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Enhancing Society Together

Seepage Induced Geotechnical Instability of Flood Embankments

Workshop on seepage induced instability
Imperial College, August 2017

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31st August 2017

Introduction

- Introduction
- Key features of flood embankment behaviour
- Summary of performance in England during floods since 2007
- Overview of 2015/6 Winter Storms
- Case History: St Michael's on the Wyre
- Flood embankment resilience to seepage
- Research needs
- Conclusions

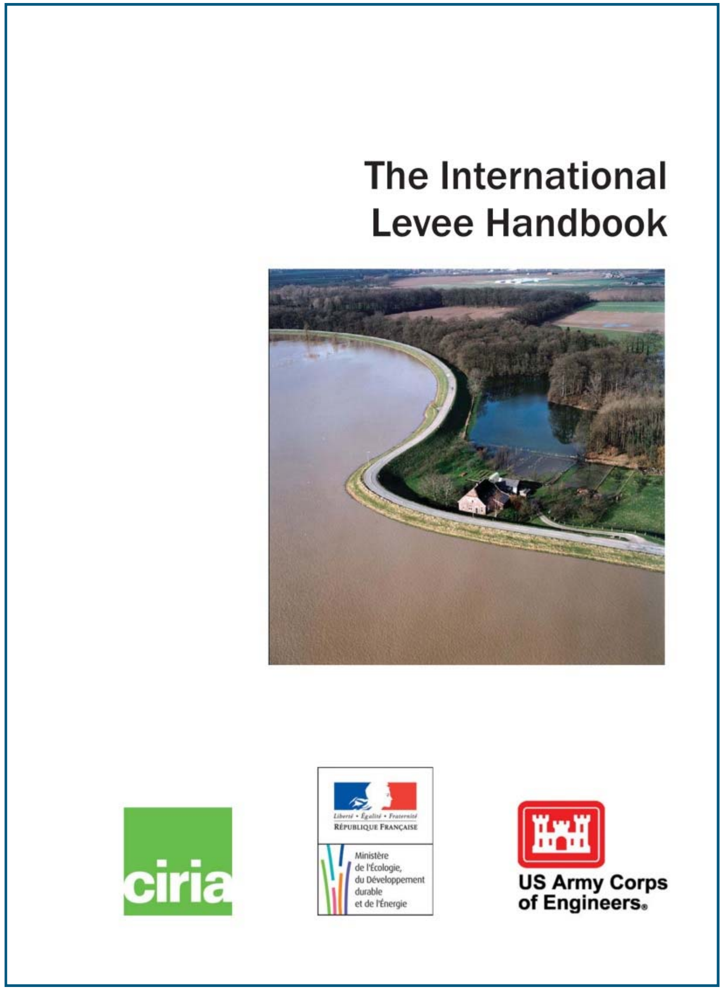
Flood embankments – The dam's poor relations?

Flood embankments – Not always reliable

Why are flood embankments vulnerable?

- Composite structures, built from a mixture of natural and manmade materials, often on poor (floodplain) ground.
- Subject to deterioration over time (settlement, desiccation, animal burrowing, uncontrolled vegetation, erosion).
- Historically, not always designed or built to established standards (particularly rural levees); lack of historical records.
- They can stand for decades without experiencing the design flood; fragility is not always apparent.
- They can get taken for granted; the physical barrier they create can give a false sense of security; maintenance can be delayed…
- Only as strong as the weakest link! Failure of a small percentage will undermine the integrity of the system.

The International Levee Handbook (ILH)



In 2008, organisations from France, Germany, NL, the UK, Ireland and the USA agreed to share the effort of producing good practice guidance for levees.

The initiative was spawned by the severe problems experienced in New Orleans during Hurricane Katrina and by the growing awareness of the general lack of guidance for the design and operation of levees.

Work on the ILH began in 2009.

The ILH was published in 2013

Levee performance – England, last 10 years

Flood Event	Nature of flood event	Number of breaches		Comment
		Overtopping	Seepage, internal erosion, uplift.	
Summer 2007	Fluvial; 1000 km of levee tested	0	4	All caused by local irregularities
Cumbria 2009	Fluvial; widespread overtopping	1	0	
Lincolnshire 2012	Fluvial	0	2	All caused by local irregularities
Winter 2013/2014	Coastal; widespread overtopping	83(ish)	?	Most breaches caused by coastal overtopping
Winter 2015/2016	Fluvial	3	3	All caused by local irregularities
Winter 2015/2016	Coastal		2	Beach erosion

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Overview of 2015-6 Winter Storms

- Storm Desmond, Storm Eva and Storm Frank 5th December to 5th January.
- Extensive flooding particularly in Yorkshire, Cumbria, Lancashire.
- c. 20,000 homes affected by flooding.
- KPMG cost estimate c. £5 billion.

