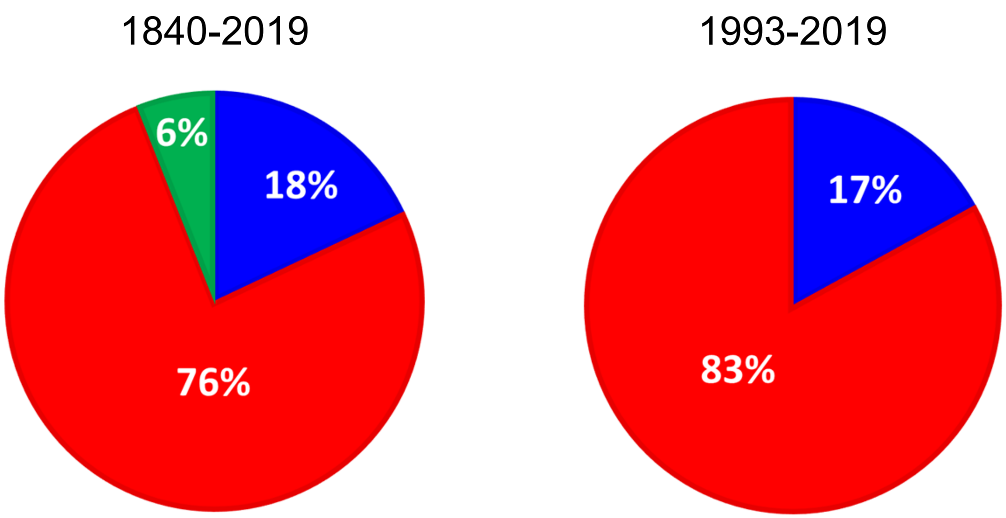
Spilling volume in 1840 ≅ 2800 million m³

Spilling volume in 1856 ≅ 1800 million m³

Estimated cost of damages today ≅ 2,8 billion €

Accidentology from 1840 to today

57 breaches (with inundation) and 57 breaches in progress (no inundation)



Breaches and breaches in progress

overflowing ■ internal erosion ■ scour

Internal erosion => concentrated leak erosion

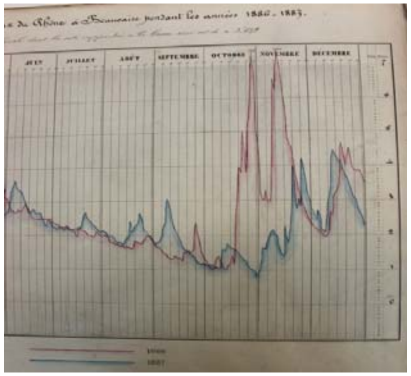
80 % in badger burrows

20 % along crossing pipes

Development of probabilistic model

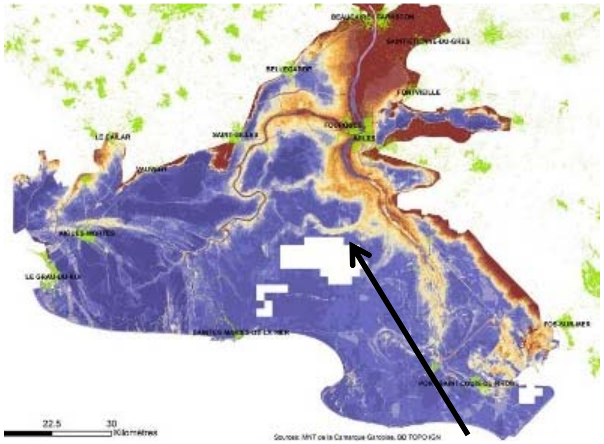
MOTIVATIONS FOR A PROBABILISTIC APPROACH

easing identification of the probabilistic nature of the hazard (data since 1816).



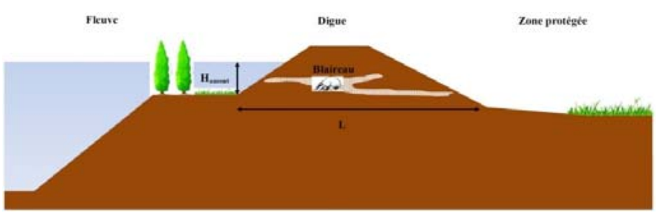
heterogeneous facies of the levees, due to the successive stages of their construction since the 12th century

heterogeneities of foundation due to multiple changes of the Rhône bed.

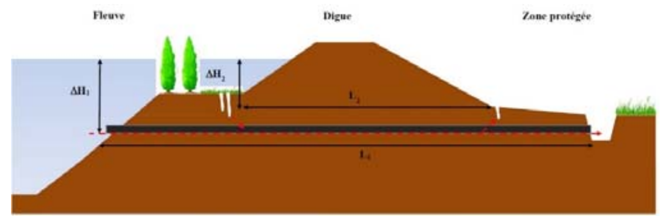


This heterogeneity makes the deterministic approach of a safety factor illusory.

