PC-RIVER: PROBABILISTIC RELIABILITY ANALYSIS FOR RIVER DIKES

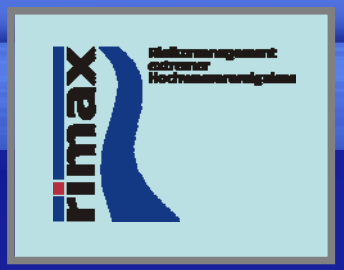
Part 2: Hydraulic Uncertainties

- Uwe Merkel -

University of Stuttgart

Institute of Hydraulic Engineering **Institute of Geotechnical Engineering**

Outline



1. PC-River Project
2. Reliability of water level prognoses
3. 2-dimensional HN Monte-Carlo Simulation
4. Geotechnical input parameters
5. Conclusions and Outlook

Funded by:

Bundesministerium für Bildung und Forschung

G F Z POTSDAM

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft
Projektträger Forschungszentrum Karlsruhe

Partners:

Dam Authority of Saxony, Pirna

Regional Administrative Authority Tübingen

Rijkswaterstaat, Dienst Weg- en Waterbouwkunde, Delft, NL

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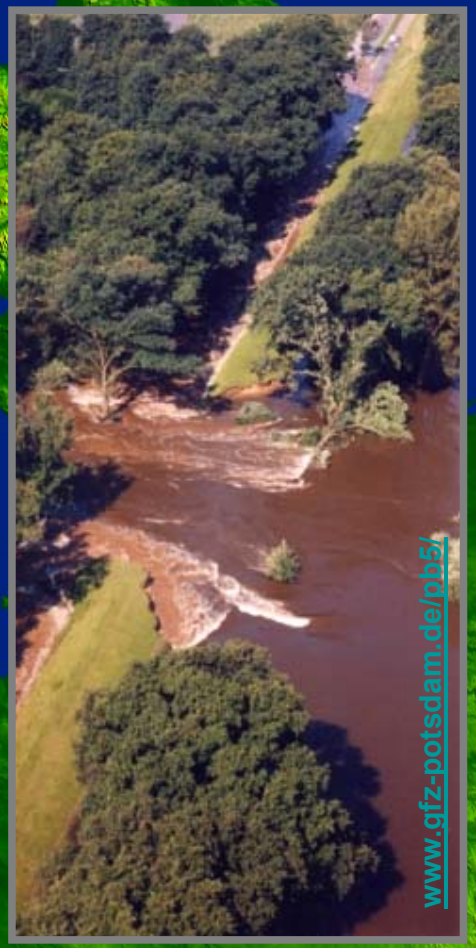
1. Objectives :
Adapting PC-Ring for non lowland Rivers

rimax
Risikomanagement extremer Hochwasserereignisse

Reliability and Risk Analysis for River Systems

PC-River

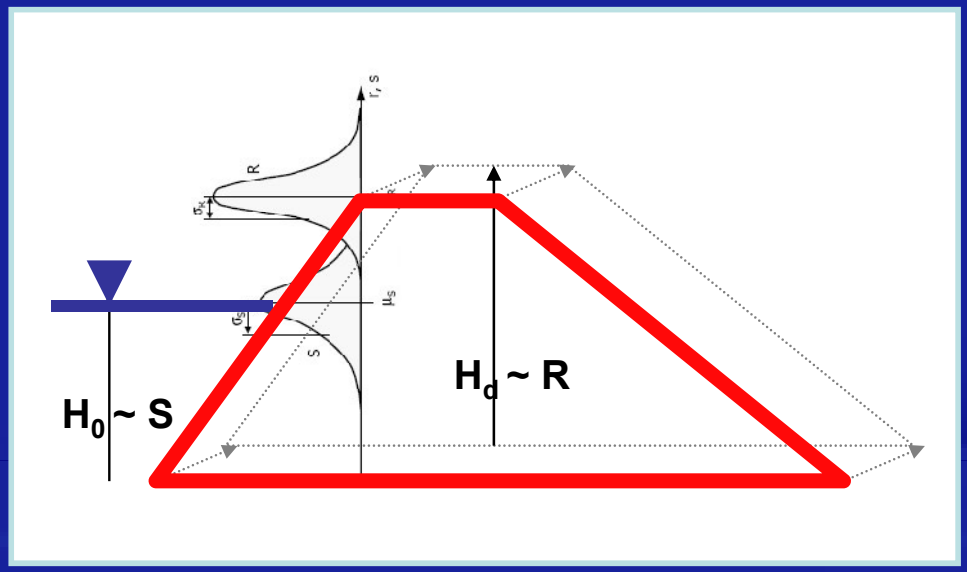


Torgau / Saxony

1. The Probabilistic Key-note

Limit State Equation:

$Z = R - S$

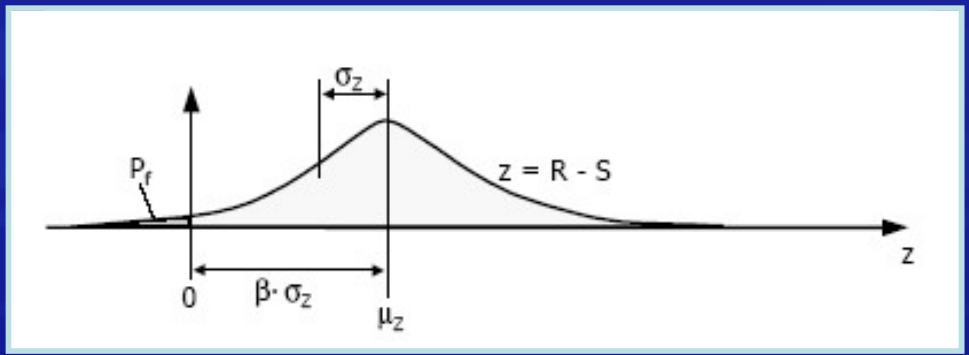


R: Resistance (pressure, erodibility)
S: Stress (water level, velocity)

Z<0 „Failure“
Z>0 „No Failure“

Input Variables:

μ: average
σ: standard deviation



Probabilistic Solution:

- Monte Carlo Simulations;
- FORM, SORM, NI, a.o.

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1. The Probabilistic Key-note

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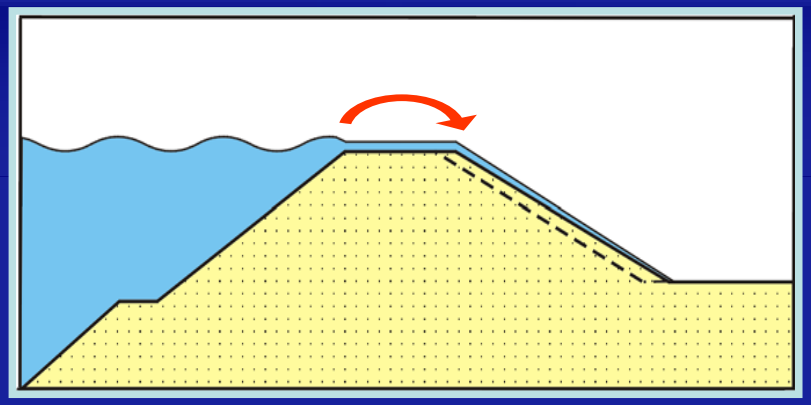
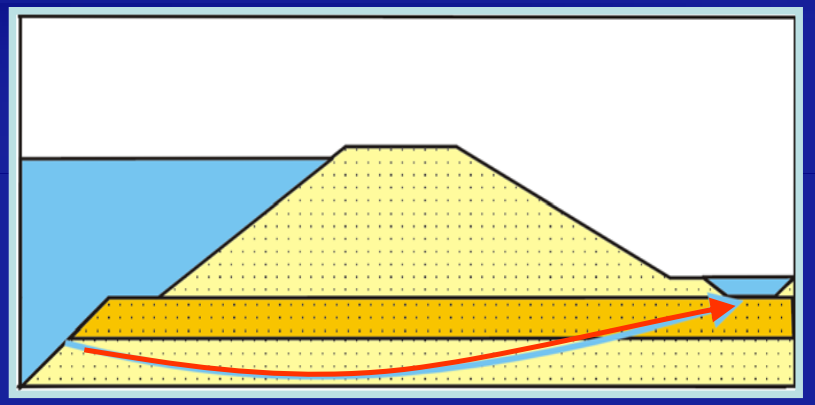