Source: House of Commons Briefing Paper CBP7427

Tadcaster Bridge collapse, River Wharfe

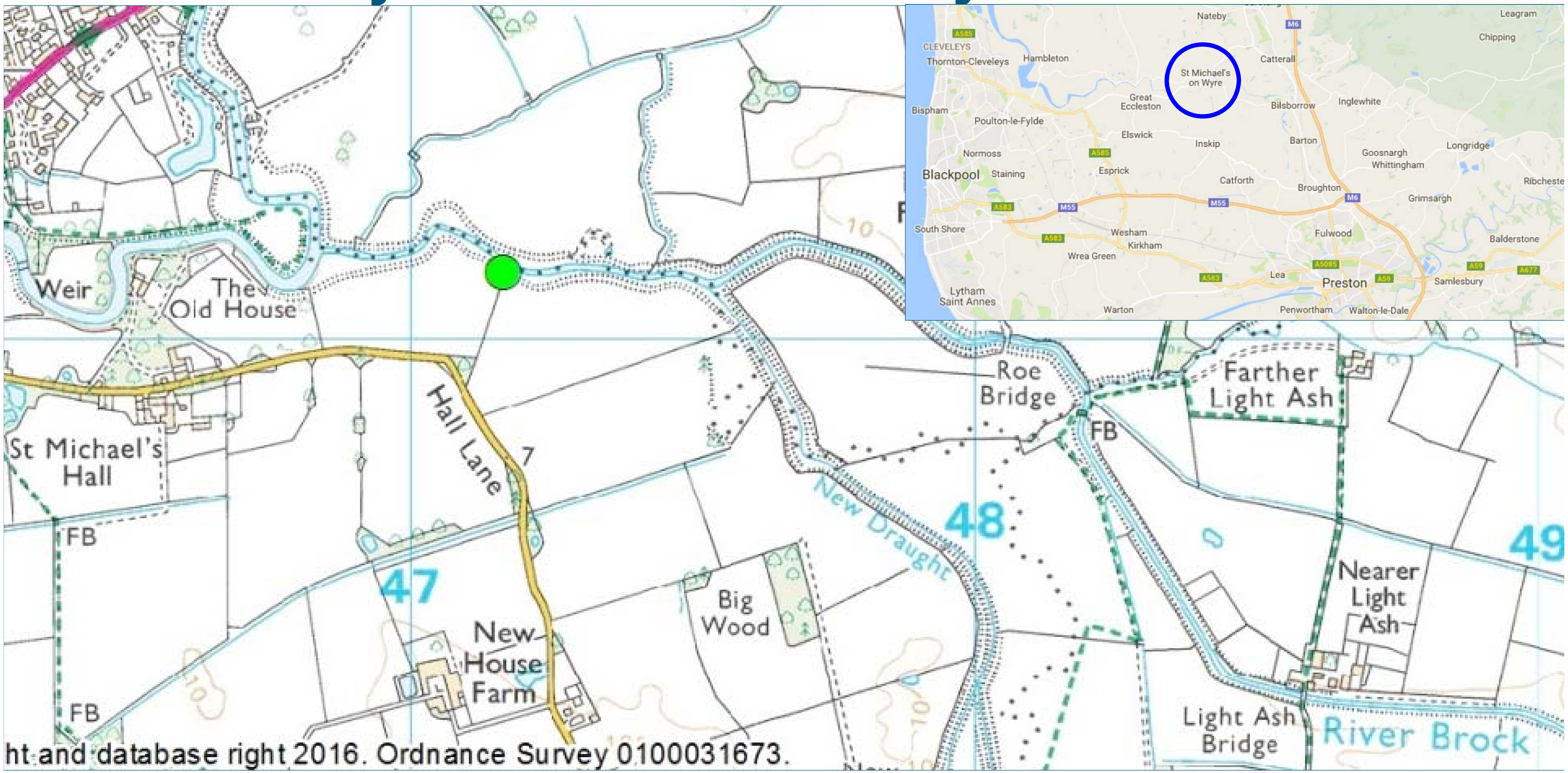
Overview of 2015-6 Winter Storms

Initial review of 2015-6 events indicated the following:

- The majority of flooding occurred due to overtopping rather than breach.
- Recently constructed defences generally withstood overtopping without breach;
- The failures generally involved older assets in “low consequence” (rural) areas. These embankments are subject to a lower level of inspection and maintenance than urban structures.
- Observations consistent with other recent flood events.

A study of the assets which either failed or partially failed during the 2015-6 winter storms was undertaken for the Environment Agency.