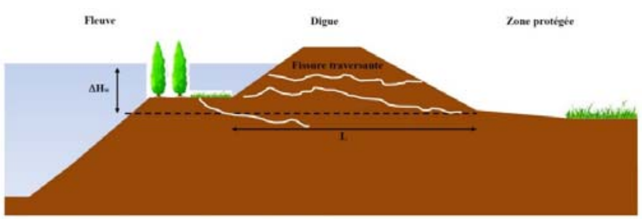
11 breach scenarios : 4 by concentrated leak erosion



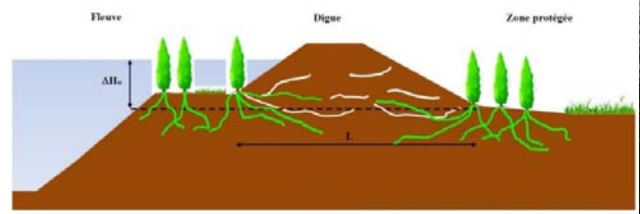
In a former badger burrow partially plugged, not visible and unknown, after hydraulic fracturing



In a hole along a crossing structure

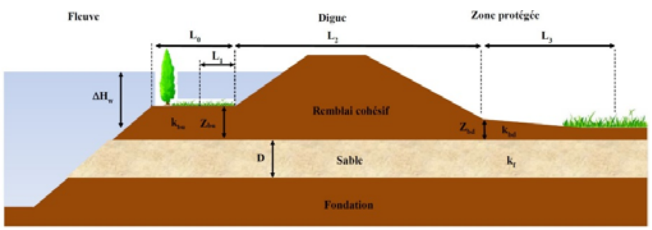


In a crossing crack along a former transition insufficiently treated

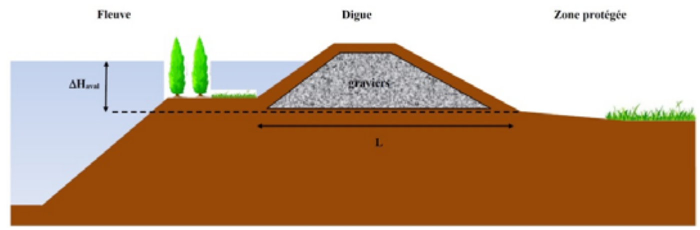


In a root of dead tree

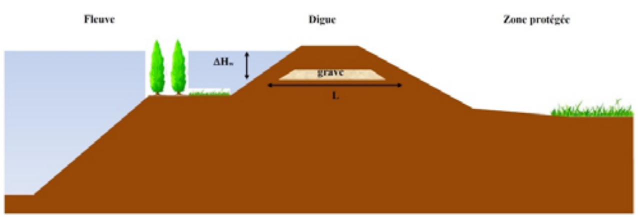
3 by other internal erosion mechanisms



Backward erosion in a sand layer
after uplift the silty blanket overlying the sandy soil strata

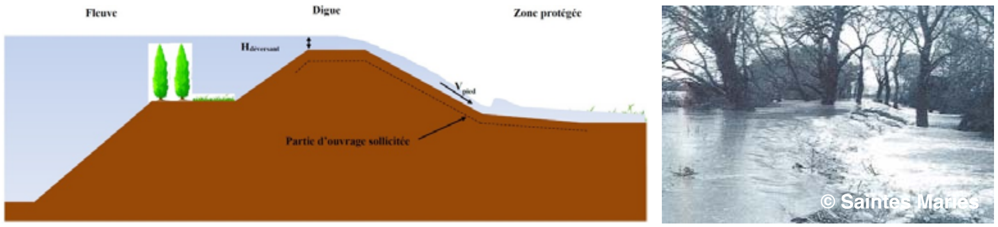


Contact erosion between gravel and silt
(case of breaches repaired in emergency situations)

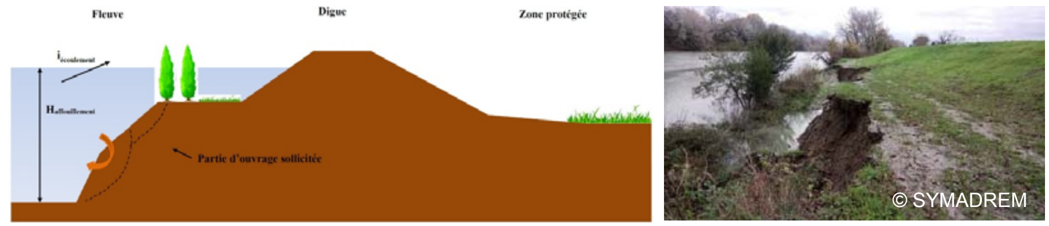


Suffusion in gravel of a ancient pavement layer
(because levees were ancient ways of communication before their general raising in the 19th century)

