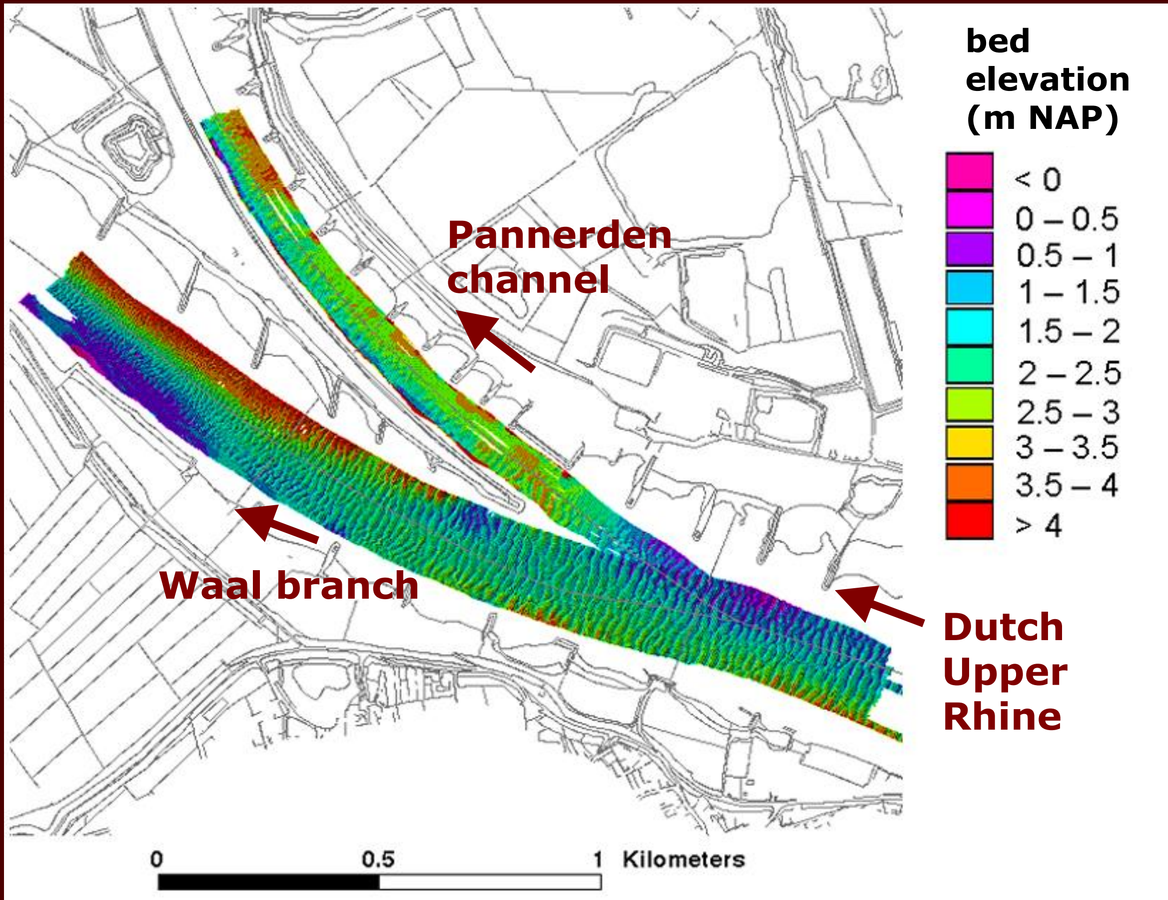
The importance of sediment supply data to modelling river morphodynamics

Wilbers & Ten Brinke (2003)

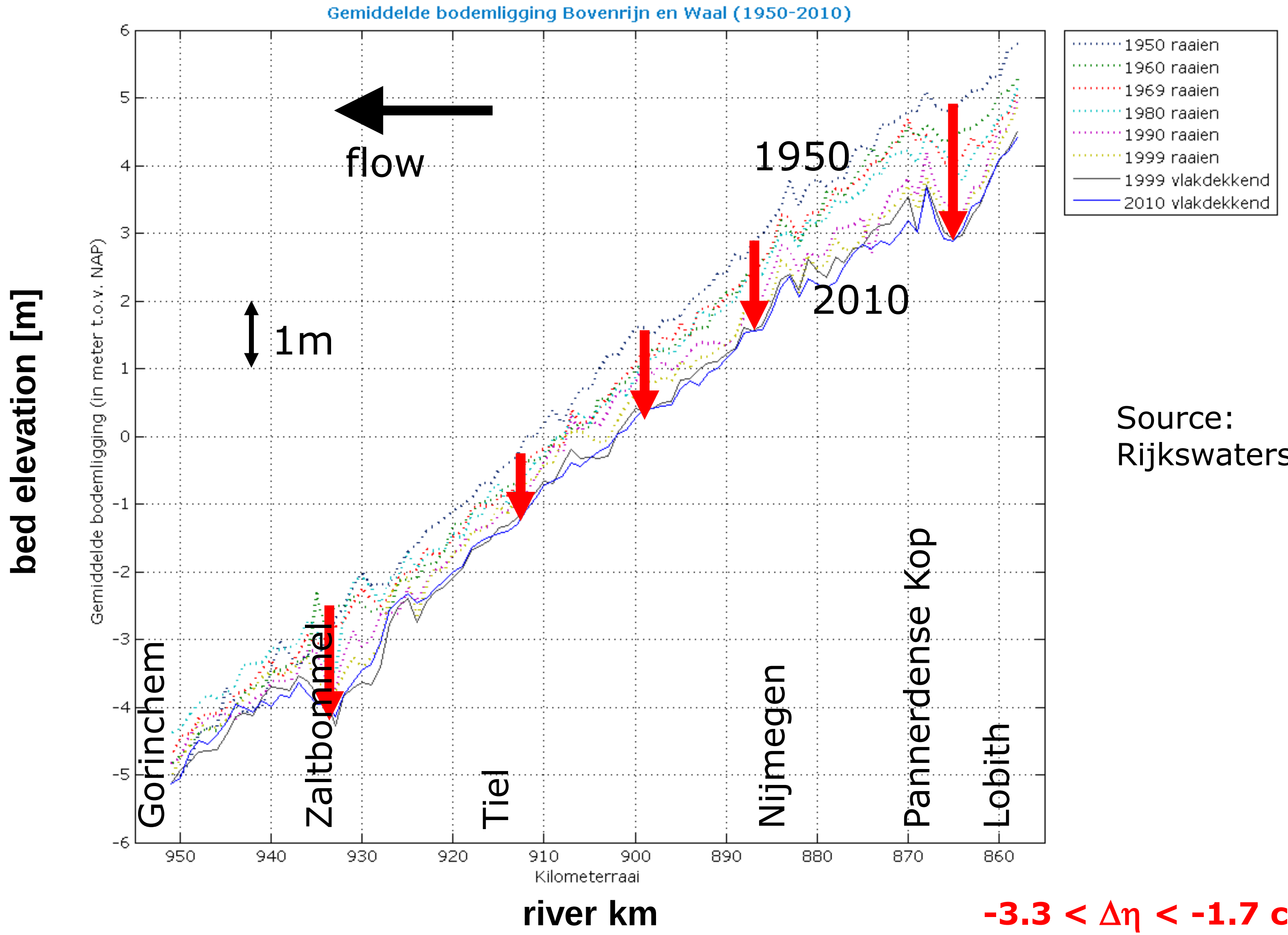


Astrid Blom

Delft University of Technology
Netherlands

Dutch reach of the Rhine River

Bovenrijn and Waal branches



Source: Rijkswaterstaat

$-3.3 < \Delta\eta < -1.7$ cm/a

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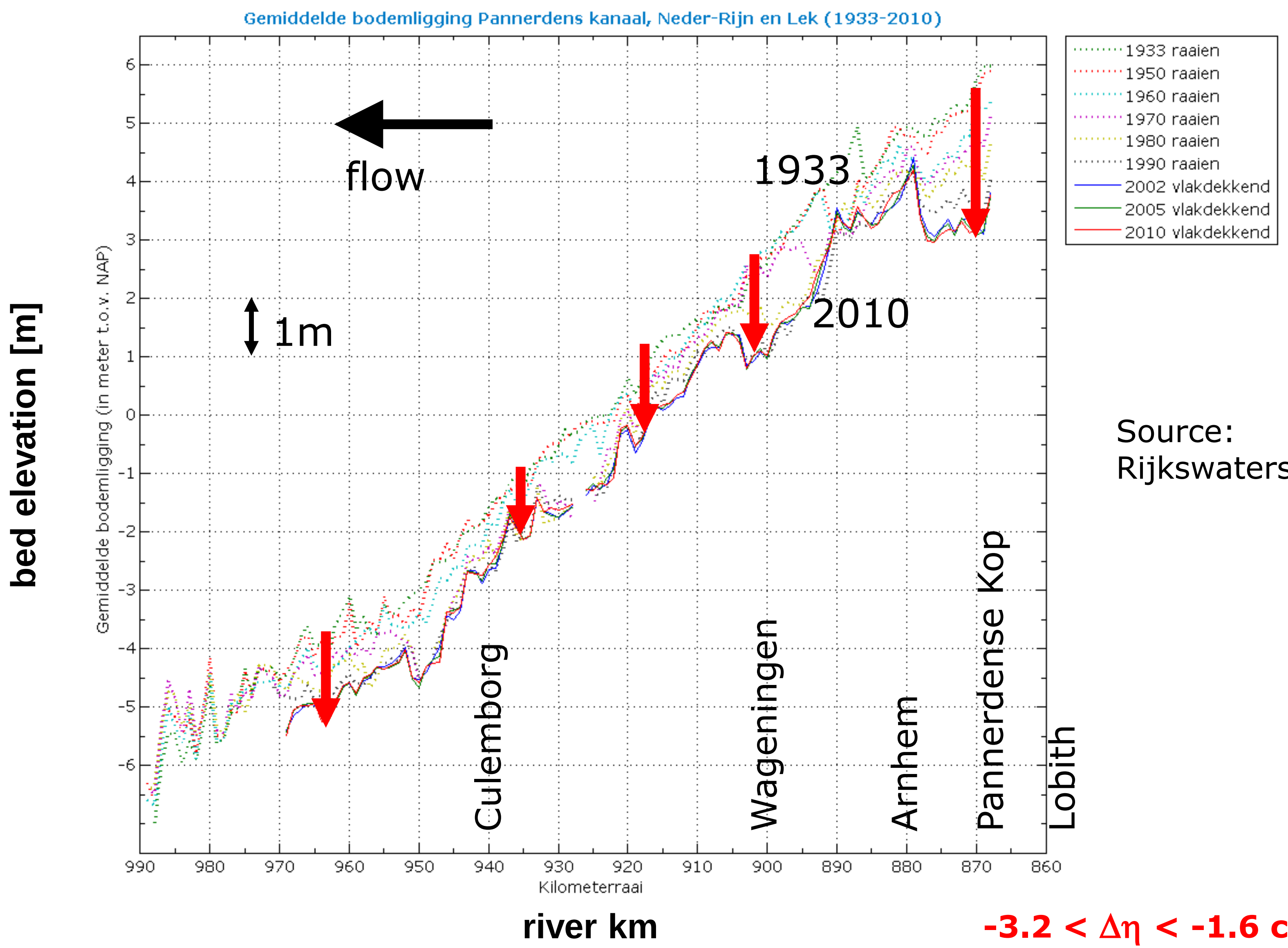
Dutch reach of the Rhine River