Case Study: St Michael's on Wyre – site location



Left bank of River Brock immediately upstream of confluence with River Wyre

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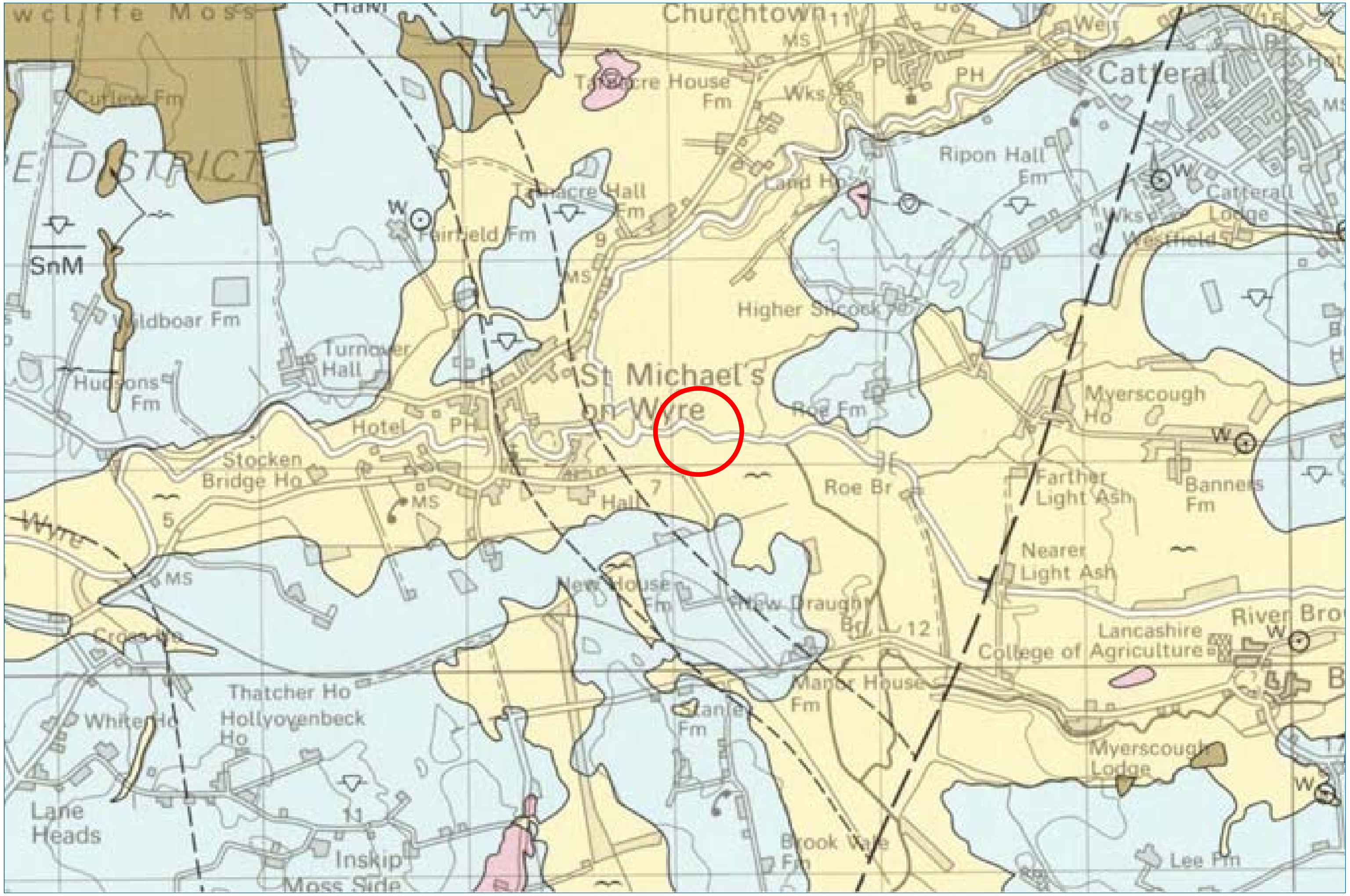
Case Study: St Michael’s on Wyre – features

Earthen embankment protecting mainly agricultural land

Case Study: St Michael's on Wyre – Geology



Alluvium overlying glacial till; Permian and Triassic solid geology.