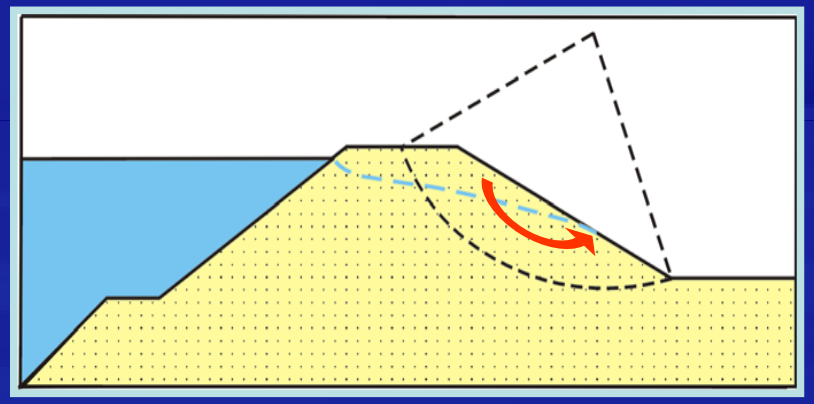
Overflow / Wave overtopping

$Z = m_{qc}q_c - m_{qo}q_o$ $Z = h_d - h$



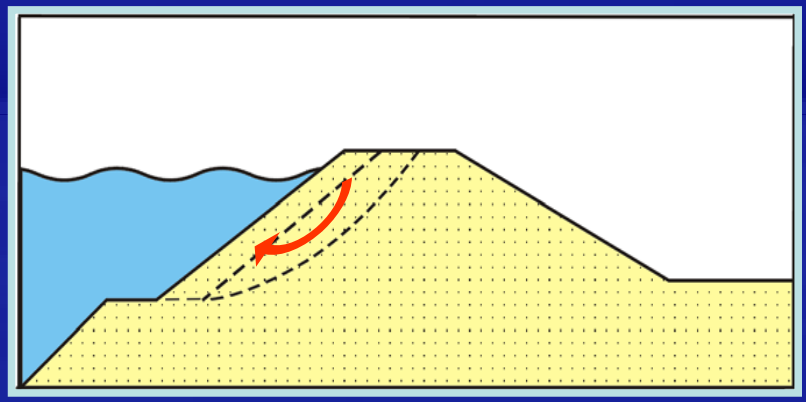
Uplift / Piping

$Z = m_p h_p - (h - 0{,}3\ d - h_b)$ (Piping)



Slope instability

Prob. Slip circle analysis
MPROSTAB (GeoDelft)



Damage of the revetment and erosion of the dike body

$Z = t_{RT} + t_{RK} + t_{RB} - t_s$ (Grass)

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Risikomanagement extremer Hochwasserereignisse

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PC-River

Probabilistic Concept

Stress - River -	Resistance - Dike -
Average Values und Variabilities	Average Values und Variabilities
• Water level W + Waves h_W • Velocities V	• Dike geometry • Soil mechanical parameters

Probabilistic Software: PC-RING – (Developed by TNO & Rijkswaterstaat)
-> Failure probability for dike systems [1/a] -

A

Sensitivity
Input Parameter
e.g. Q, z, kst

- Case Studies -
Elbe & Iller

B

Geotechnical Data
& Results

Application / Implementation

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2. Uncertainties in Stress inherited by Input Parameter:

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Stress
- River -

$S = \mu +/- ß * \sigma$

- **Water level + Waves**
- **Velocities V**

Discharge Q

Discharge Duration Q(t)

Topography z

Morphology Δz + n (kst)

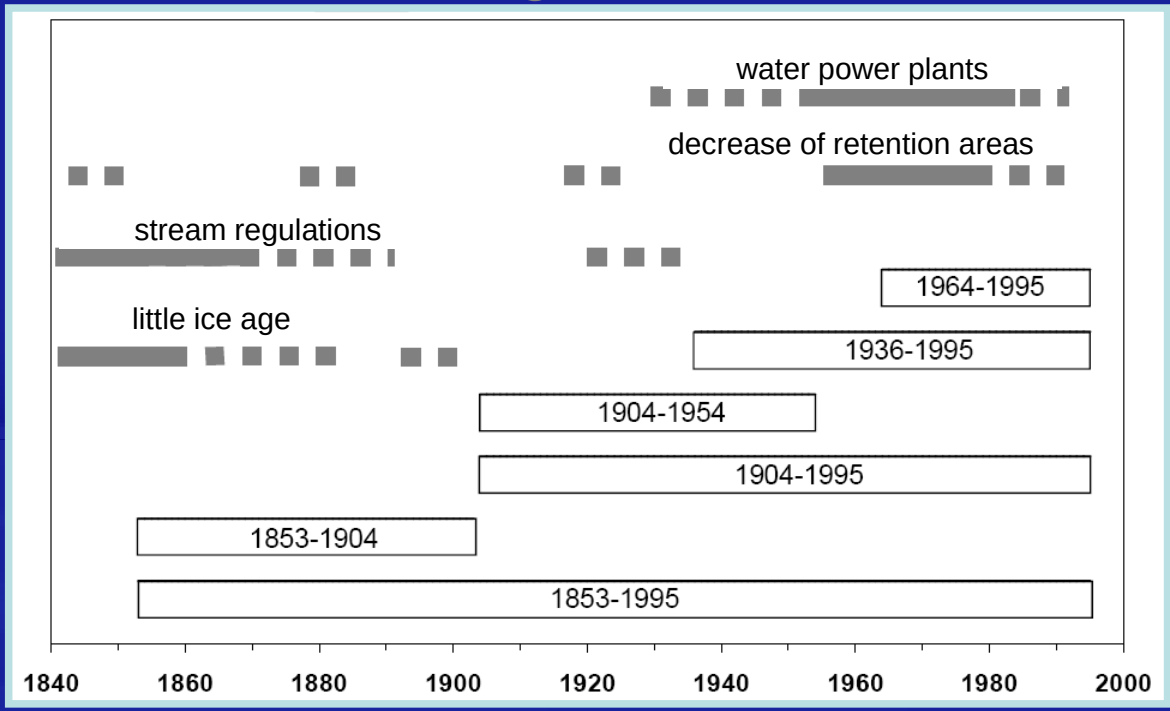
Friction n (kst)

Weather: Ice & Wind

Unpredictable Parameters

What is HQ100 @ Gauge DRESDEN

- 1999: Helms, Ihringer:



Changes of landuse, river geometry & climate changes -> Changes in Q

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Unpredictable Parameters

What is HQ100 @ Gauge DRESDEN

- 1999: Helms, Ihringer:
  HQ100 ~ 3423m³/s +/- 500m³/s

  MAJOR FLOODS IN 1999, 2002 and 2003

- 2003: LTV Sachsen
  HQ100 ~ 4370m³/s

  MAJOR FLOOD IN 2006

- 2006: Federal Institute of Hydrology
  Time series: 1852 to 2006
  HQ100 ~ 4500m³/s
- 2007: Jensen, Frank
  HQ100 ~ 3100m³/s - 4700m³/s
  HQ10000 ~ 4800m³/s - 10800m³/s

2. Uncertainties in Stress inherited by Input Parameter:

BWS Stuttgart

rimax Risikomanagement extremer Hochwasserereignisse

Stress
- River -

$S = \mu \pm \beta * \sigma$

- **Water level + Waves**
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Discharge Q

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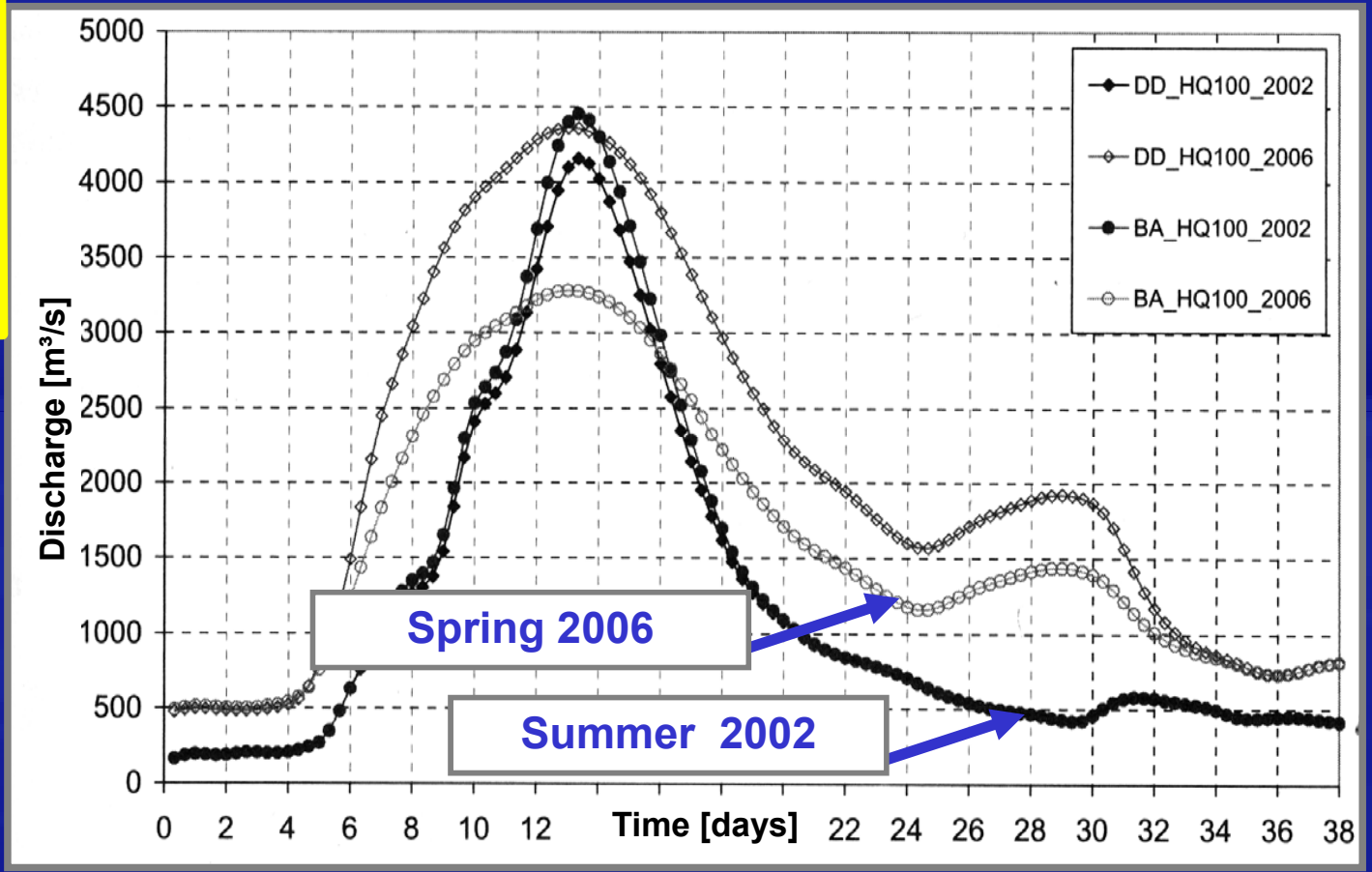
Weather: Ice & Wind

Unpredictable Parameters

What Runoff Volume can we expect ?