Pannerden channel, Nederrijn, Lek

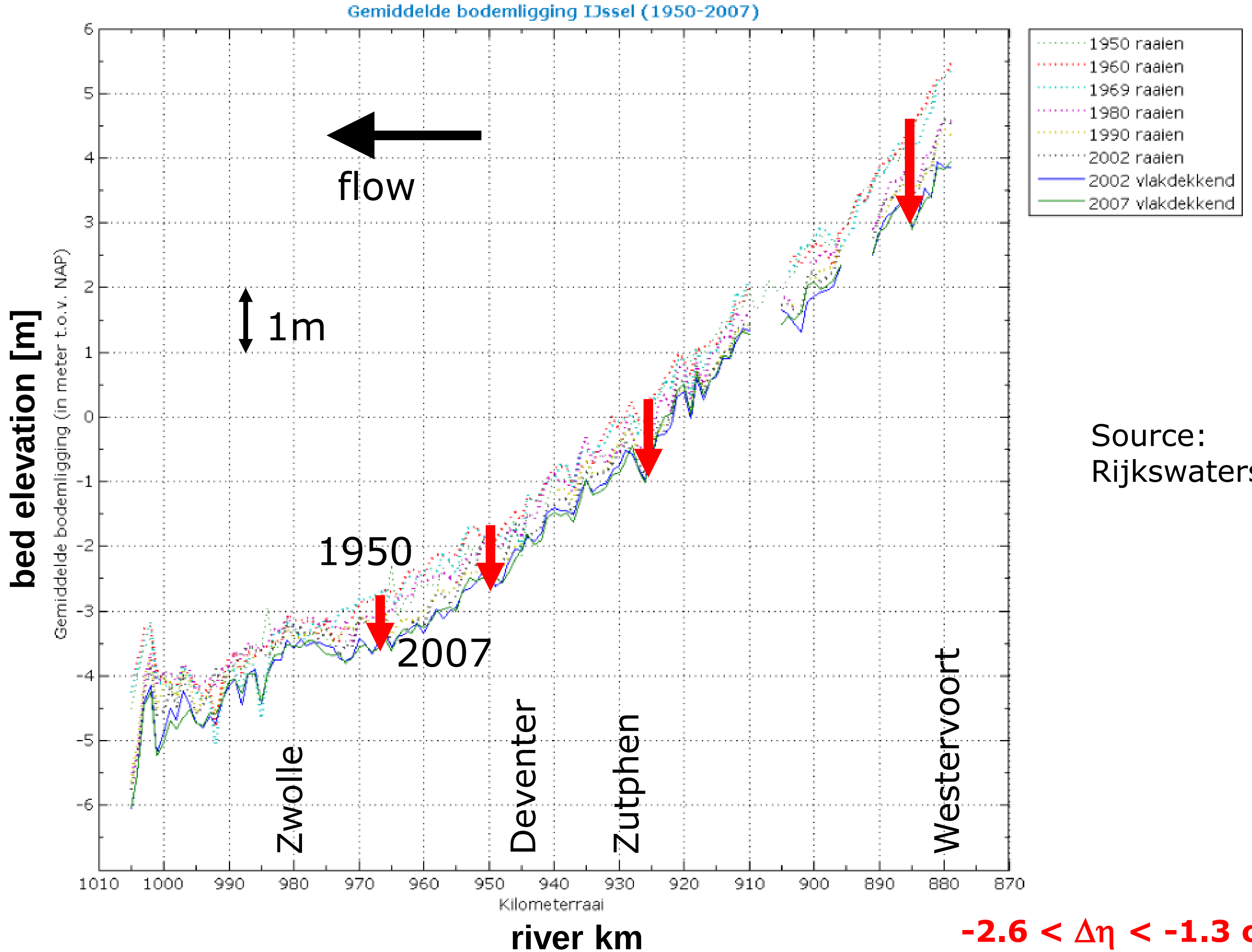


Source:
Rijkswaterstaat

-3.2 < Δη < -1.6 cm/a

Dutch reach of the Rhine River

IJssel branch



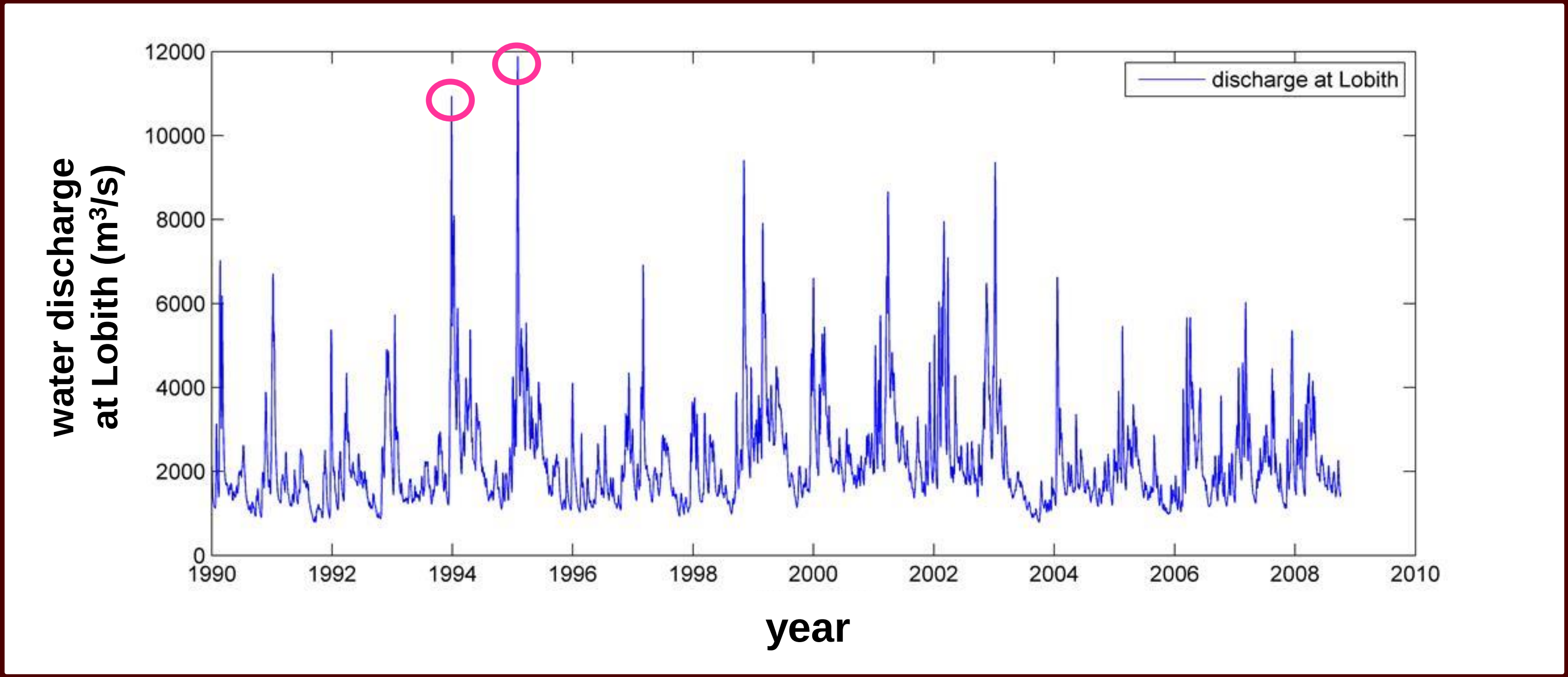
Source: Rijkswaterstaat

$-2.6 < \Delta\eta < -1.3$ cm/a

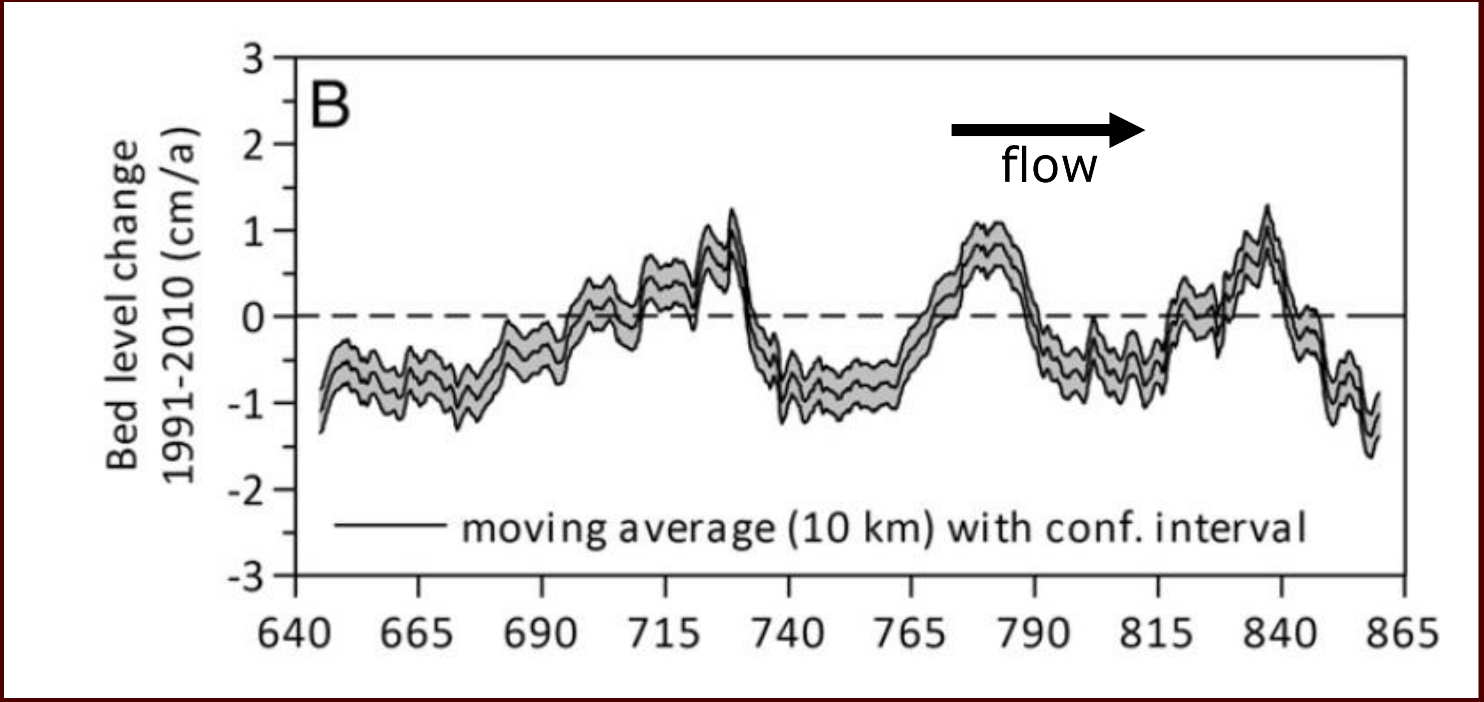
Does the degradation rate decrease?

We may observe a decrease in the degradation rate over the past 10-20 years.