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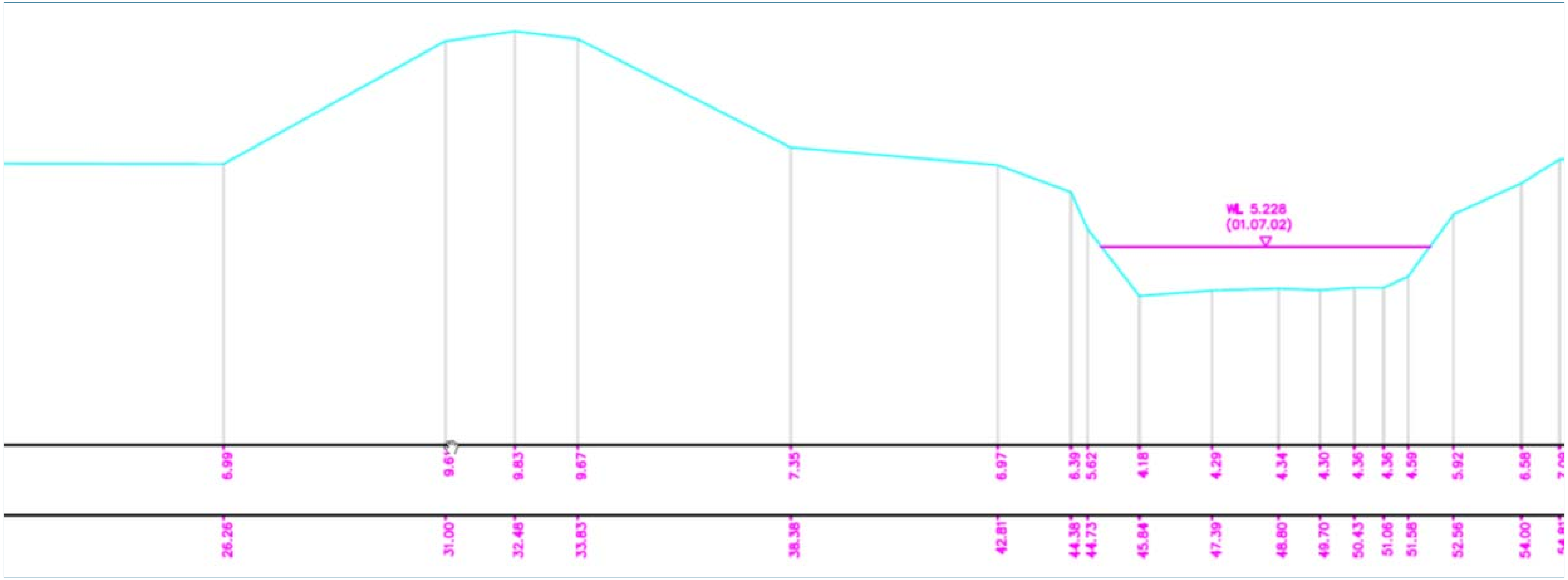
Case Study: St Michael’s on Wyre – features



- c. 1V:1.75H (30°) landward slopes
- <3m wide crest
- 3m wide berm on riverward side

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Case Study: St Michael's on Wyre – Storm Desmond 5th/6th December 2015

Flooding affected 16 properties and a large area of agricultural land.

100mm depth of overtopping over 60m of embankment.