- 2007: Busch, Hammer, BfG:



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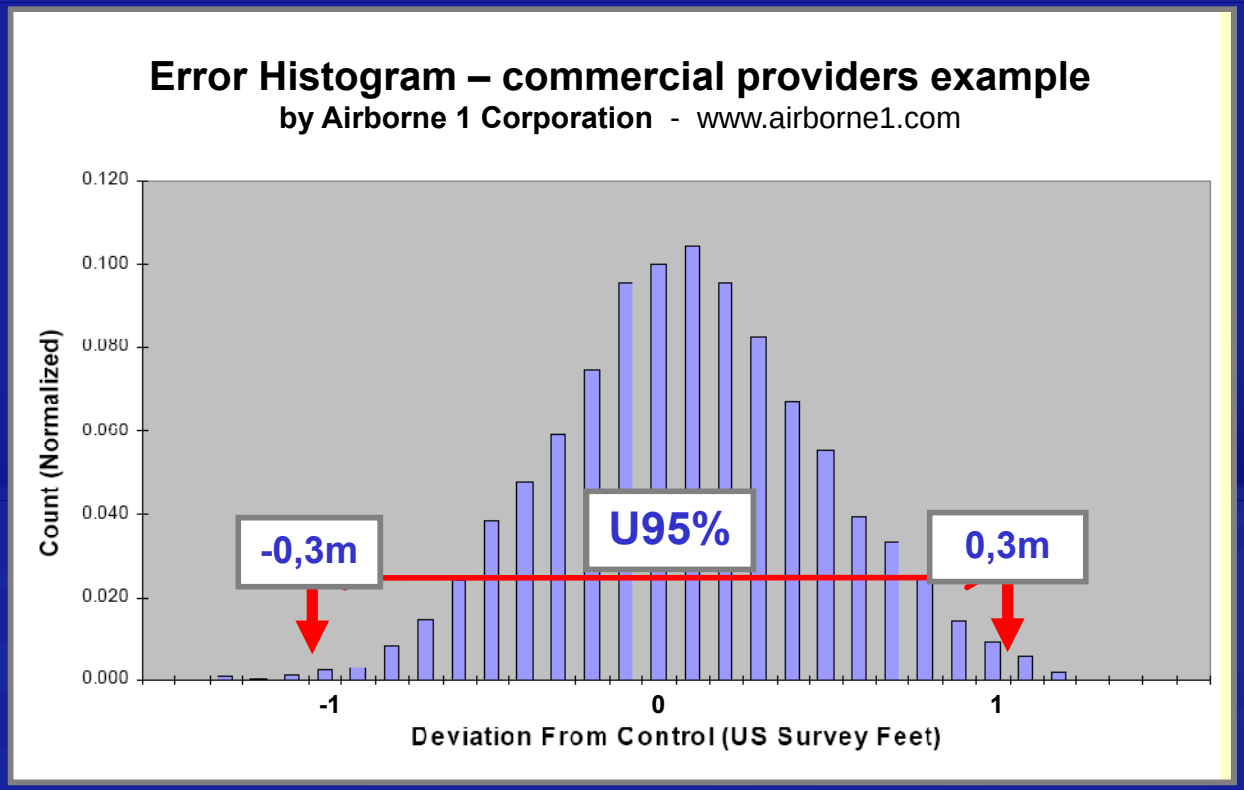
Unpredictable Parameters

How accurate are today's Digital Elevation Models ?



average error distribution after elimination of well known systematic errors

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2. Uncertainties in Stress inherited by Input Parameter:

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Stress
- River -

$S = \mu +/- ß * \sigma$

- **Water level + Waves**
- **Velocities V**

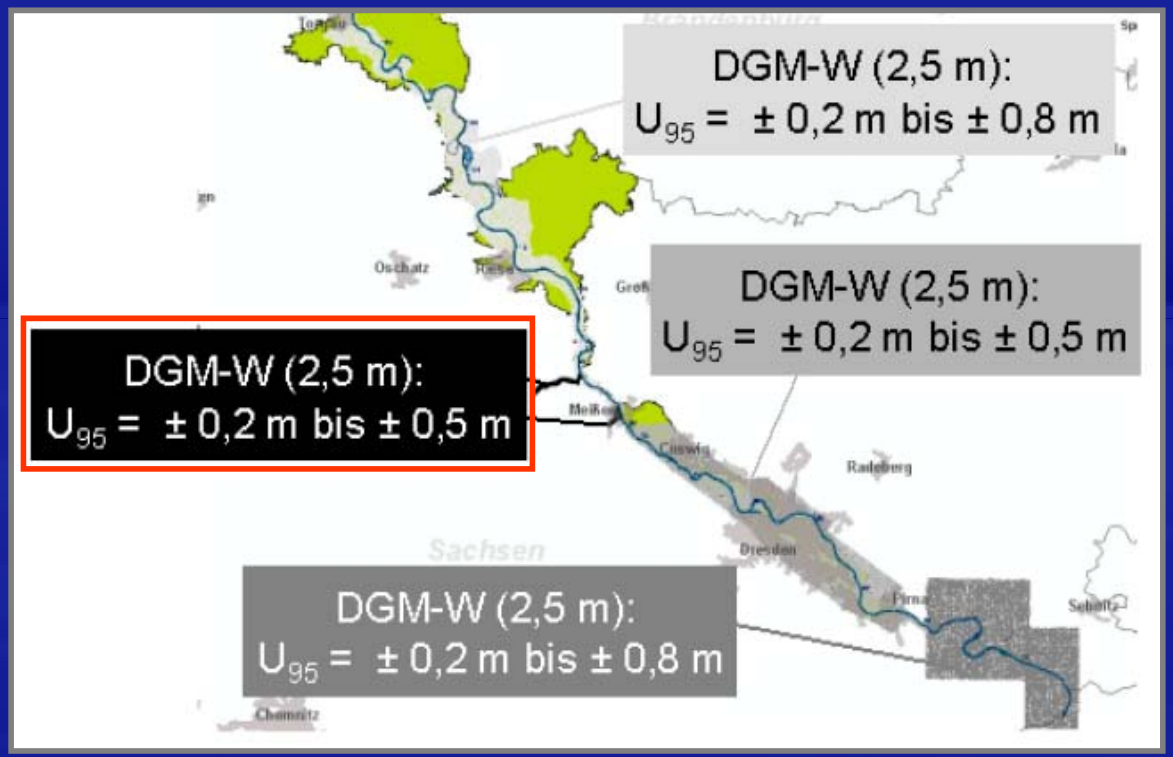
↑

- **Discharge Q**
- **Discharge Duration Q(t)**
- **Topography z**
- **Morphology Δz + n (kst)**
- **Friction n (kst)**
- **Weather: Ice & Wind**
- **Unpredictable Parameters**

How accurate are "real life" Digital Elevation Models?