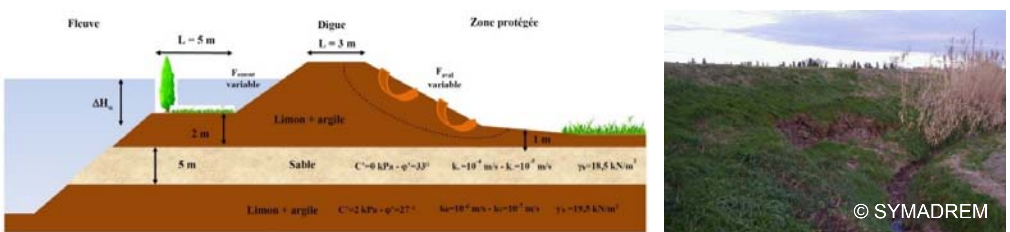
2 by external erosion and 2 by sliding



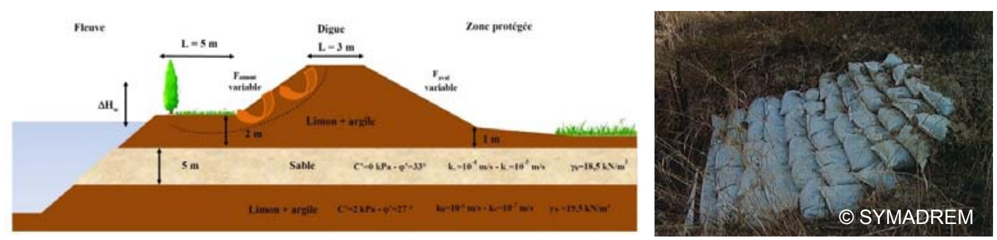
Overflowing



Scour

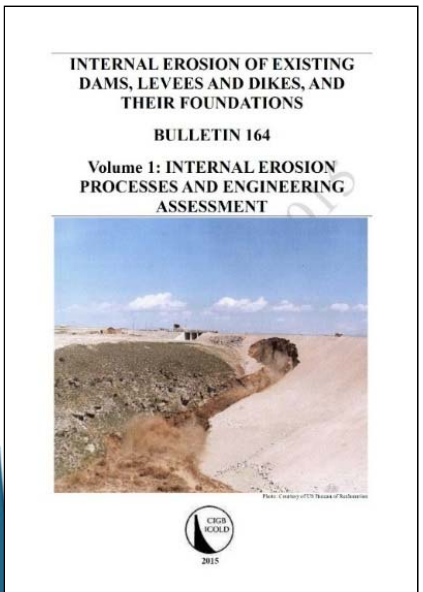


Downstream slope sliding during flood



Upstream slope sliding during flood draw down

For each breach scenario, building of a events tree

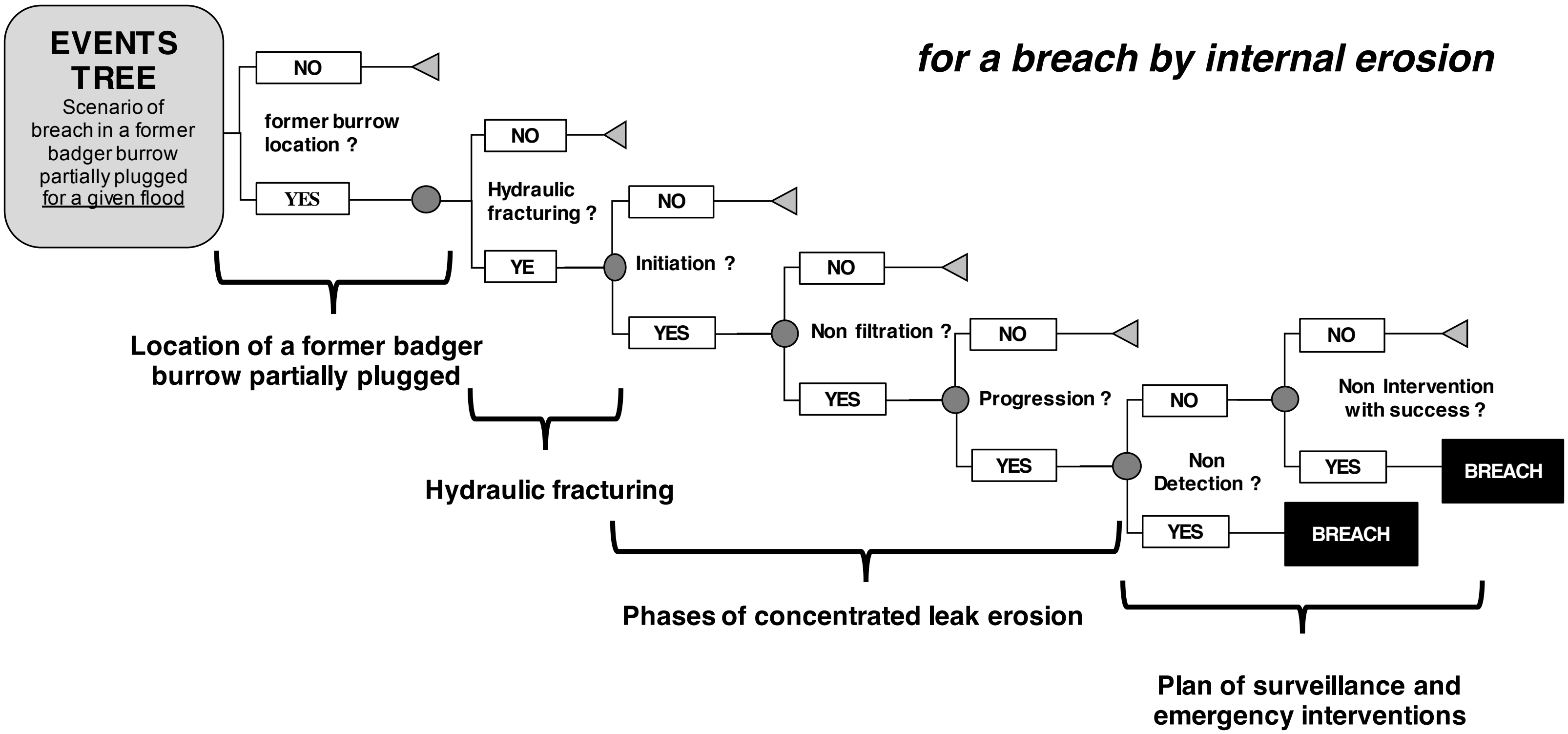

INTERNAL EROSION OF EXISTING DAMS, LEVEES AND DIKES, AND THEIR FOUNDATIONS

BULLETIN 164

Volume 1: INTERNAL EROSION PROCESSES AND ENGINEERING ASSESSMENT

2015

for a breach by internal erosion



$$\textbf{\textit{P(breach)}} = P_{location} \cdot P_{fracturing} \cdot P_{initiation} \cdot P_{non\ filtration} \cdot P_{progression} \cdot [\,P_{non\ detection} + P_{non\ intervention} - P_{non\ detection} \cdot P_{non\ intervention}]$$