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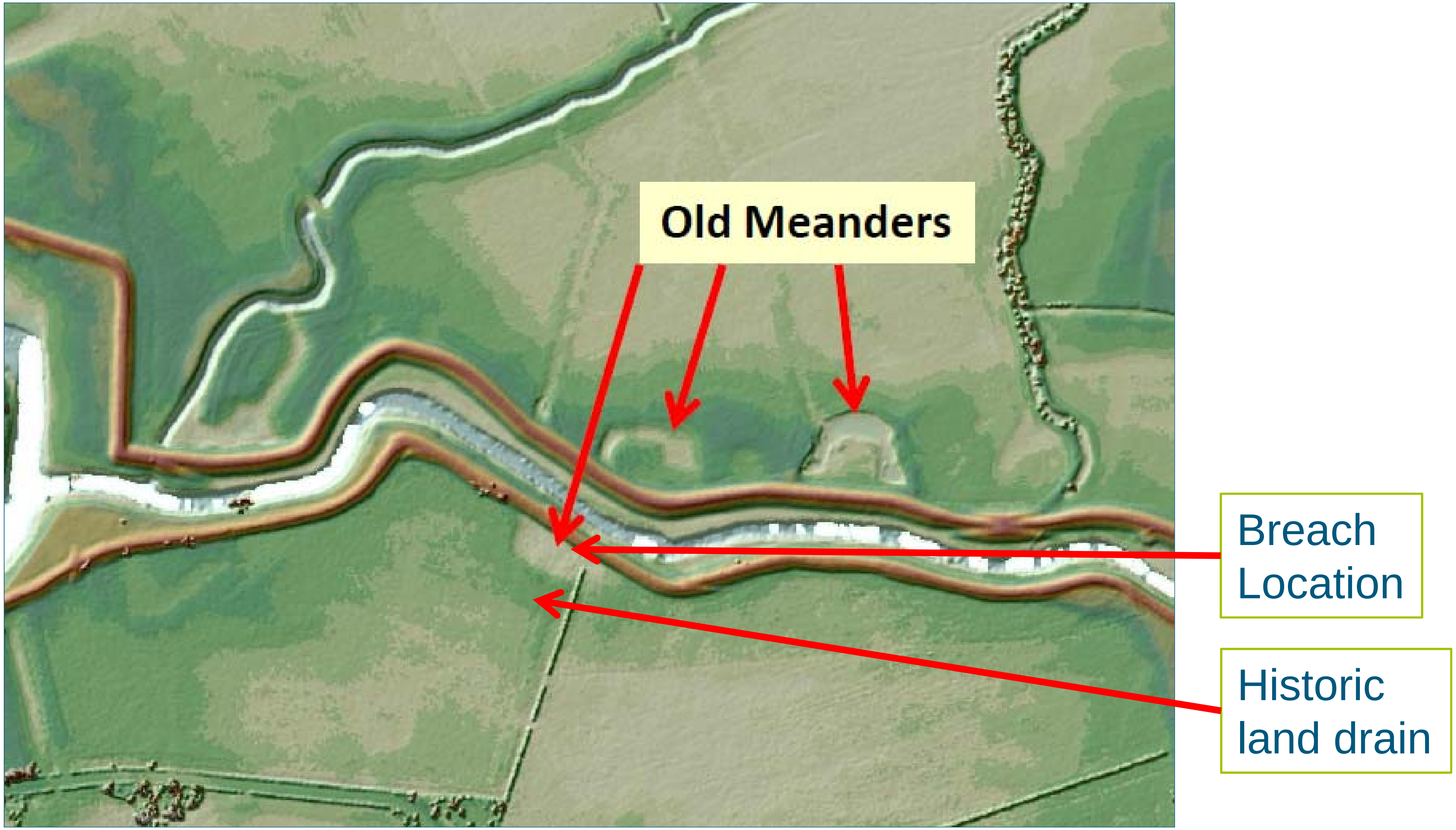
Case Study: St Michael's on Wyre – Storm Desmond 5th/6th December 2015

Case Study: St Michael's on Wyre – Storm Desmond 5th/6th December 2015

Case Study: St Michael's on Wyre – LIDAR data



St Michael's on Wyre – evidence of piping

Evidence of piping on landward side of embankment at location of breach.

Coincides with location of historic land drain

Case Study: St Michael's on Wyre – key findings

Breach failure initiated by overtopping erosion of landward slope

Causal factors:

1. Localised low crest leading to overtopping.
2. Reduction in toe resistance caused by possible piping at location of historic land drain.
3. Steep landward slope;
4. Relatively poor quality embankment fill material.

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“Stabs in the back”

Cooling & Marsland, (1954) identified many of the same mechanisms after the North Sea Floods of 1953 (overtopping, seepage erosion, uplift of landward toe).

They termed these failure mechanisms “*Stabs in the back*”.

Similar causes and failure mechanisms were experienced in New Orleans during Hurricane Katrina.

Extreme flood events occur rarely and with little warning; flood defences may not have been tested over recent years and so problems of land-side deterioration may not always be obvious in advance.

Local irregularities (transitions, areas of deterioration and geological features) are particularly vulnerable and are commonly the focus of breaching.

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- Most breaches were triggered by the actions of flowing water (overtopping, seepage, internal erosion) or uplift rather than simple rotational failures.
- Rotational failures more common during construction or post flood.

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Comparison with dams

Causes of Dam Failures	Percentage
Overtopping & Spillway	23 - 52%
Piping/Seepage/Internal Erosion	25 - 44%
Slides	2 - 15%
Miscellaneous	9 - 40%

(Vijay Singh - “Dam Breach Modeling Technology”, 1993)