- 2005: Federal Institute of Hydrology

BfG, Veranstaltungen 1/2005, Koblenz



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2. Uncertainties in Stress inherited by Input Parameter:

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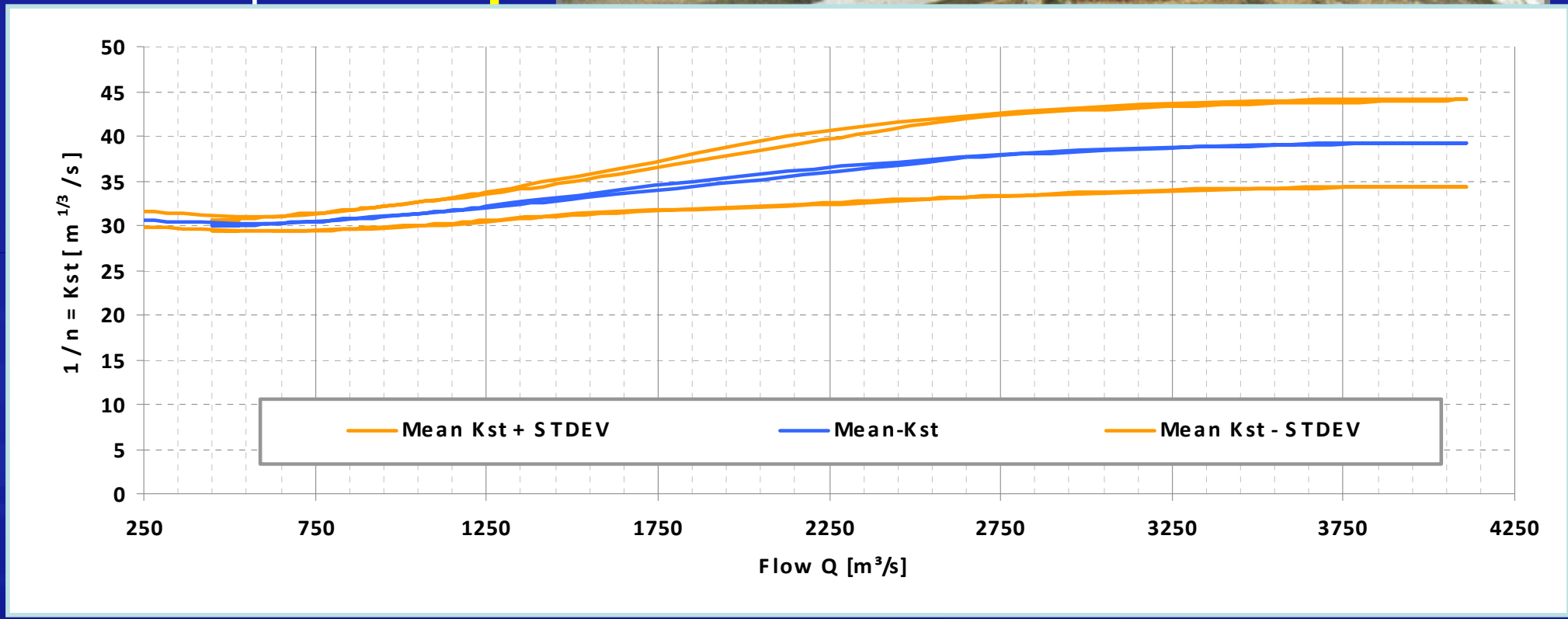
Stress
- River -

$S = \mu_s \pm \eta * \sigma_s$

- **Water level + Waves**
- **Velocities V**

Bedforms change during a flood event

-> See Vanoni & Hawang, Engelund & Hansen, Kennedy, Senturk, Einstein & Barbarossa



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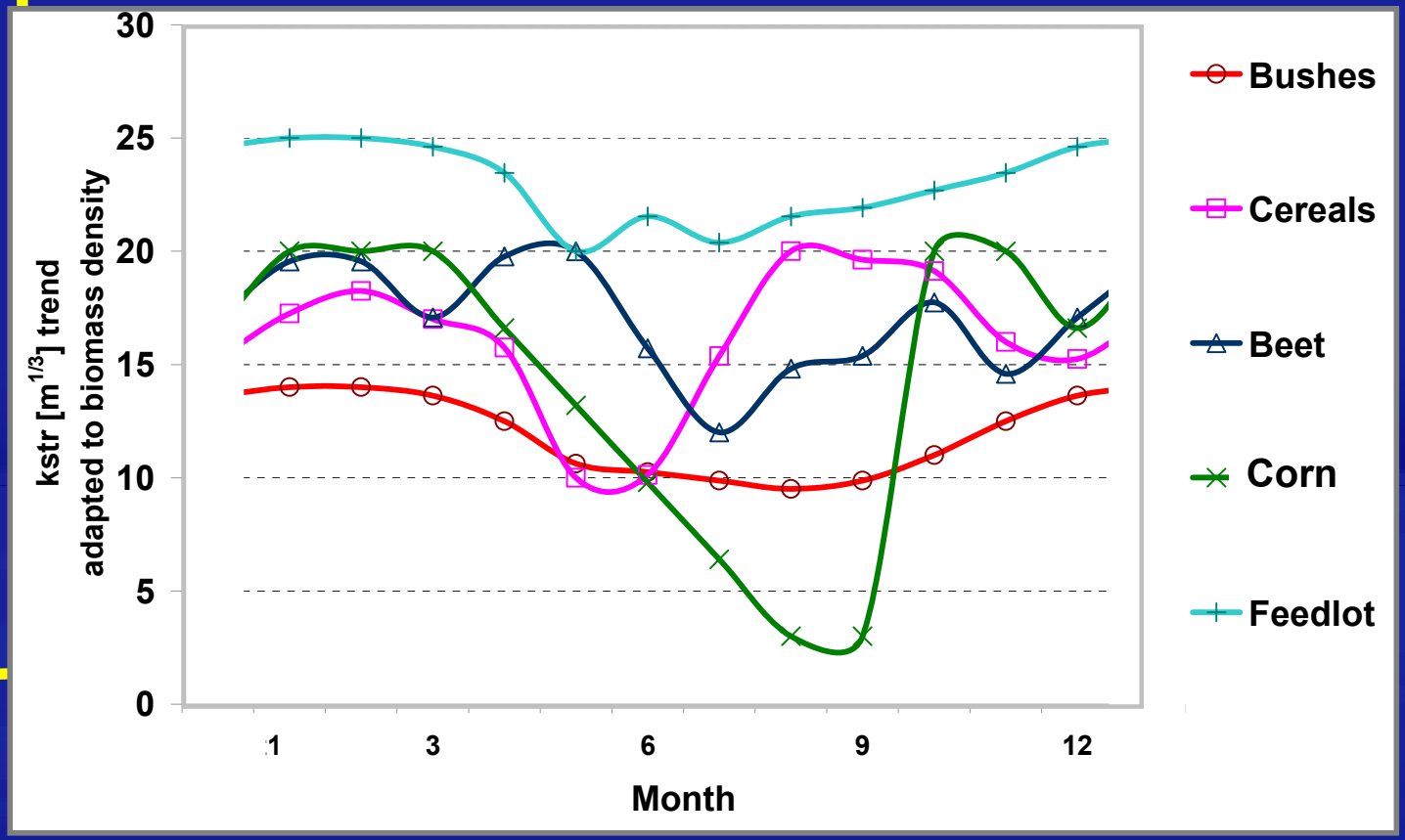
Weather: Ice & Wind

Unpredictable Parameters

Friction influence varies during the vegetation period / over the years !?!



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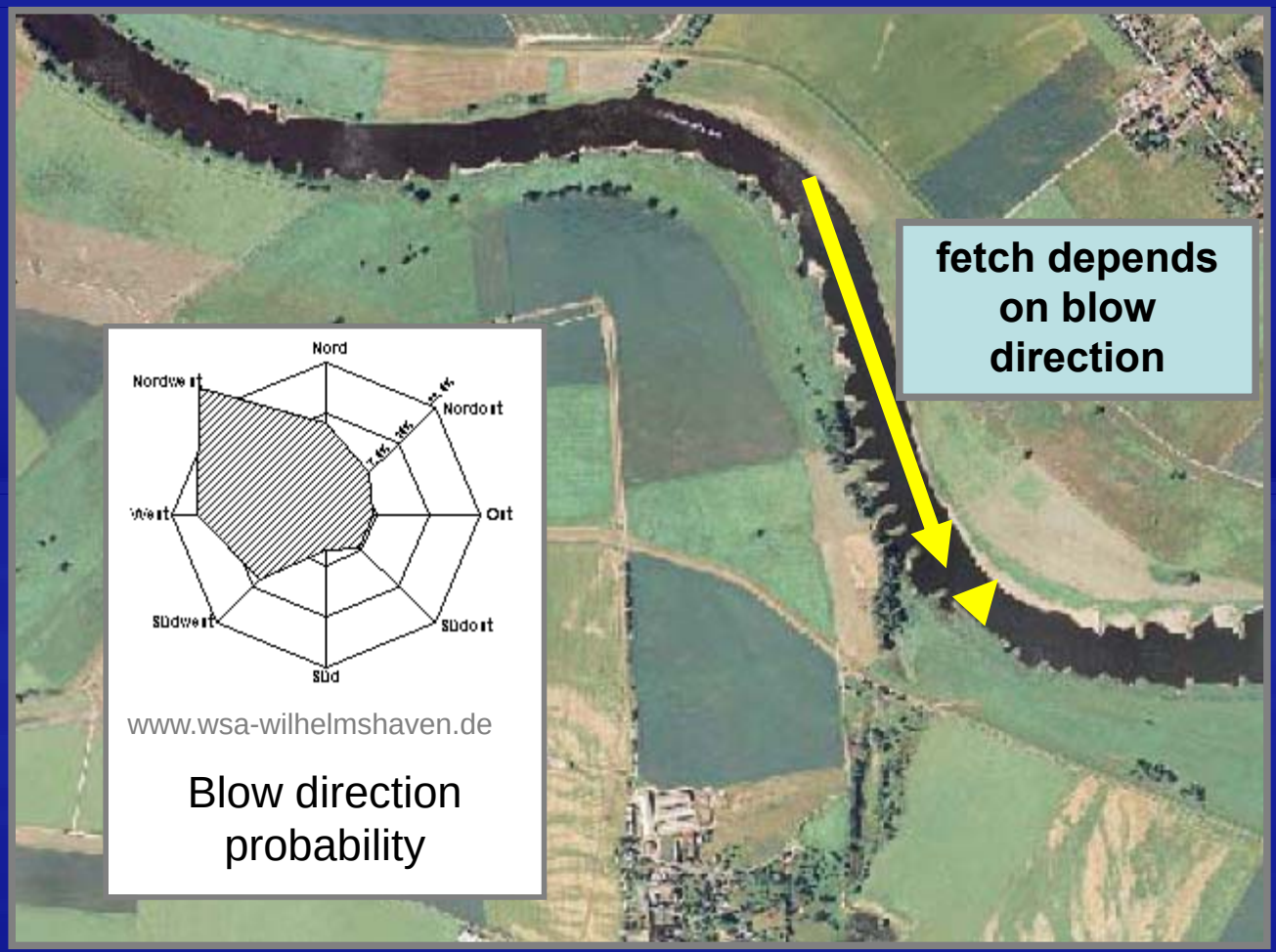
Weather: Ice & Wind

Unpredictable Parameters

Weather Phenomena may influence discharge impact significantly !?!