This may be due to a lack of peak flows over this period:

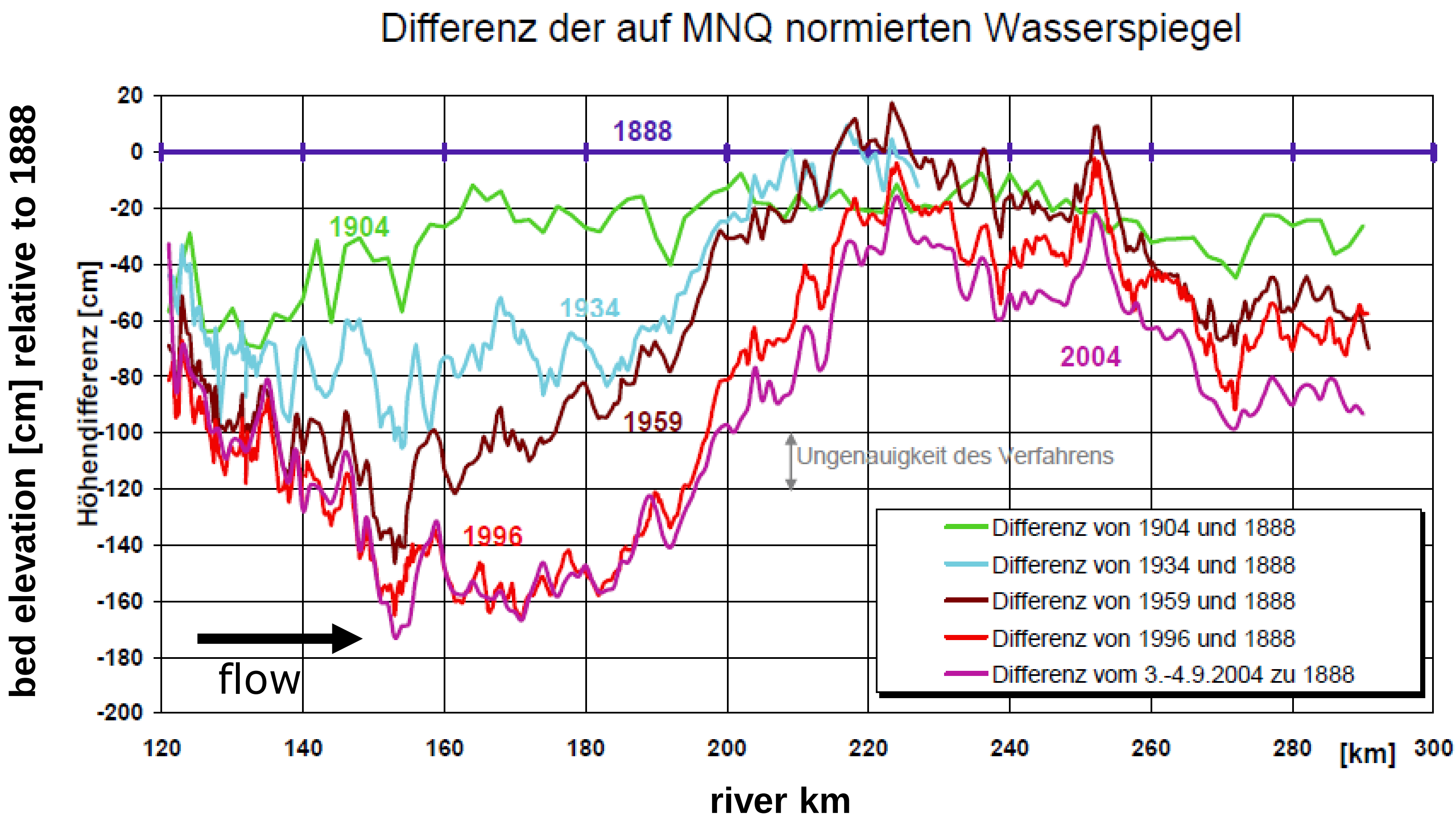


German reach of the Rhine River



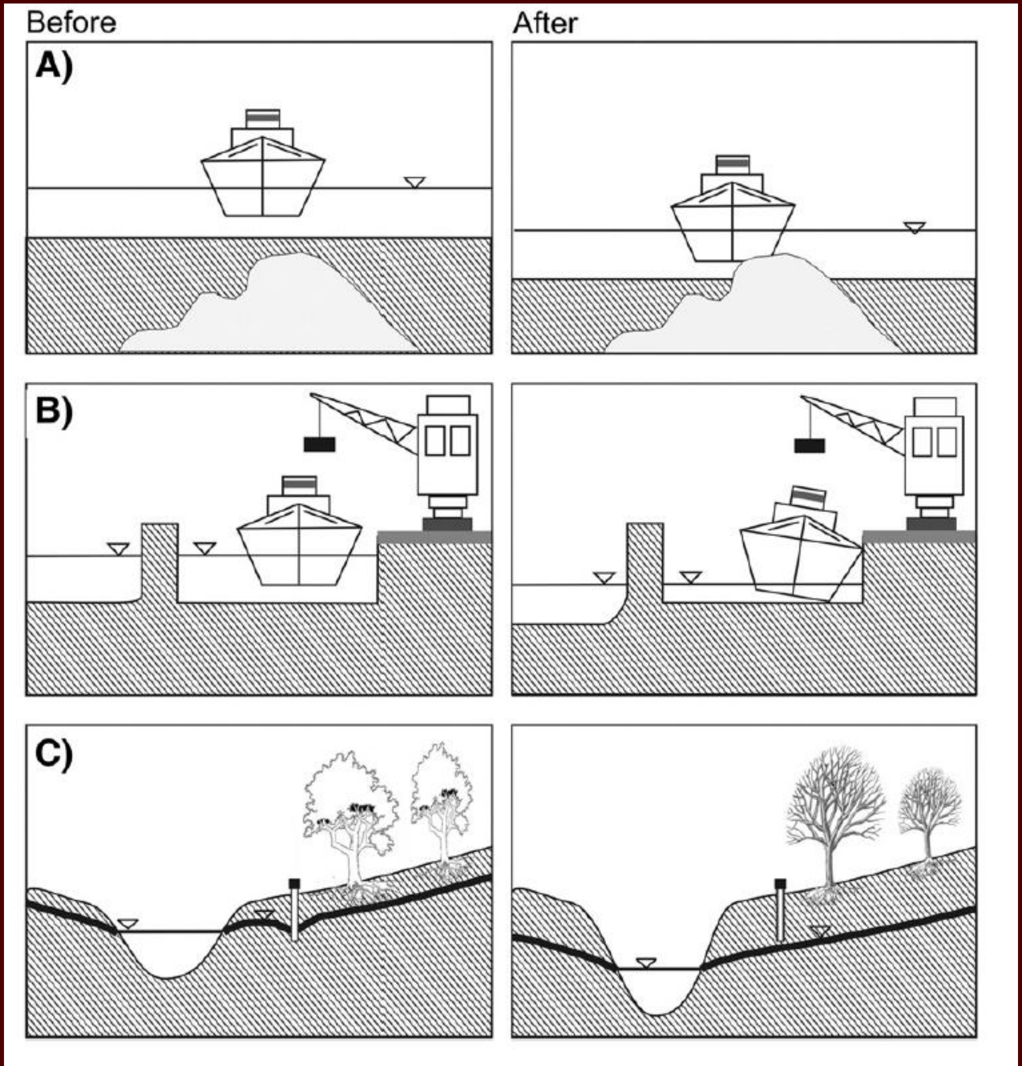
Frings et al. (Catena, 2014)

Elbe River



Source: PG Erosionsstrecke Elbe (2009)

Problems related to bed degradation



Frings et al. (Geomorphology, 2014)

and also:

- destabilization of structures;
- flood water level increases;
- flood risk downstream of bifurcations may increase.

Potential causes of long-term bed degradation

a) construction of levees

b) construction of groynes

c) bend cut-offs

d) extensive dredging

e) construction of dams

f) coarsening of the load

g) coarse augmentation measures

h) sea level change ?

i) temporal change of the PDF of water discharge ?

Potential causes of long-term bed degradation

a)	construction of levees	narrowing → degradation
b)	construction of groynes	narrowing → degradation
c)	bend cut-offs	shortening → degradation
d)	extensive dredging	reduction of sediment supply to downstream reaches → degradation
e)	construction of dams	idem → degradation
f)	coarsening of the load	coarsening of sediment supply to downstream reaches → degradation + (later) aggradation
g)	coarse augmentation measures	idem → degradation + (later) aggradation
h)	sea level rise	aggradation (migrating upstream)
i)	temporal change of the PDF of water discharge ?	very difficult to say

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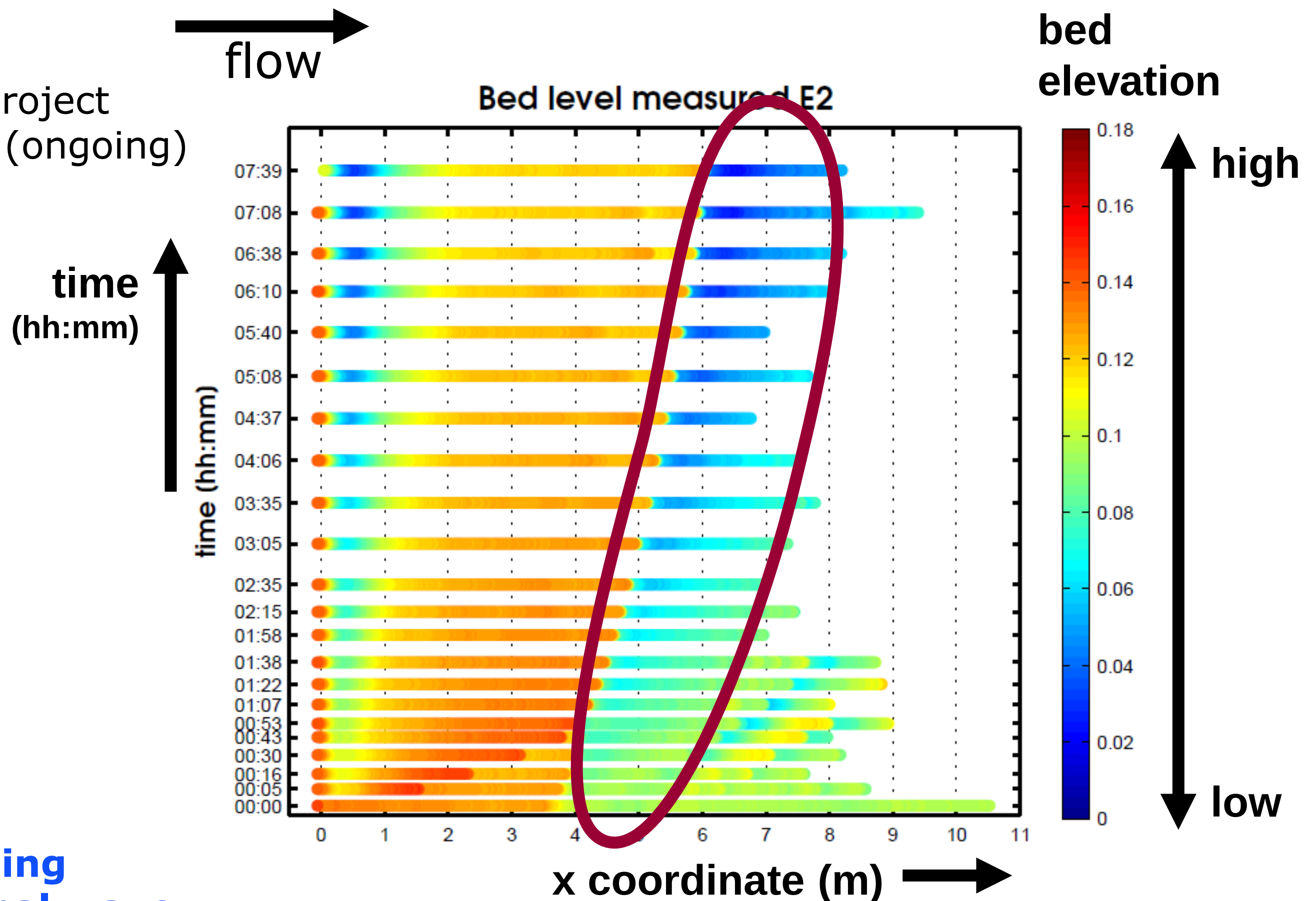
h)	sea level rise	aggradation (migrating upstream)
i)	temporal change of the PDF of water discharge ?	very difficult to say