Conditional probability of breach

in function of load intensity by using

subjective probabilities

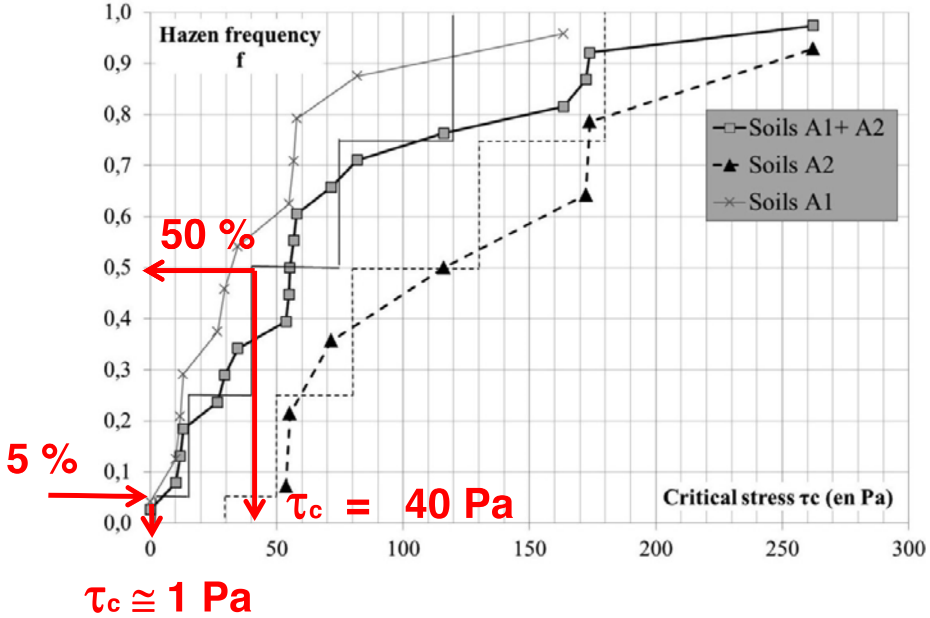
(USBR 2012 adapted from Vick 2002)

Descriptor	Assigned Probability
Virtually certain	0,999
Very Likely	0,99
Likely	0,9
Neutral	0,5
Unlikely	0,1
Very Unlikely	0,01
Virtually Impossible	0,001

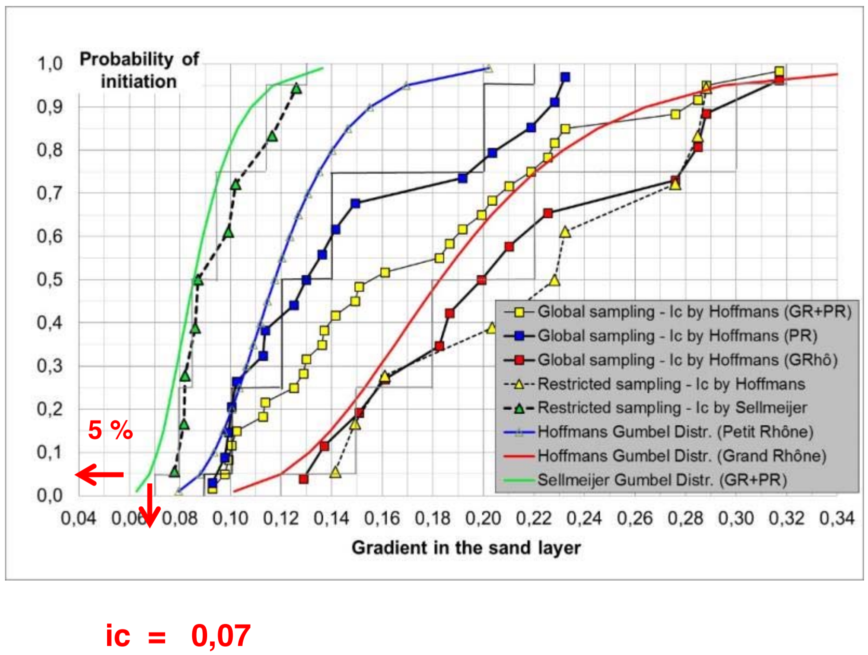
Conditional probability of breach

in function of load intensity by using **frequency probabilities**

Distribution of critical shear in coherent soils



Distribution of critical gradient in sands



Probability of location (ex. former badger burrow)

Ancient levee with negative feedback

Probability = 0,5

New levee with grid against burrowing

Probability = 0,001

Probability of initiation

Concentrated Leak Erosion

Bonelli, Fell & Behnamed (2013)

initiation if $\tau > \tau_c$

$$\tau = \frac{1}{2}.R.\alpha.\rho_w.g.i \qquad \alpha = (1 + \frac{kR}{4Lf})^{-1}$$

Backward erosion

Sellmeijer (2011)

initiation if $i > ic$

$$ic = \frac{\gamma'_p}{\gamma_w}\tan\vartheta \left(\frac{RD}{RD_m}\right)^{0.35}\left(\frac{U}{U_m}\right)^{0.13}\left(\frac{KAS}{KAS_m}\right)^{-0.02}\frac{d_{70}}{\sqrt[3]{\kappa L}}\left(\frac{d_{70m}}{d_{70}}\right)^{0.6} 0.91\left(\frac{D}{L}\right)^{\frac{0.28}{\left(\frac{D}{L}\right)^{2.8}-1}+0.04}$$