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2. Uncertainties in Stress inherited by Input Parameter:

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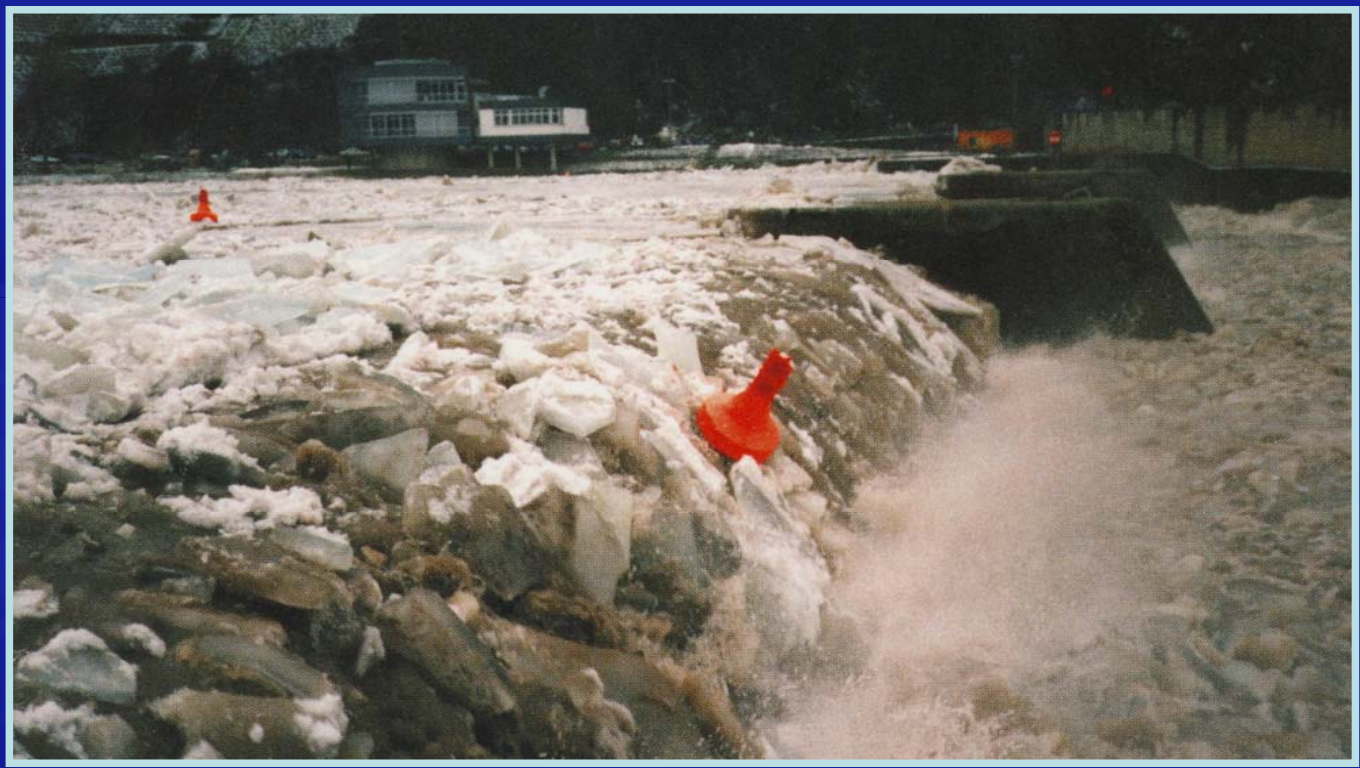
Weather: Ice & Wind

Unpredictable Parameters

Weather Phenomena may influence flood events significantly !?!

Mosel, Cochem, 21. 1. 1997



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- Discharge Q
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- Unpredictable Parameters

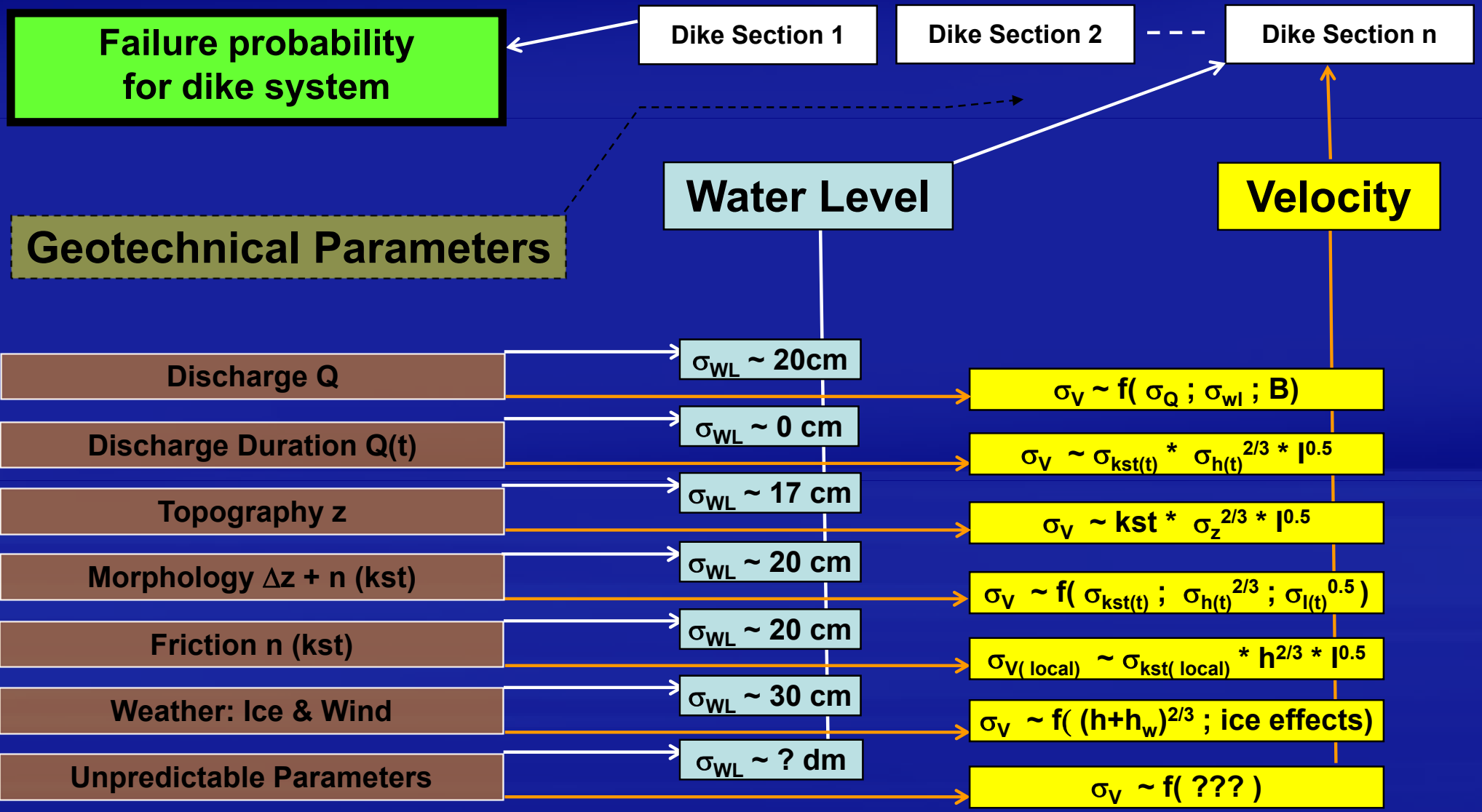
What else might happen, what we have no historical data about ???