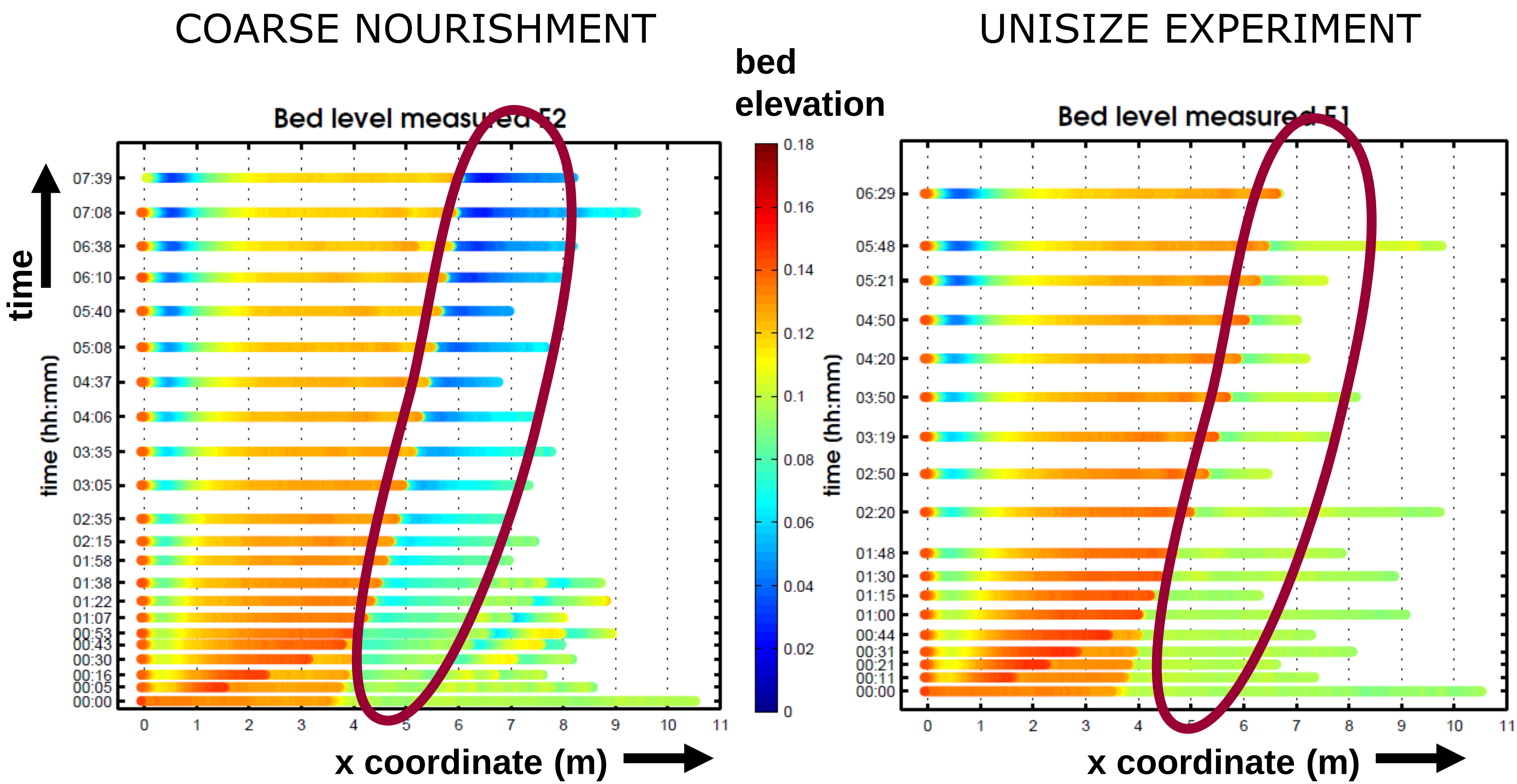
Frings et al. (2009)

Coarse sediment nourishment

Source: MSc project
Bart Berkhout (ongoing)

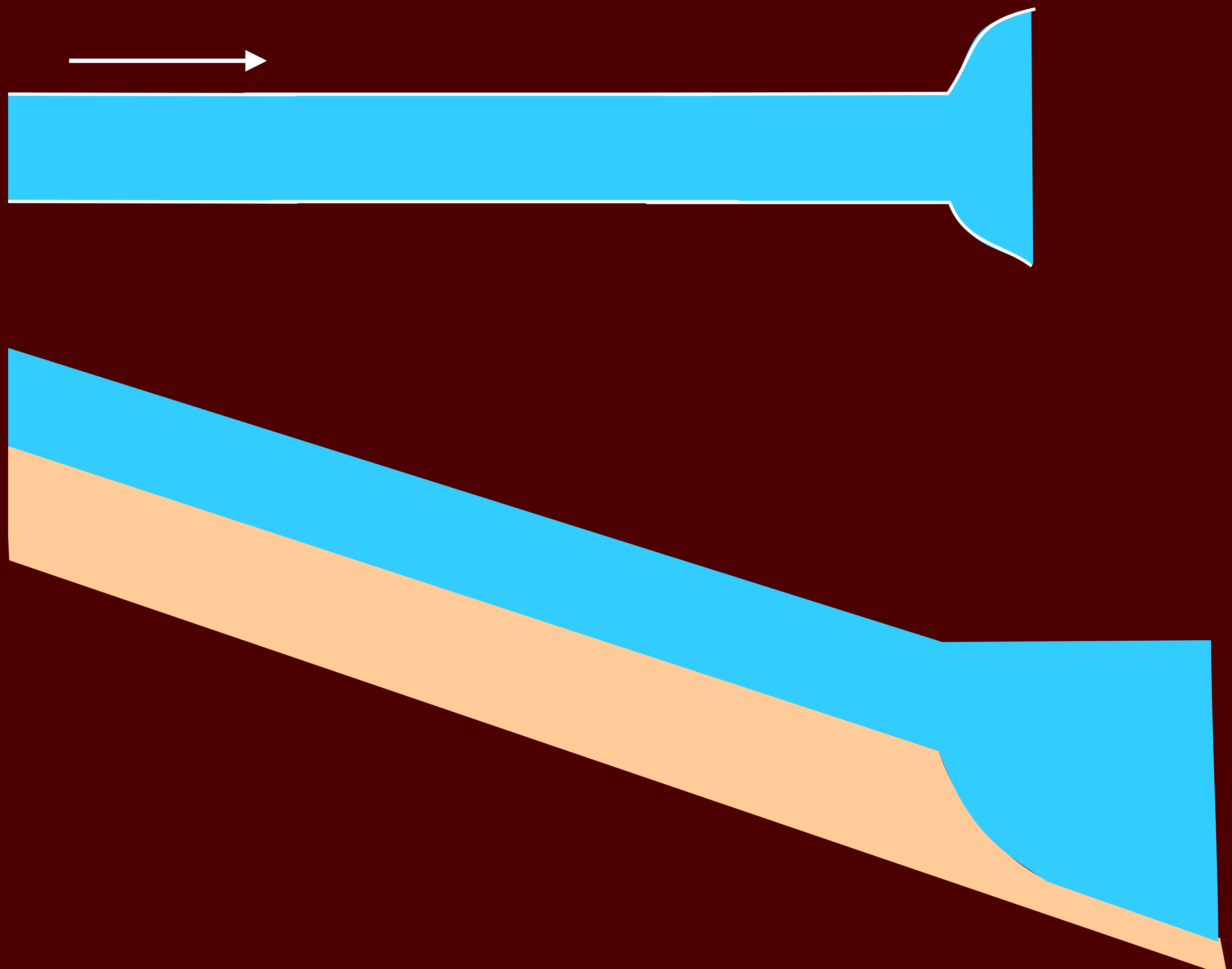


This preceding degradational wave was first observed by Ribberink (1987).

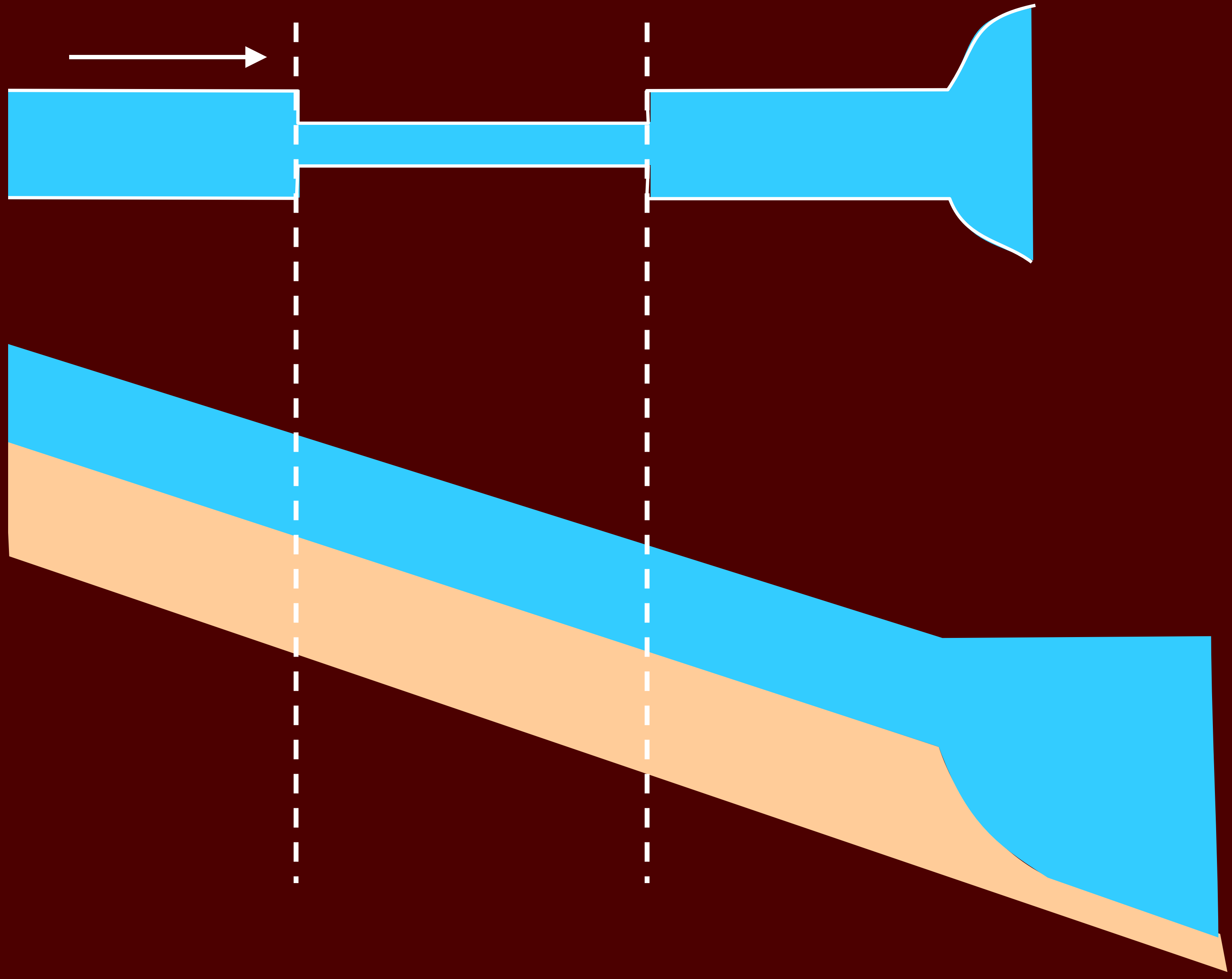


Source: MSc project Bart Berkhout (ongoing)