Contact Erosion

Beguin(2011)

initiation if $V > Vc$ $\qquad V = k.i = 7.10^{-2}.i$

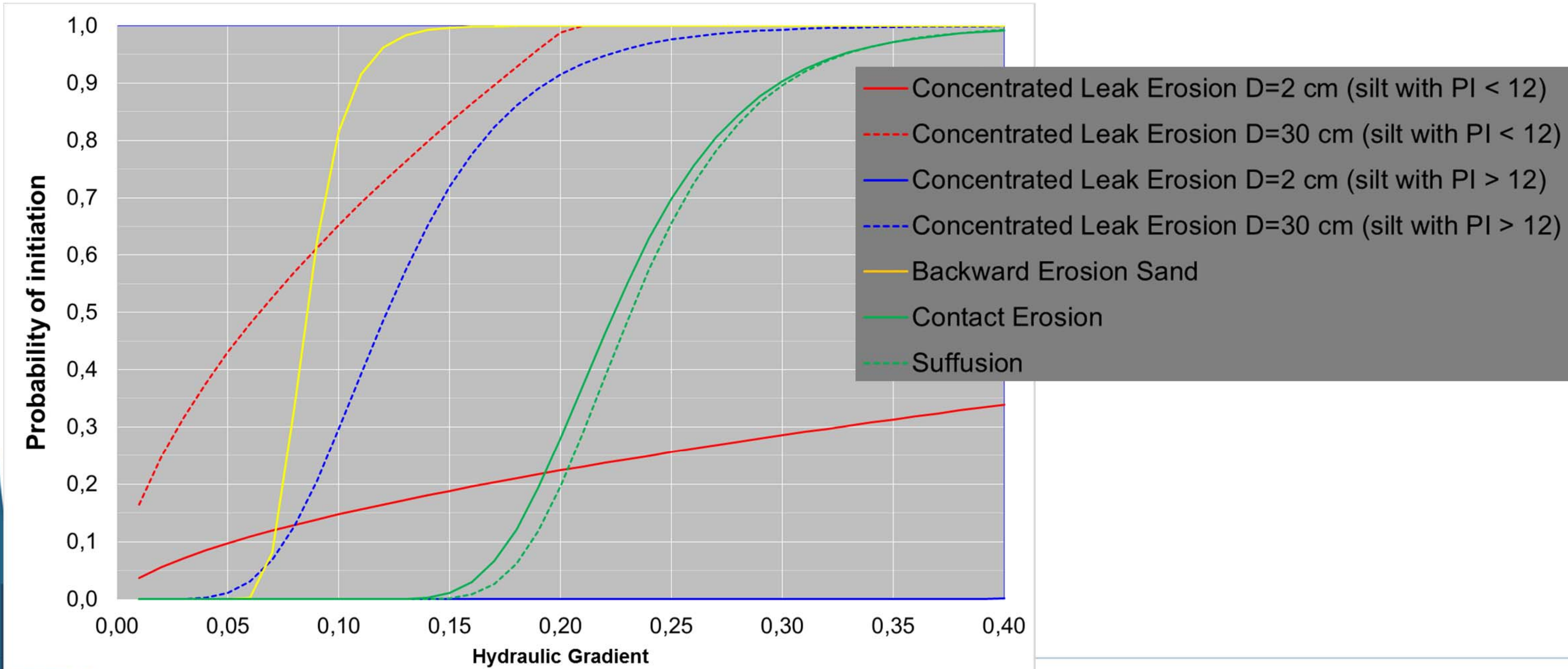
Darcy Velocity	Probability of initiation	Comments
1 cm/s	0.01	No érosion
1,5 cm/s	0.5	
2 cm/s	0.9	Erosion

Suffusion

Wan & Fell (2004, 2007); Marot&al (2012)

Hydraulic Gradient	Probability of initiation	Verbal Qualification verbale
0,1	0.001	Virtually impossible
0,15	0.01	Very unlikely
0,2	0.1	Unlikely
0,3	0.9	likely