- Blocked bridges and narrows

  -> temporary blockages might break - > flood waves

- Extreme rainfall -> landslides, dam breaks ... -> flood waves
- Human failure & planers errors
- Retention effects due to dike breaks
- a. o. …

2. Uncertainties in Stress inherited by Input Parameter:



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3. Water level accuracies along Dikes determined by 2D-HN Monte Carlo Simulation

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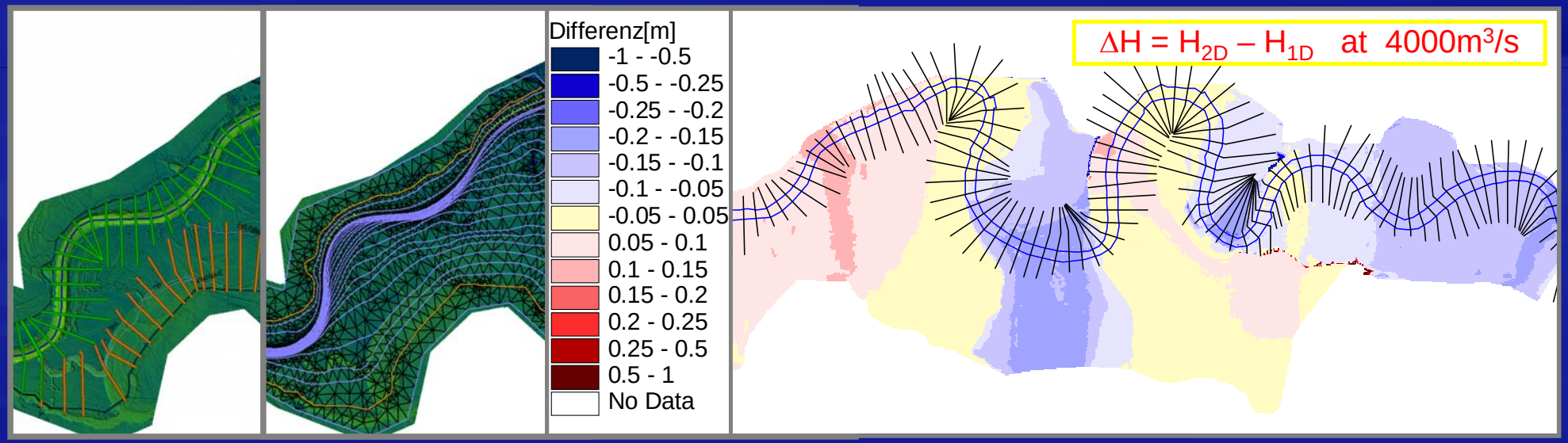
Which simulation tools fit best?

- Slopes & Oxbows
- 4km width floodplains
- W.L. transverse gradients up

-> 2D-HN-Modelling needed

2007 Merkel U., Oberle P.; Aqua Terra Proceed.



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3. Water level accuracies along Dikes: Necessary 2D-HN Model Improvements

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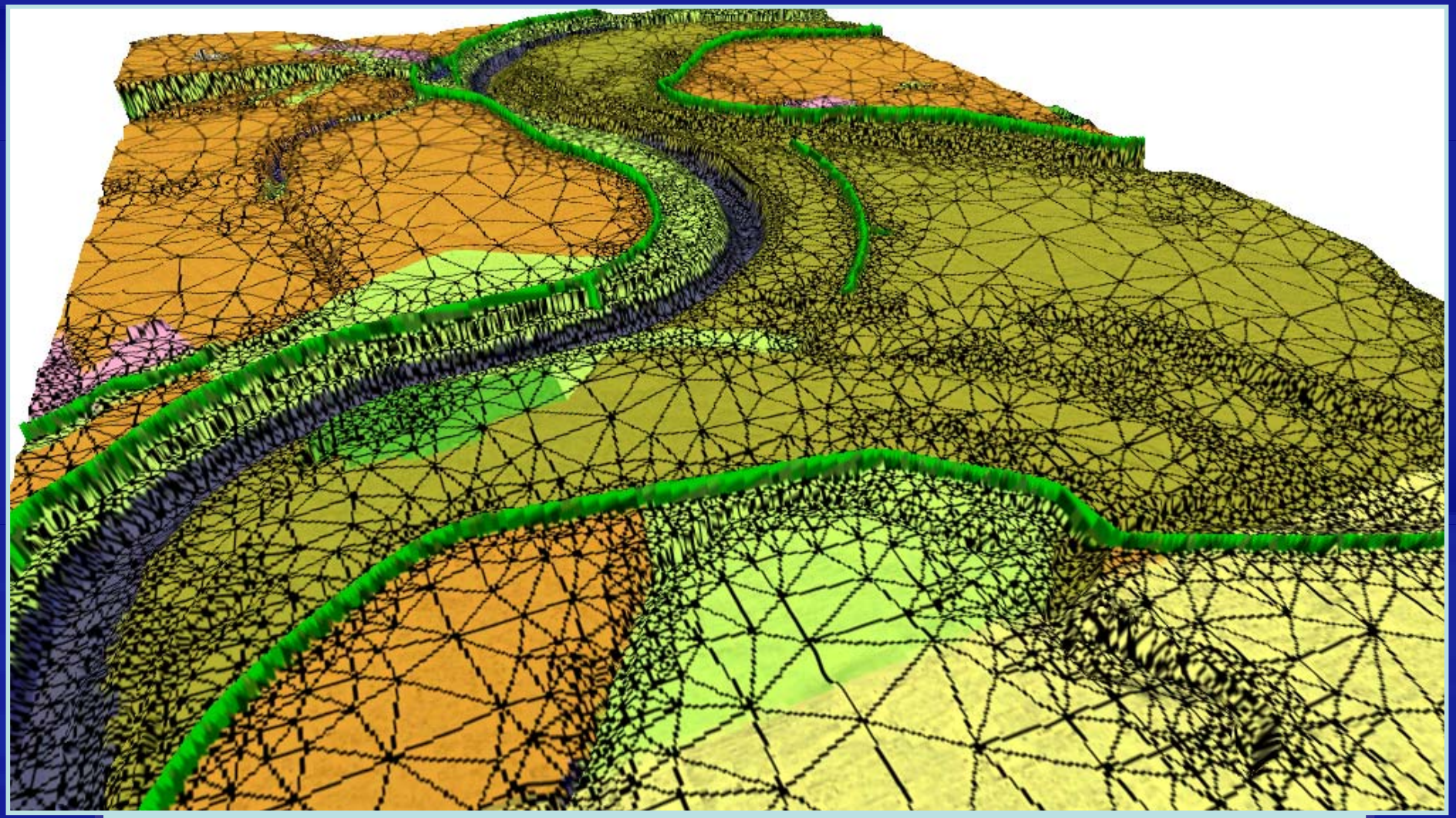

-> faster & more accurate 2D hydrodynamic numerical meshes

3. Water level accuracies along Dikes determined by 2D-HN Monte Carlo Simulation

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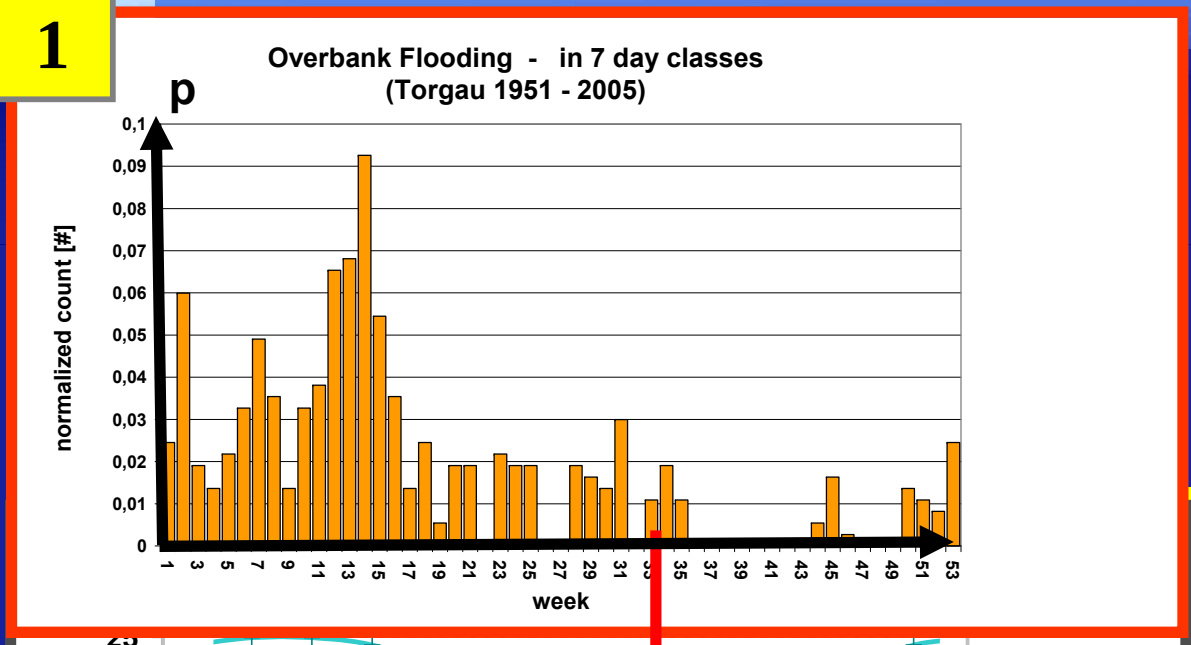
1