A certain river reach in equilibrium



Local constriction (due to levees or groynes)



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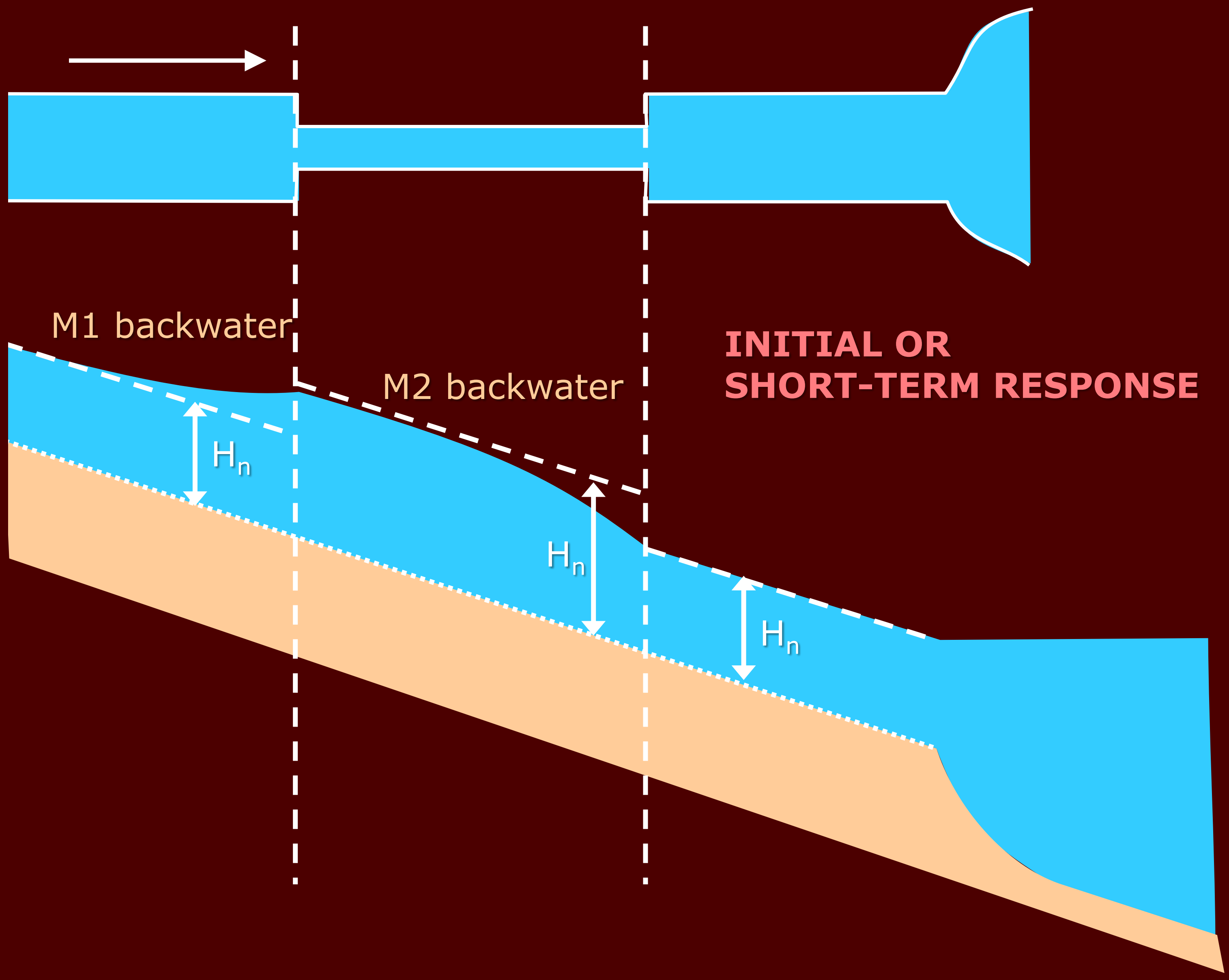

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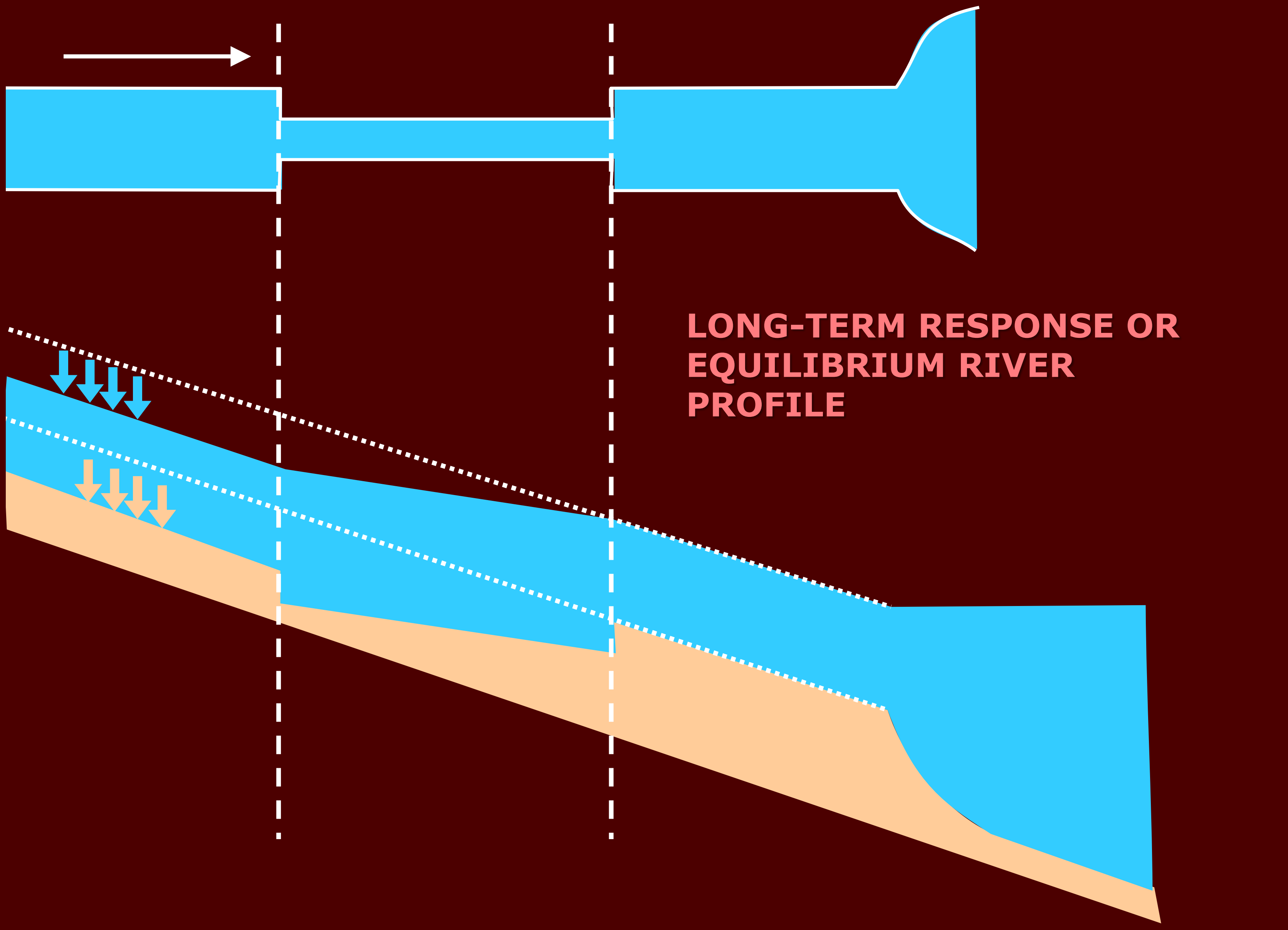