Probability of initiation by internal erosion mode



Probability of non filtration

No filter

Probability = 1

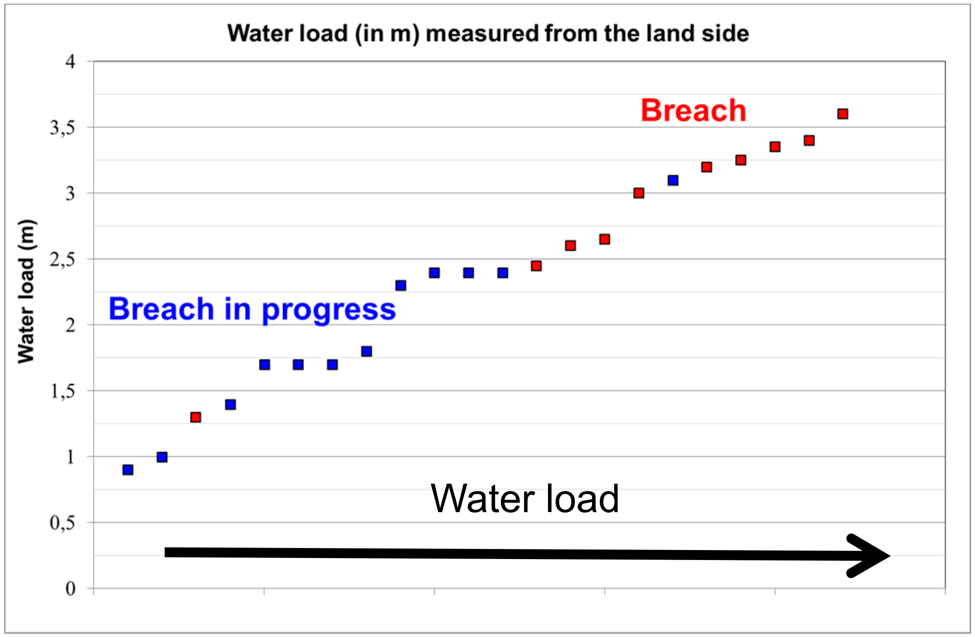
Filter but incertainties

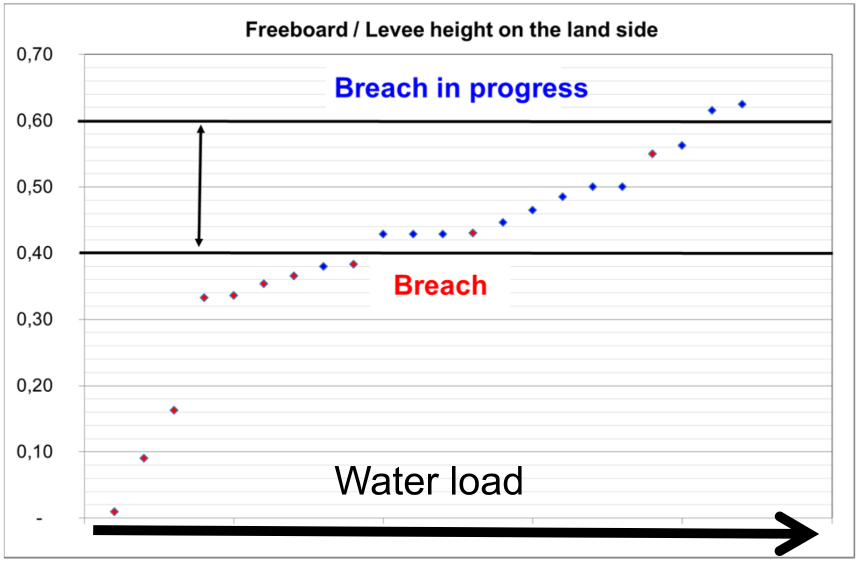
Probability = 0,1

Filter well designed and constructed

Probability = 0,01

Probability of progression





Probability of non detection and non intervention

$$P_{non\ detection} = \max(0{,}01; \left(1 - \frac{\Delta t_u}{P_s}\right))$$

$$P_{non\ intervention} = \min(1; \frac{\Delta t_i}{\Delta t_u})$$

Ps : duration between 2 visits (between 3 & 6 hours) checked during flood in november 2016
Δt_u : time from detection to failure
Δt_i : intervention time (trafficable crest => 3 hours or not => 24 h) => checked in 2016 and 1993