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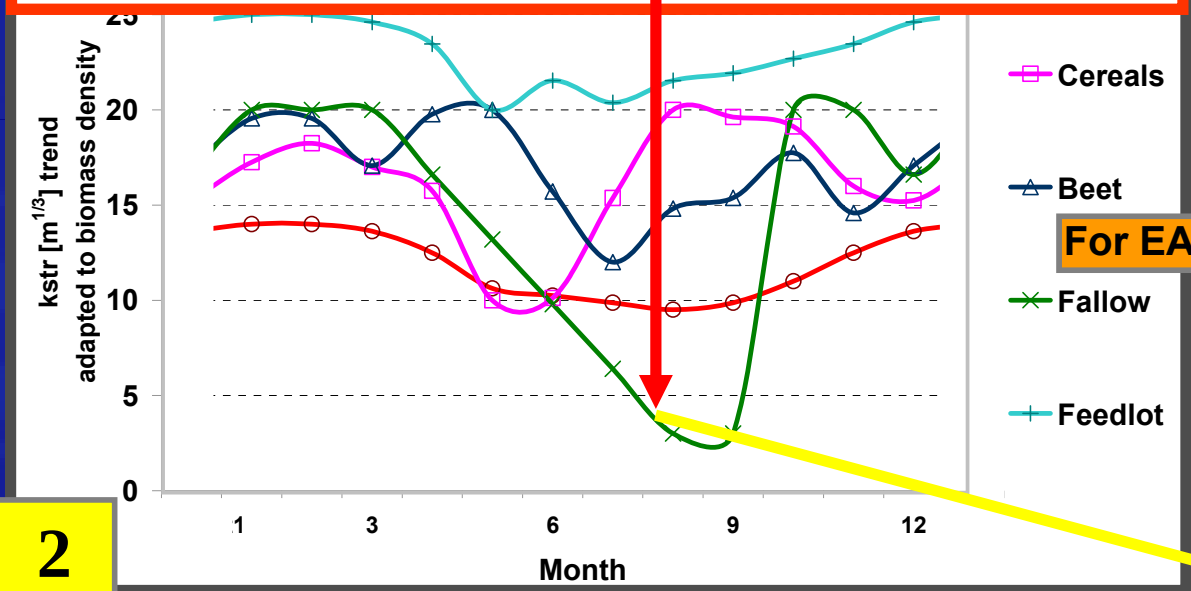

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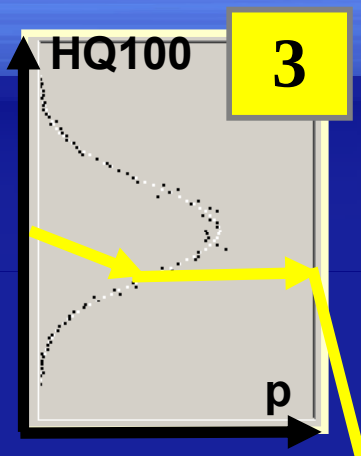

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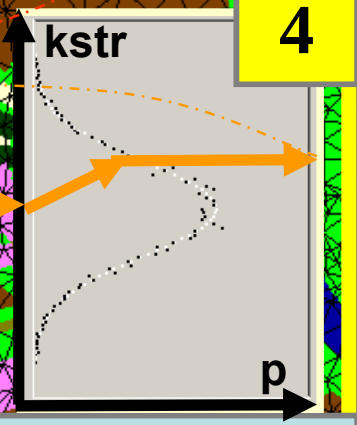

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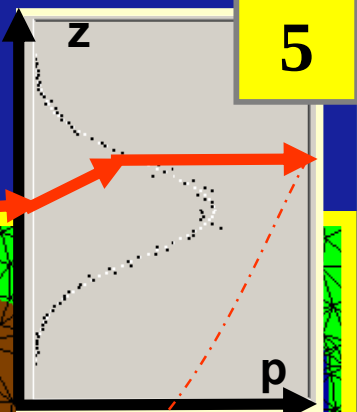

For EACH area ->

Floodplain Example

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3. Water level accuracies along Dikes determined by 2D-HN Monte Carlo Simulation

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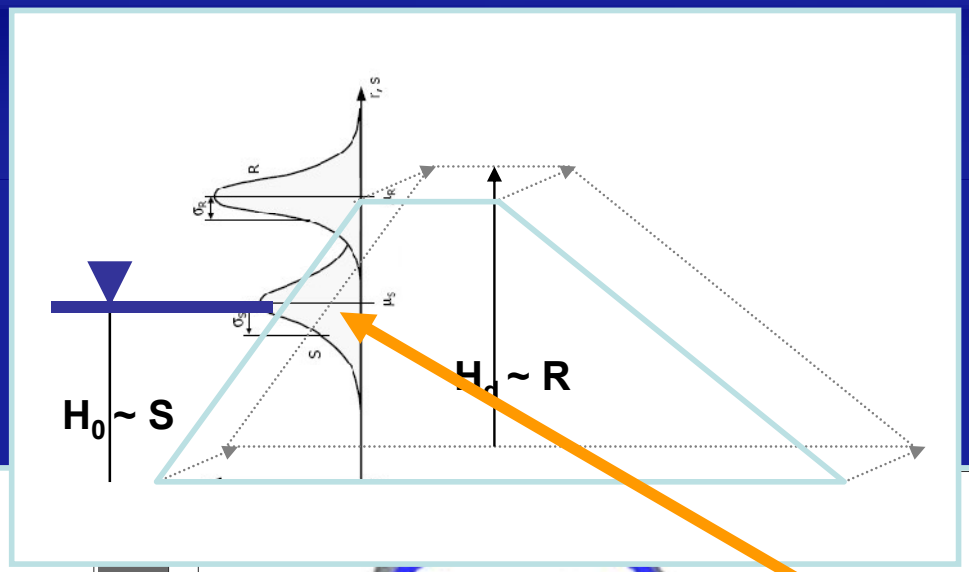

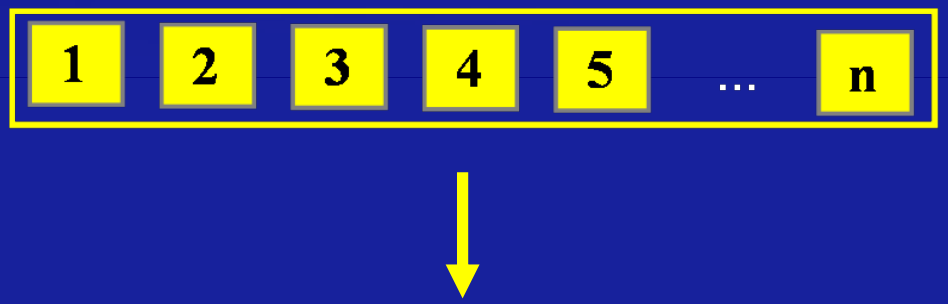

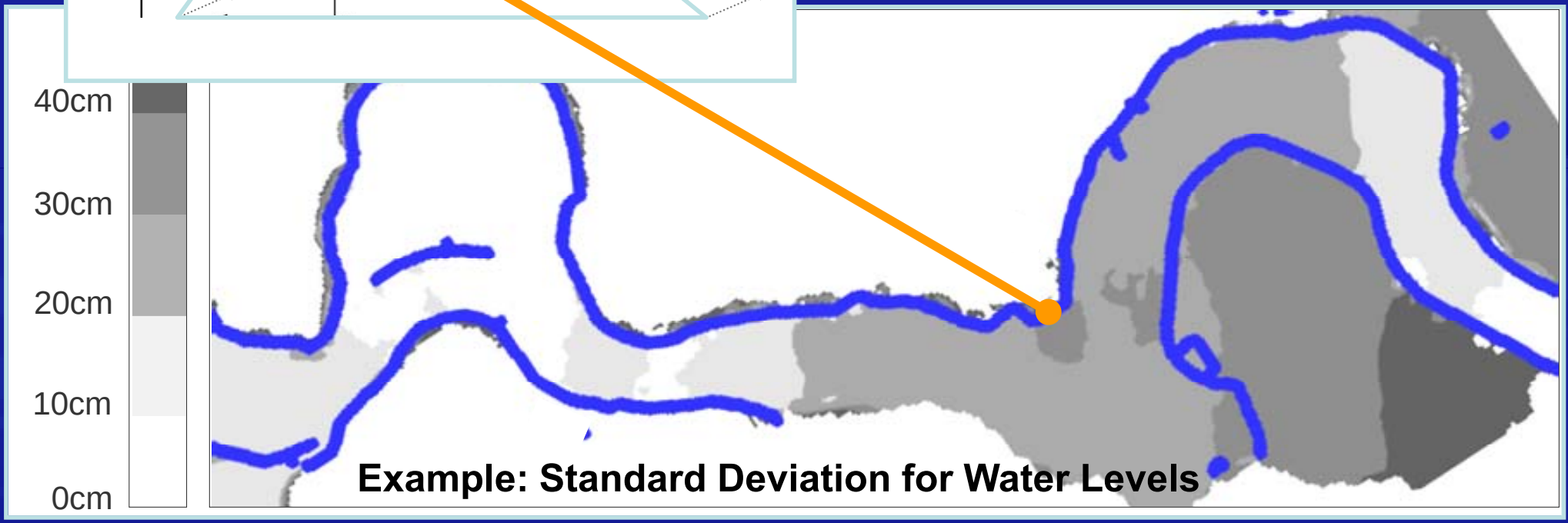

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Adapting PC-Ring for non lowland Rivers