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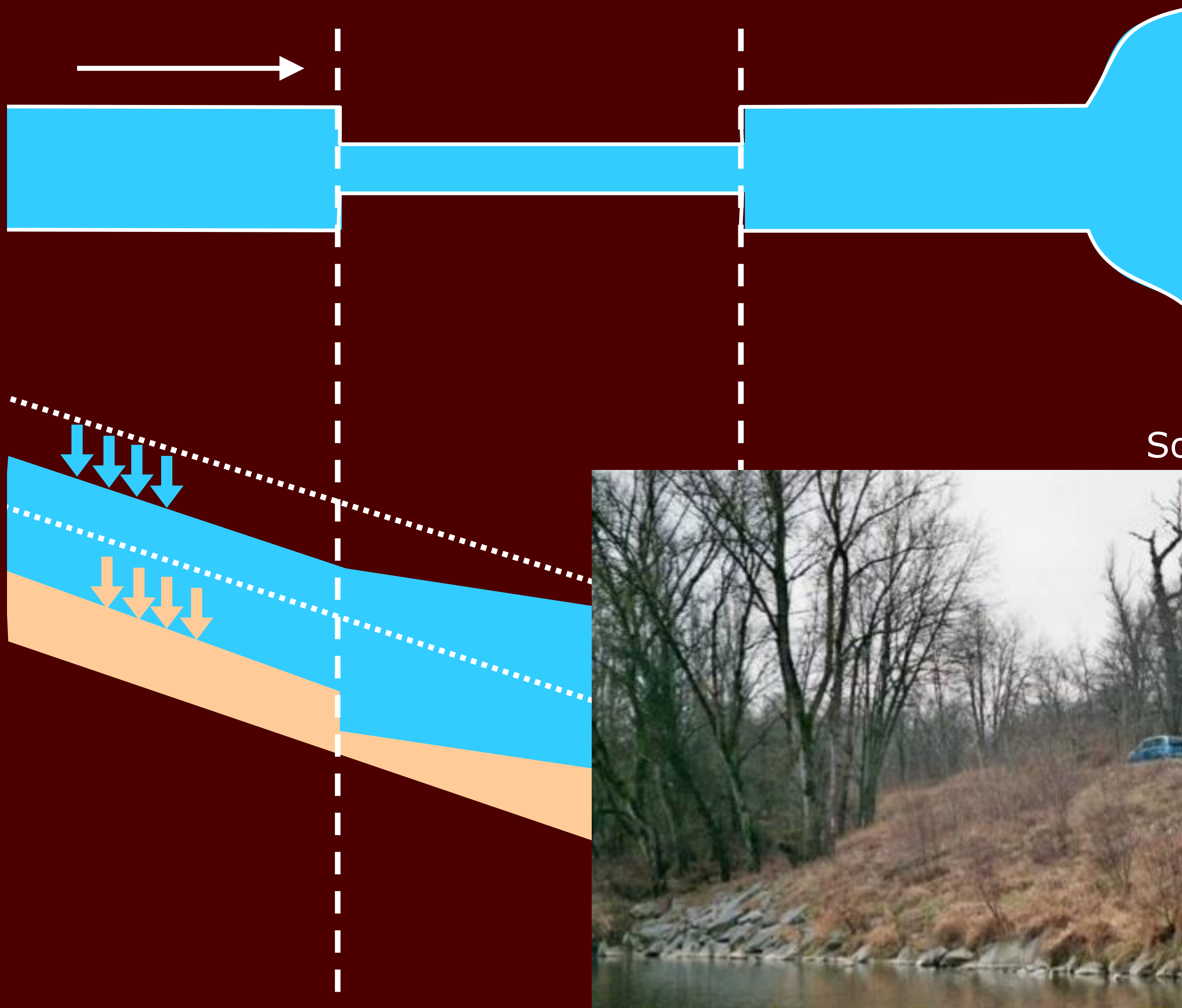
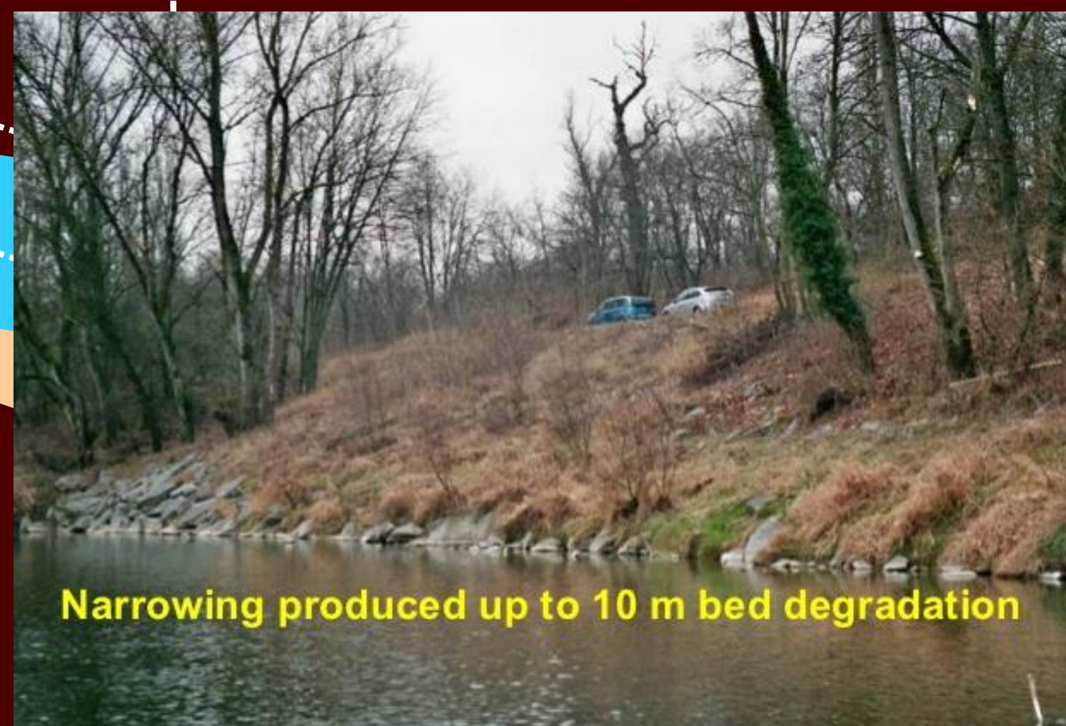


Source: Erik Mosselman



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The equilibrium river profile

1. The ***undisturbed*** equilibrium river profile

   The equilibrium longitudinal profile the river tends to approach before human intervention

2. The ***engineered*** equilibrium river profile

   The equilibrium longitudinal profile the river tends to approach after human intervention

3. The ***restored*** equilibrium river profile

   The equilibrium longitudinal profile the river tends to approach after river restoration measures

Viparelli et al. (2015)

Equilibrium river profile, for unisize sediment

Conservation of sediment mass (Exner) $$c_b B \frac{\partial \eta}{\partial t} = -\frac{\partial Q}{\partial x}$$ where $Q = B\frac{K}{D}U^n$

Engelund & Hansen (1967)

Conservation of water mass $$\frac{\partial BH}{\partial t} + \frac{\partial Q_w}{\partial x} = 0$$

Conservation of streamwise momentum $$\frac{\partial UH}{\partial t} + \frac{\partial U^2 H}{\partial x} = -gH\frac{\partial H}{\partial x} - gH\frac{\partial \eta}{\partial x} - C_f U^2$$

In a steady state $\rightarrow$ all $\frac{\partial}{\partial t} = 0$

Van Bendegom (1967), De Vries (1971, 1974), Jansen (1979)

Equilibrium river profile, for unisize sediment

Flow velocity
$$U_e = \left(\frac{QD}{BK}\right)^{1/n}$$

Flow depth
$$H_e = \frac{Q_w}{BU_e} = \frac{Q_w}{B^{1-1/n}}\left(\frac{K}{QD}\right)^{1/n}$$

Slope
$$S_e = \frac{C_f B^{1-3/n}}{gQ_w}\left(\frac{QD}{K}\right)^{3/n}$$

VAN BENDEGOM-
DE VRIES EQUATIONS

$$\eta + H = \eta_w$$

Van Bendegom (1967), De Vries (1971, 1974), Jansen (1979)

Morphodynamic steady state, for unisize sediment

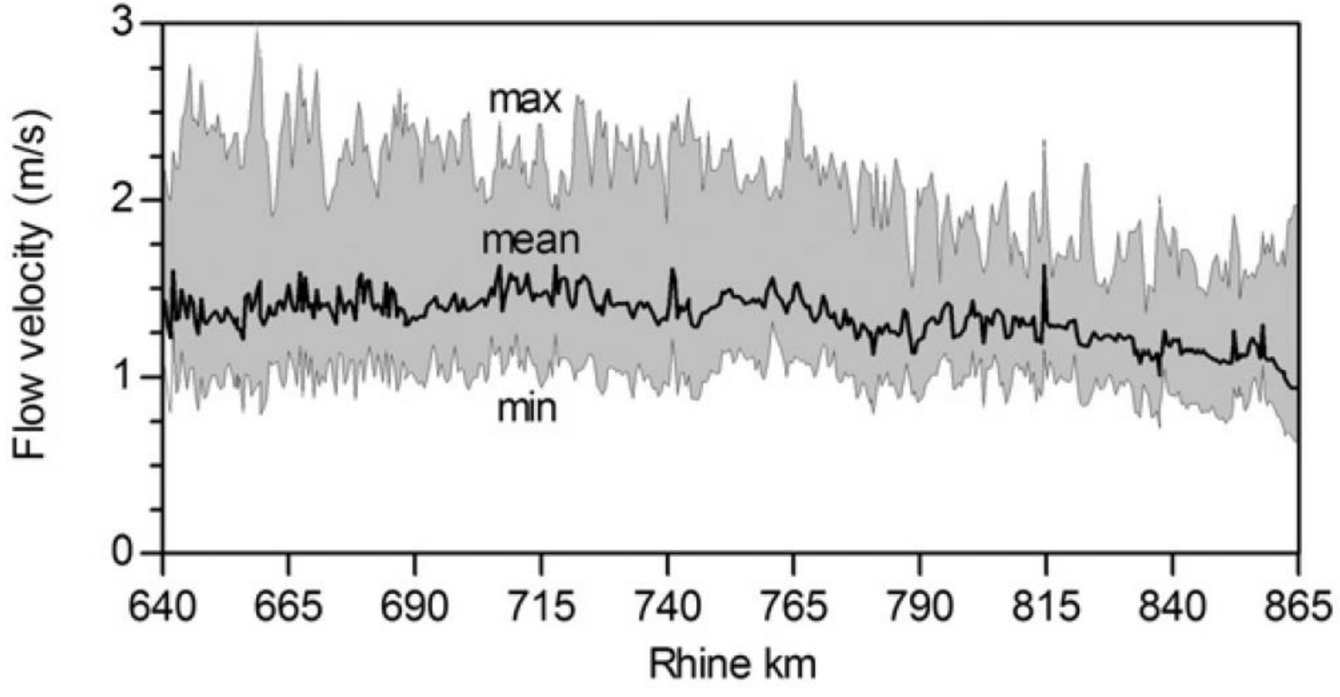


Fig. 2. Longitudinal velocity profile of the lower Rhine Embayment (SOBEK model computation, period 1993–2010).

Frings et al. (Catena, 2014)

Equilibrium river profile, for unisize sediment

Importance of the load!

Flow velocity $$U_e = \left(\frac{QD}{BK}\right)^{1/n}$$

Flow depth $$H_e = \frac{Q_w}{BU_e} = \frac{Q_w}{B^{1-1/n}}\left(\frac{K}{QD}\right)^{1/n}$$

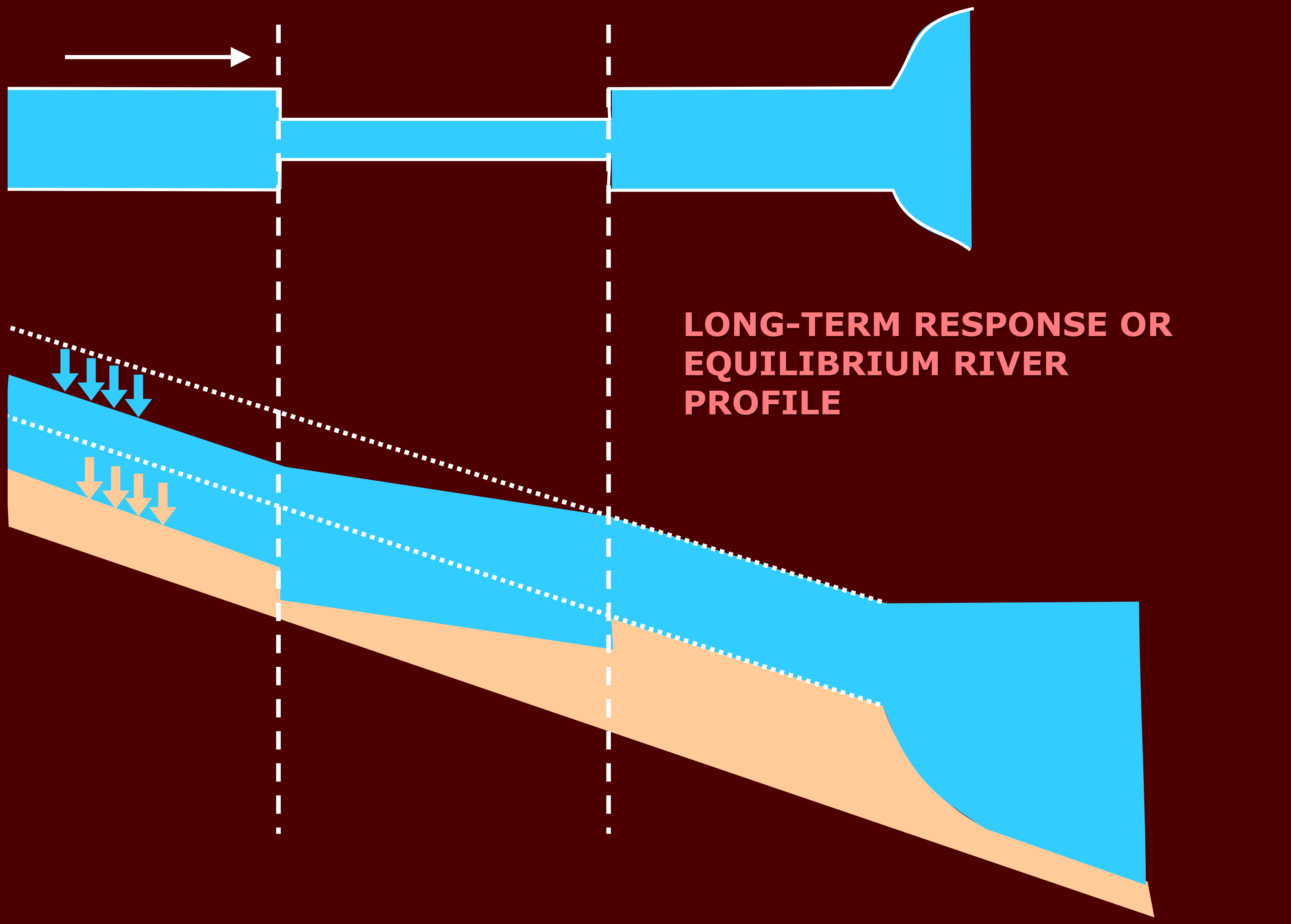
Slope $$S_e = \frac{C_f B^{1-3/n}}{gQ_w}\left(\frac{QD}{K}\right)^{3/n}$$