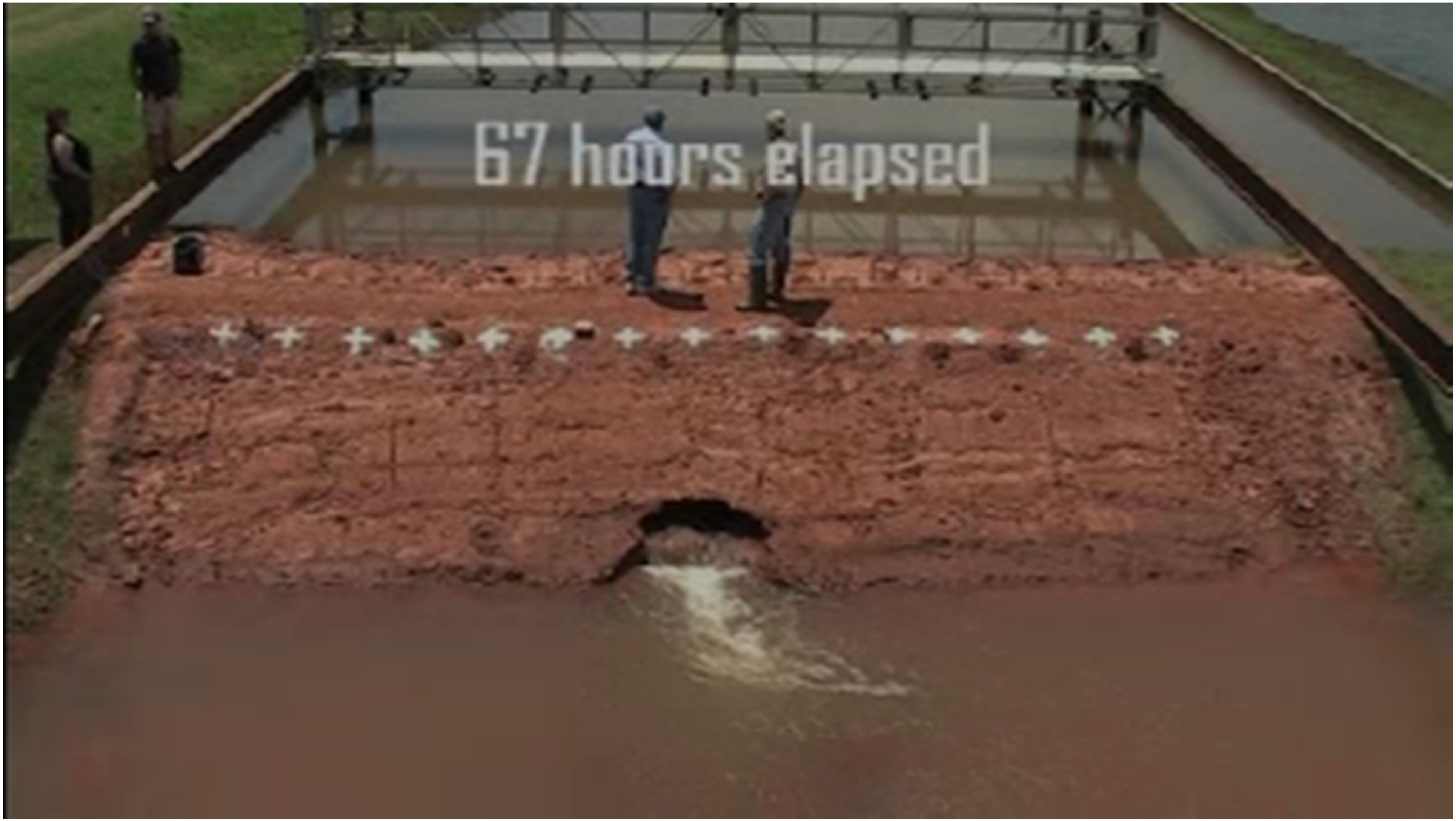
Resilience and soil type

Susceptibility to seepage induced instability is material dependent.

- United States Department of Agriculture carried out some simple studies to look at resilience of levees to seepage and piping.
- USDA built a number of embankments to provide a comprehensive and definitive guide to good practice.
- Two videos of two cases presented:
  - Case 1 – silty sand embankment (non-plastic, ~5% clay)
  - Case 2 – low-PI clay embankment (PI = 15%)
- Important to remember that most flood embankments are built out of locally won material.