Probabilistic Concept

Stress
- River -

Average Values und Variabilities

- Water level W + Waves h_W
- Velocities V

Resistance
- Dike -

Average Values und Variabilities

- Dike geometry
- Soil mechanical parameters

Probabilistic Software: PC-RING – (Developed by TNO & Rijkswaterstaat)
-> Failure probability for dike systems [1/a] -

A

Sensitivity
Input Parameter
e.g. Q, z, kst

- Case Studies -
Elbe & Iller

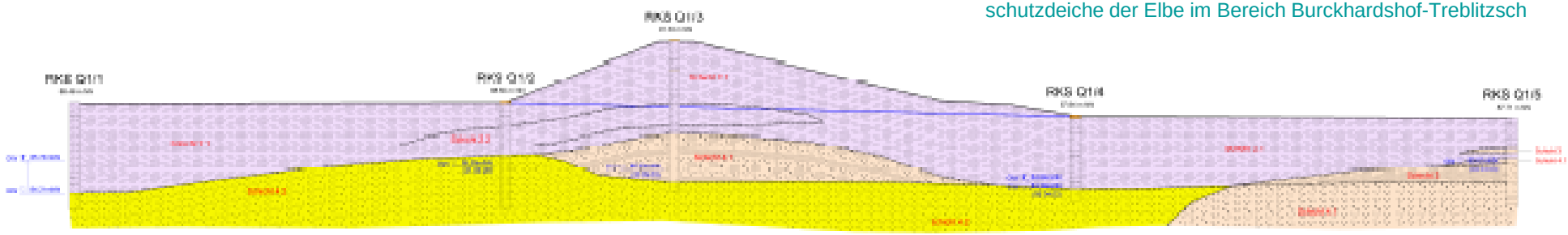
B

Geotechnical Data
& Results

Application / Implementation

4. Uncertainties in Resistance Data Base

From: Schwachstellenanalysen der linksseitigen Hochwasser-schutzdeiche der Elbe im Bereich Burckhardshof-Treblitzsch



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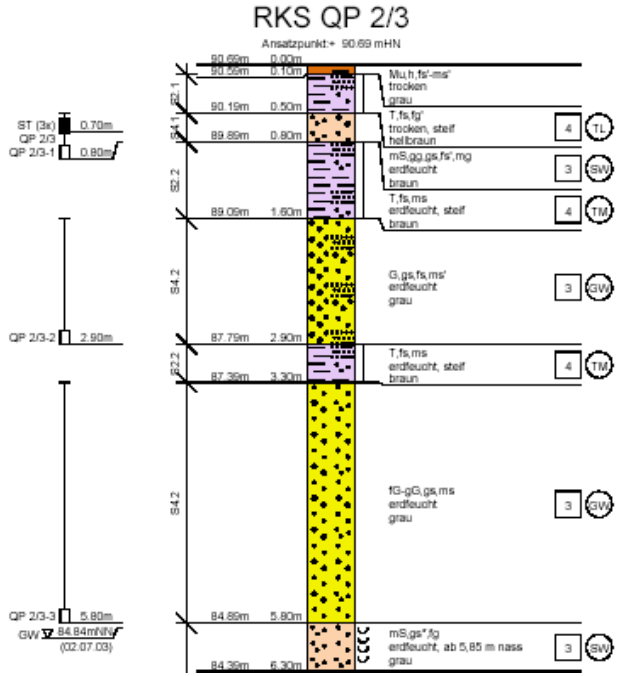
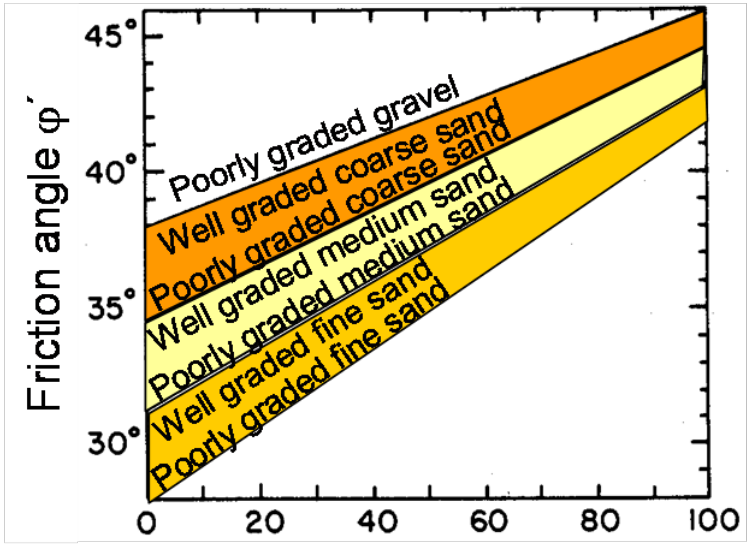


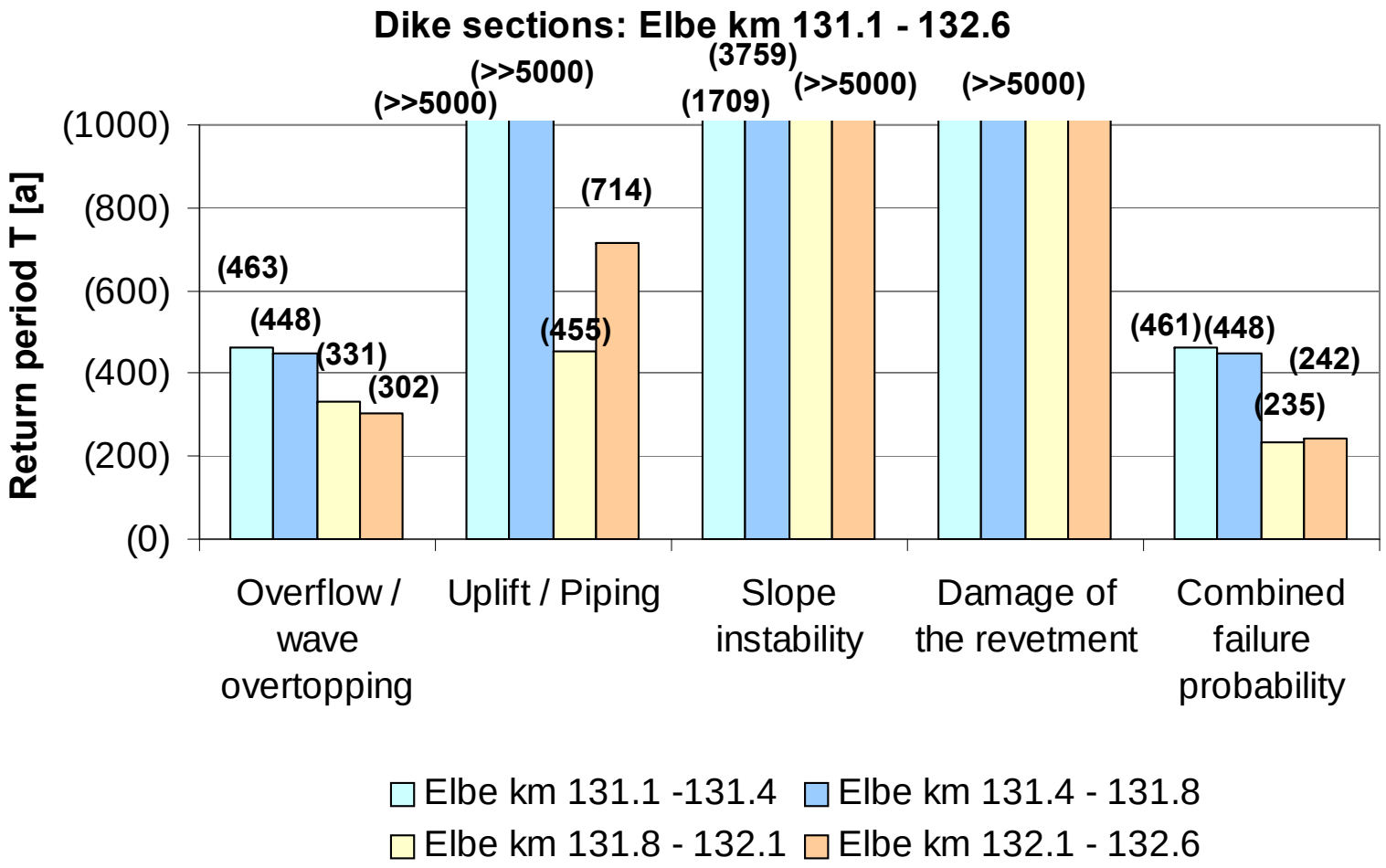


$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

Schmertmann, 1978. Guidelines for Cone Penetration Test, Performance and Design. Report FHWA-TS-78-209, US Department of Transportation, Washington

4. Uncertainties in Resistance
Failure probability

Comparison of the failure mechanisms

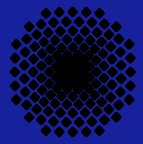


5. Summary & Outlook

- PC-Ring adaption for general use under non-lowland conditions
- Extending, validating and automating the hydraulic uncertainty analysis
- Flexible connection to hydraulic models
- Interface for geotechnical FE-Analysis
- Promotion of a probabilistic dike design

Provision of a tool for risk-based river flood protection

Thanks for your attention!



University of Stuttgart
Institute of Hydraulic Engineering
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uwe.merkel@iws.uni-stuttgart.de