VAN BENDEGOM-
DE VRIES EQUATIONS

$$\eta + H = \eta_w$$

Van Bendegom (1967), De Vries (1971, 1974), Jansen (1979)

Local constriction (due to levees or groynes)



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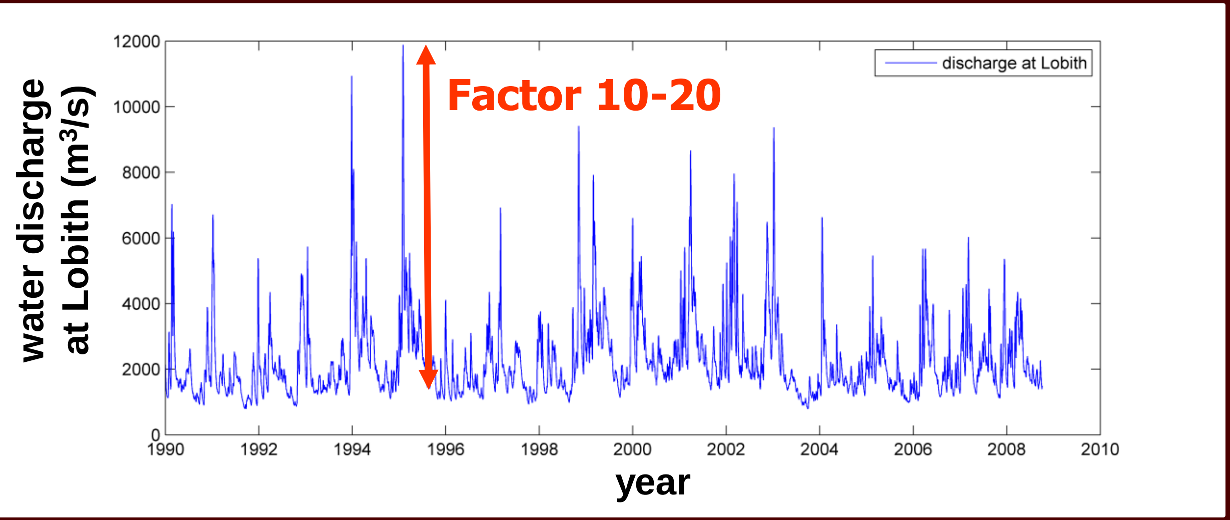
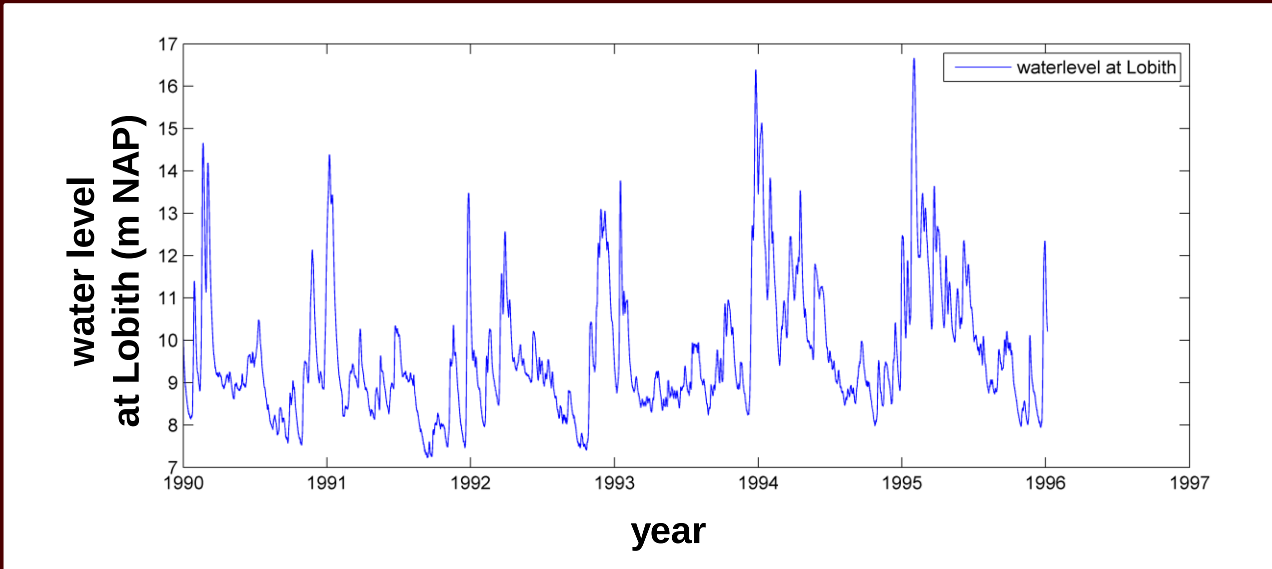
Temporal variation of the flow