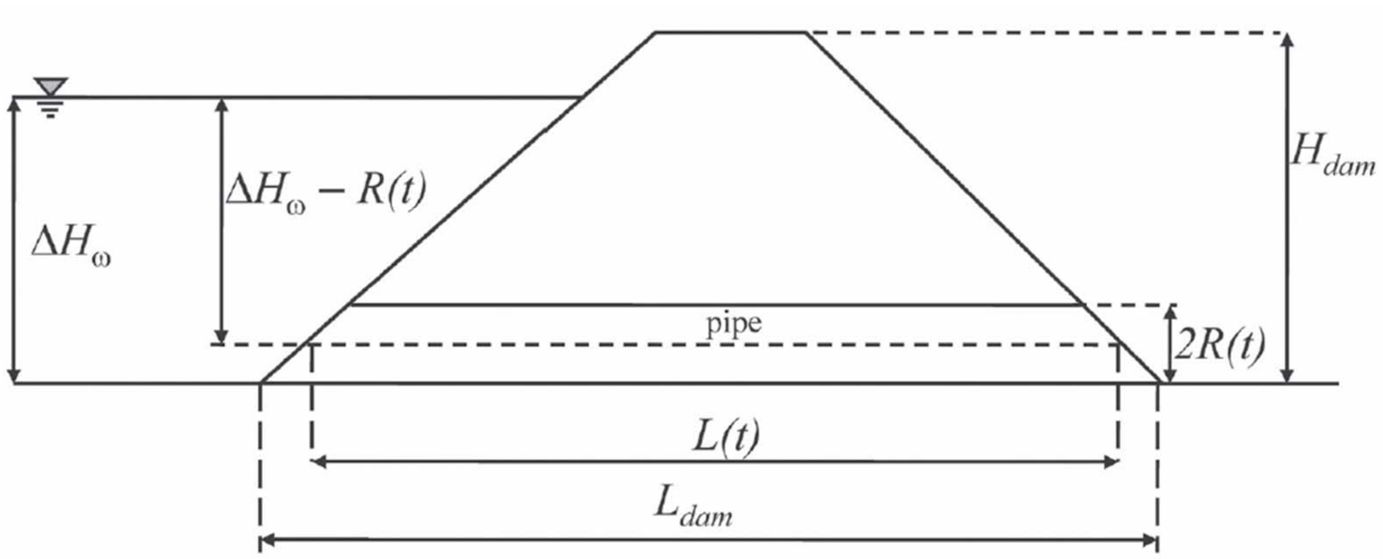
Resilience and soil type – silty sand fill material

Resilience and soil type – clayey (CL) fill material



Resilience and soil type – clayey (CL) fill material

ILH Section 8.5.2 suggests a method for predicting time to failure based on the "erosion index" (I_e) of the embankment fill material.



If I_e = 2 (C_e = 1x10^{-2} s/m), soil is highly erodible

If I_e = 4 (C_e = 1x10^{-4} s/m), soil is resistant to erosion

$$\triangle t_u \approx t_{er} \ln \left(\frac{R_u}{R_d} \right) \propto \frac{1}{C_e}$$

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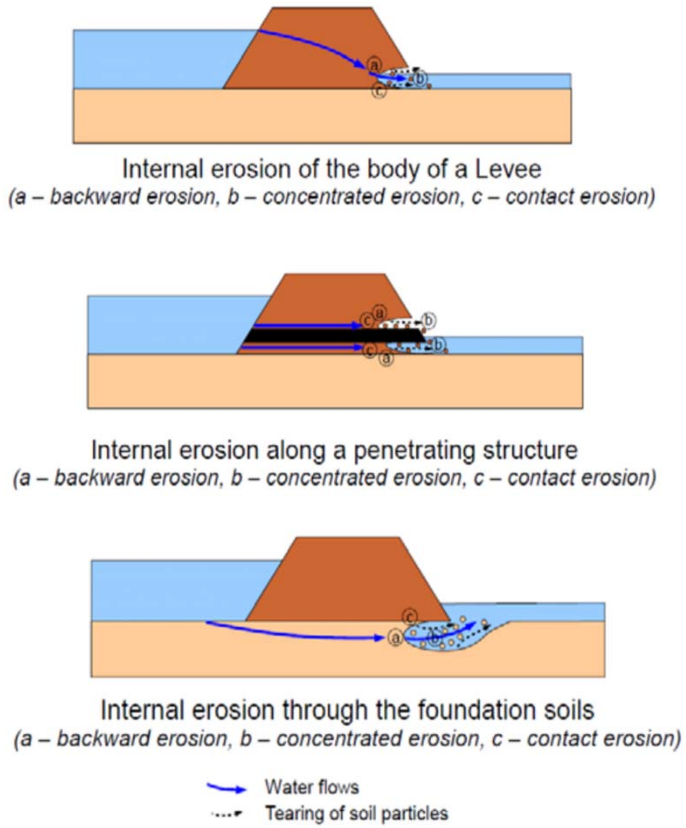
Effects of deterioration on resilience to seepage