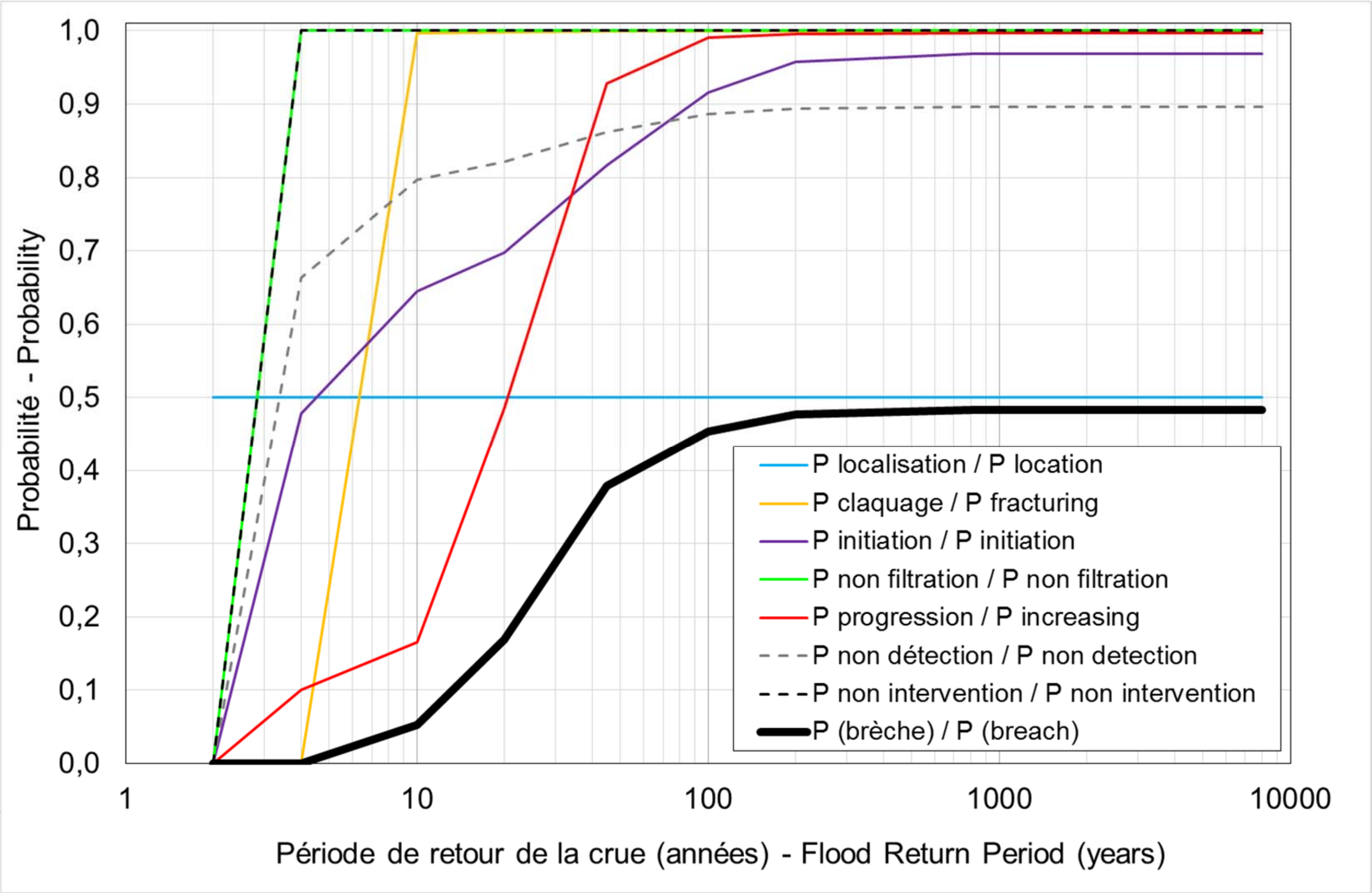
For concentrated leak erosion

$$\Delta t_u \approx \frac{2\rho_d}{C_e \alpha \rho_w g\ i} Ln\left(\frac{R_u}{R_d}\right)$$

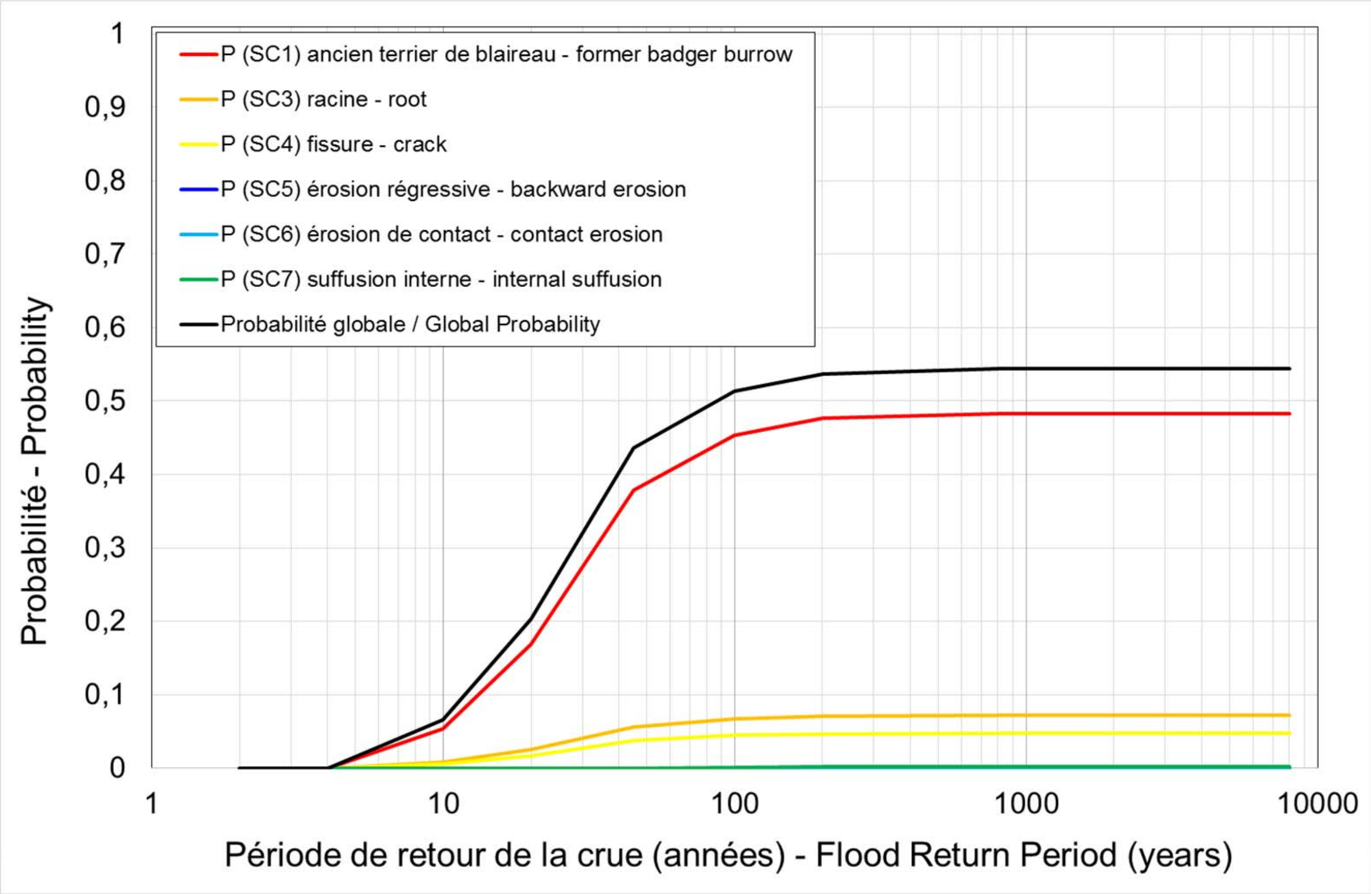
For backward erosion $\Delta t_u \approx$ 24h