Rabbit burrowing, Scotland

Desiccation cracking of clay embankment

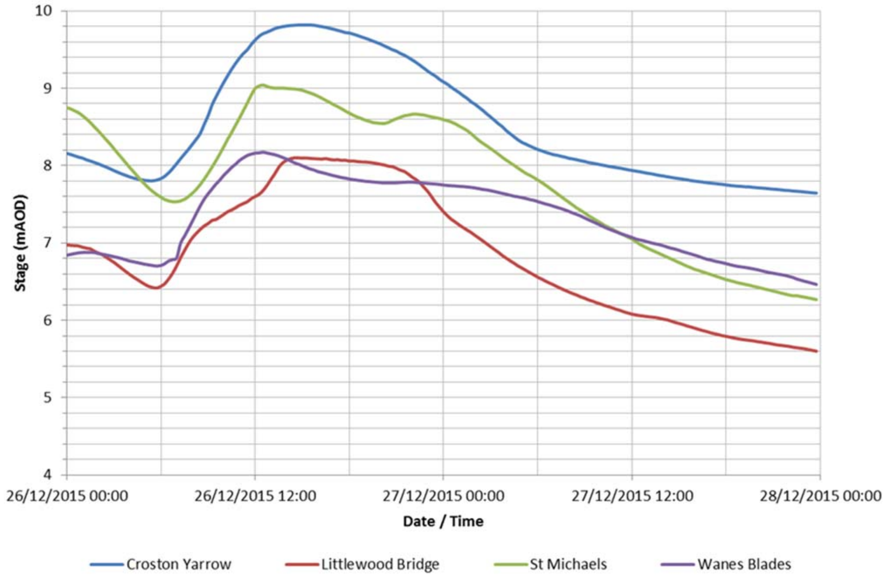


Ongoing and cumulative effects of seepage and internal erosion

Importance of flood duration to internal erosion

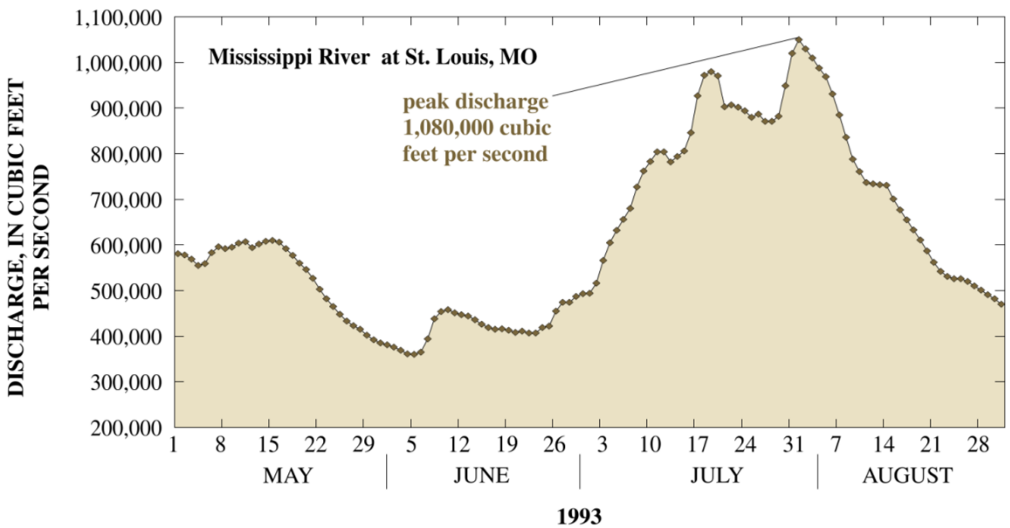
Croston, Lancashire, December 2015

Flood duration 1 day



Mississippi River, St Louis, 1993

Flood duration 2 months



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Design to reduce susceptibility to seepage

- Understand the importance of geological features, historical structures and transitions. Manage the situation as appropriate.

- Local ground conditions will be as they are and fill materials will generally be difficult to change (e.g. embankment already constructed or because of the environmental imperative to use local material) .

- Understand the potential impact of deterioration.

- Assess resilience of foundation soil and fill material to seepage.

- Carry out appropriate seepage analyses; consider the use of transient analyses if flood duration is short.

- If necessary, design features to inhibit seepage or uplift e.g.:
  - careful design of transitions and inclusions;
  - cut-off barriers;
  - relief wells; and/or
  - shoulder berms.

Summary

- Reviews of levee performance in England during the floods of the last ten years suggest that breaches are generally caused by overtopping erosion, seepage or uplift.
- Rotational "slip" failures are more common during construction or possibly rapid drawdown after a long duration flood.
- Well designed and maintained "high and medium consequence" assets have generally withstood design flood levels and overtopping without breach failure occurring.
- Where breaches occur, they can commonly be related to local ground conditions, construction defects, embankment deterioration or transitions (or a combination of these). Seepage or uplift can significantly reduce stability.
- Causes of failure can usually be explained after the event but there are practical difficulties associated with assessing all 9000km of EA's levees.
- A review of known issues (transitions, local settlement, local seepage) will help to identify lengths of levee vulnerable to poor performance so that resilience can be improved.

Research needs (seepage induced instability)

- Cost-effective measures for identifying vulnerable sections of flood embankment, e.g. Lidar, geophysics, gathering of historical performance during floods.

- Development of techniques to obtain better inspections of levees during floods, particularly to safely identify areas of seepage (e.g. drone inspections).

- Development of techniques to assess erodibility of particles as a pipe develops for use in e.g. the Sellmeijer et al, 2011 method.

Thank You