For contact erosion and suffusion $\Delta t_u = 48$h

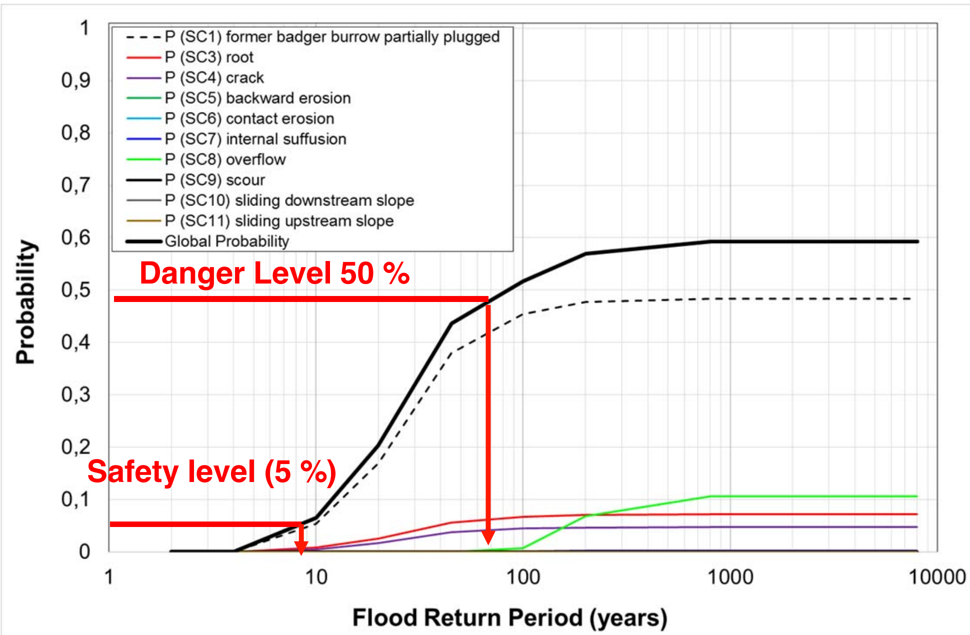
Conditional probability of each scenario



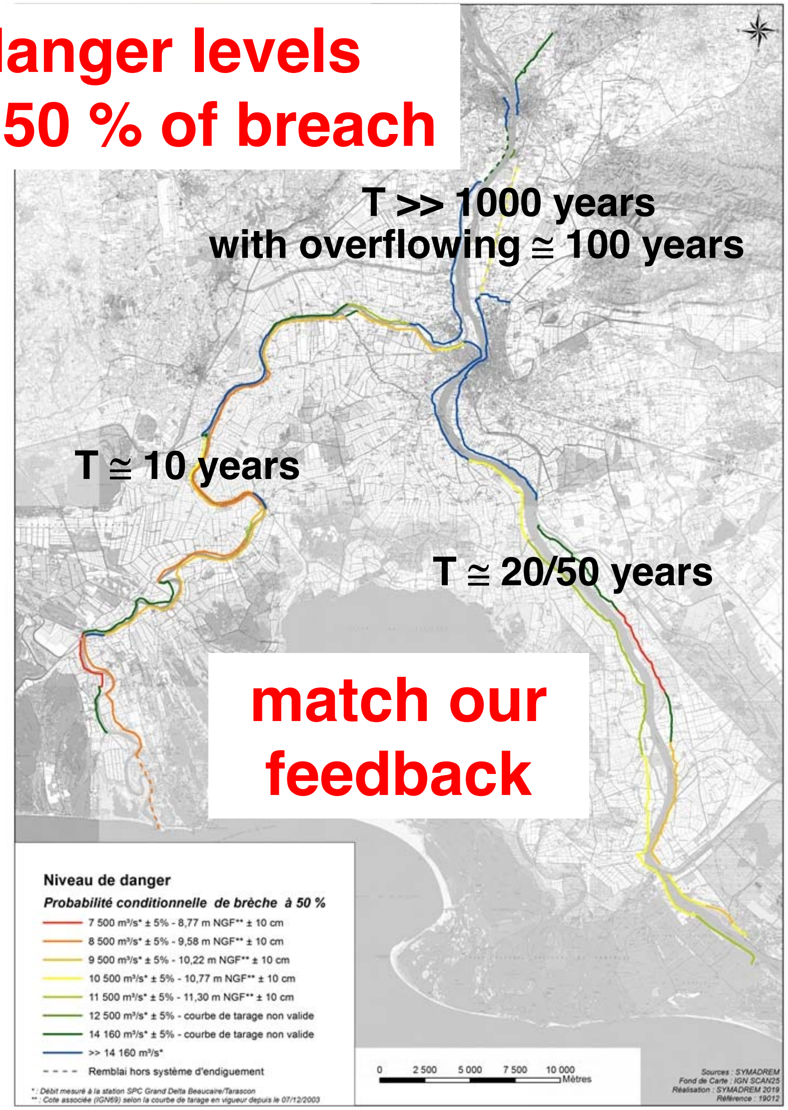
Global probability of all internal erosion mechanisms



Conclusion



danger levels
P = 50 % of breach



match our feedback

more details at http://www.symadrem.fr/enquete-publique/

pages 1280 to 1510

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