Water discharge at Lobith

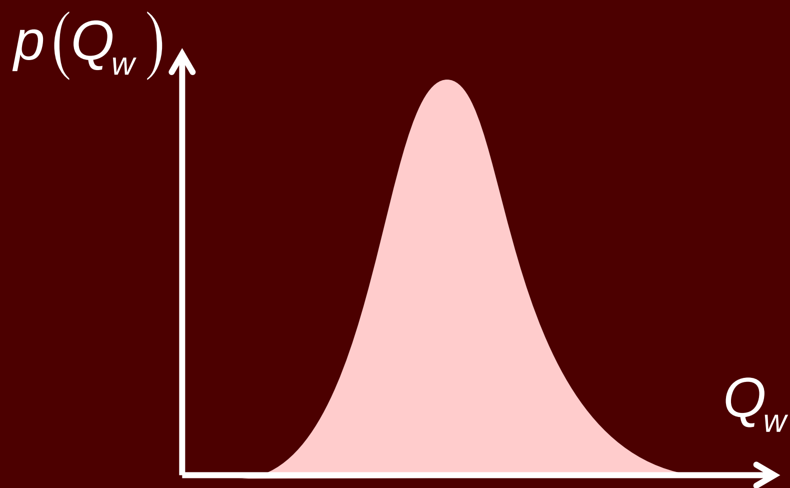


Water level at Lobith

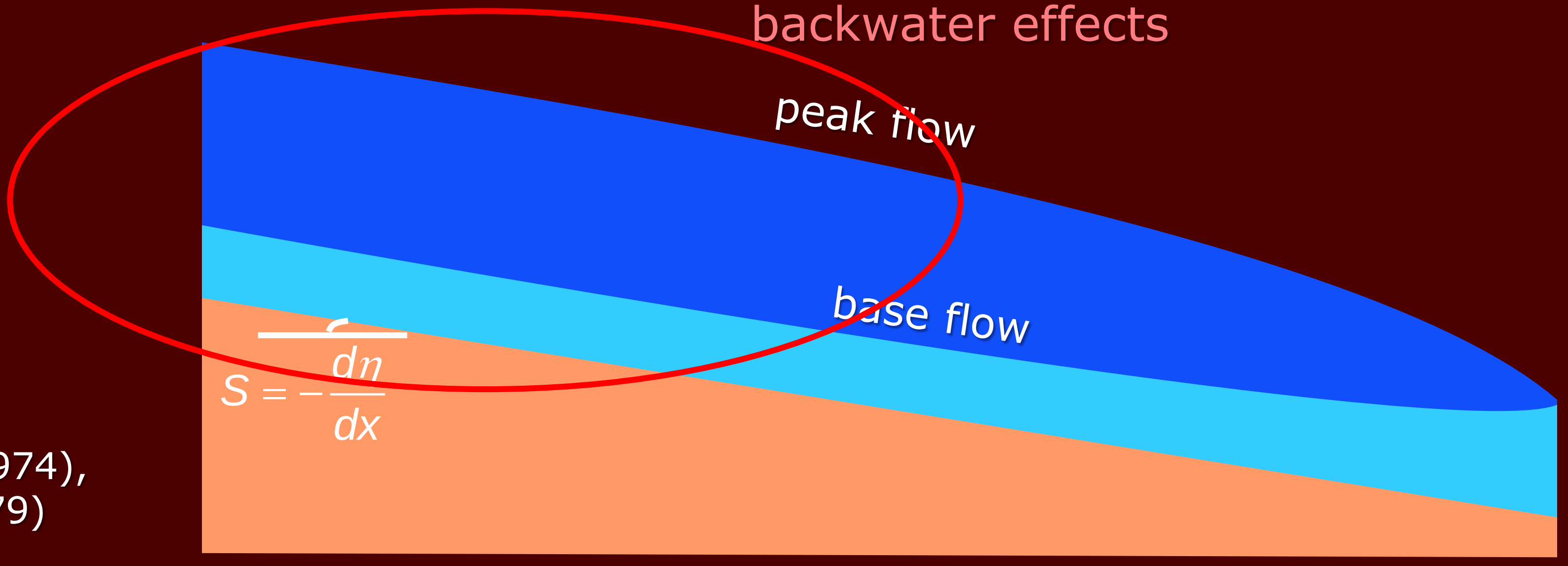


Source: Rijkswaterstaat

How to deal with temporal variations



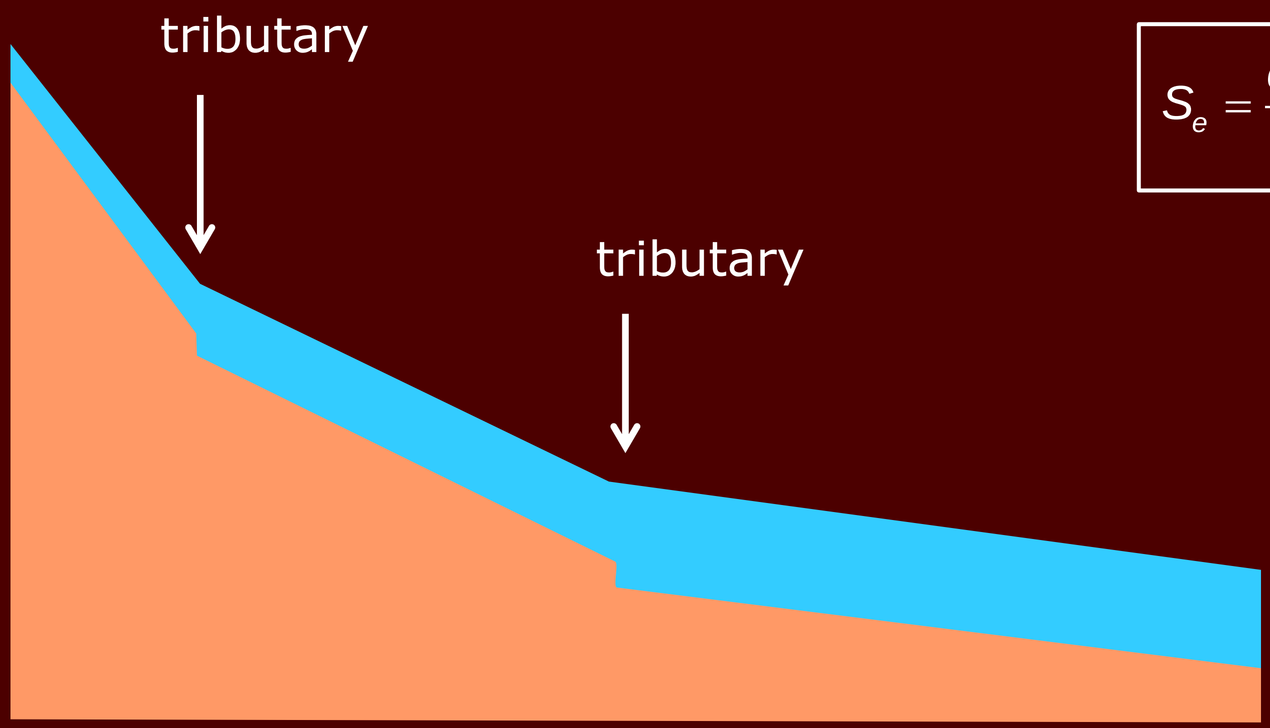
upstream from
backwater effects



De Vries (1974),
Jansen (1979)

The effect of tributaries

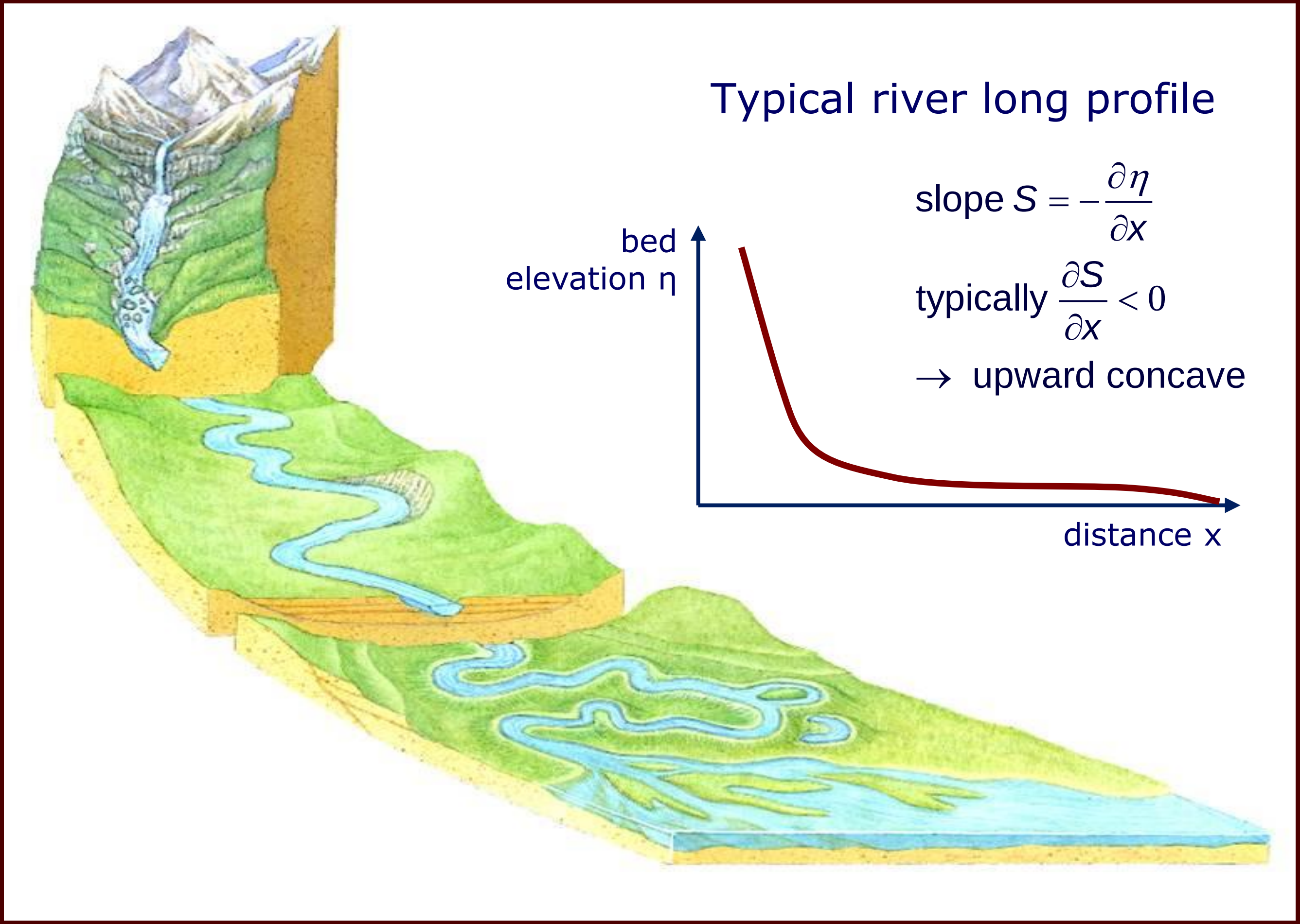
As they generally add more water than sediment (De Vries, 1974, Parker, 2004), tributaries induce a stepwise reduction in slope.



$$S_e = \frac{c_f B^{1-3/n}}{g Q_w} \left(\frac{Q}{m} \right)^{3/n}$$

Importance of the load!

Yet, we see no *stepwise* reduction in slope.



Parker (2004, E-Book)

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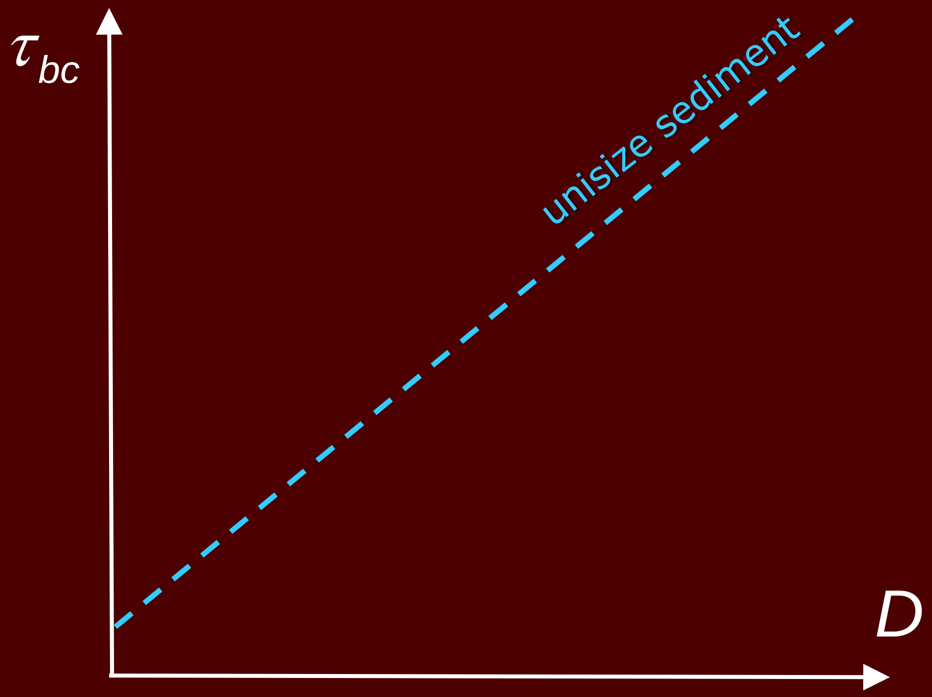
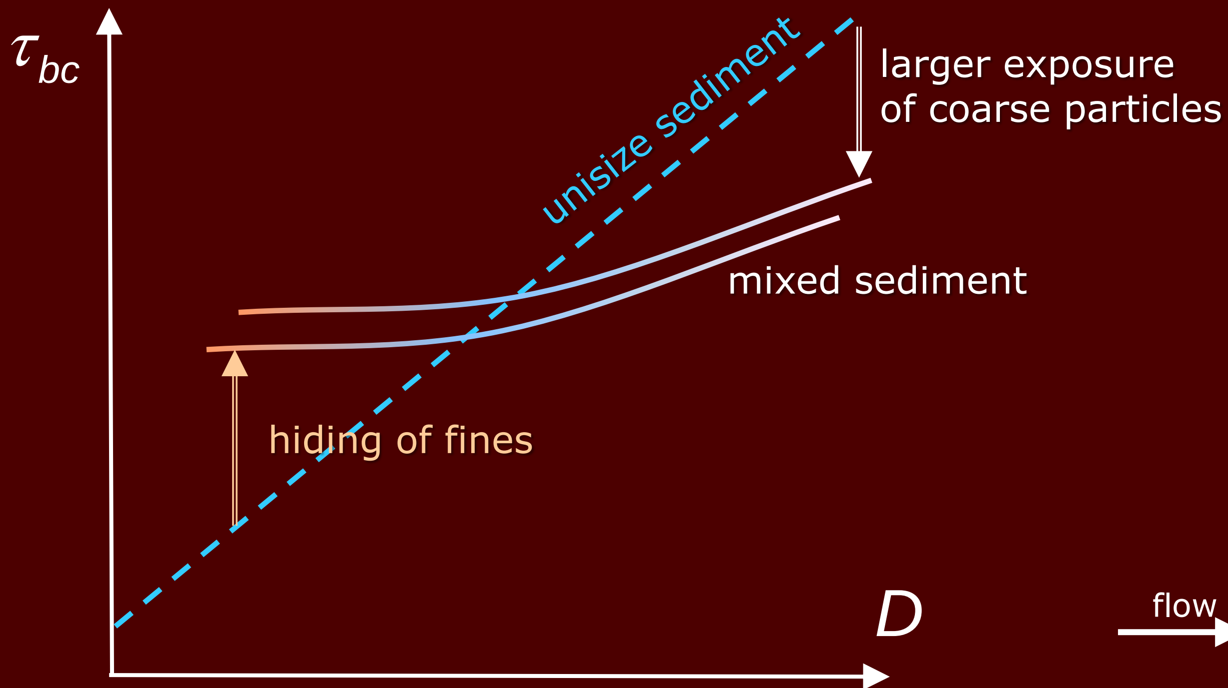
Coarser unisize grains are harder to move



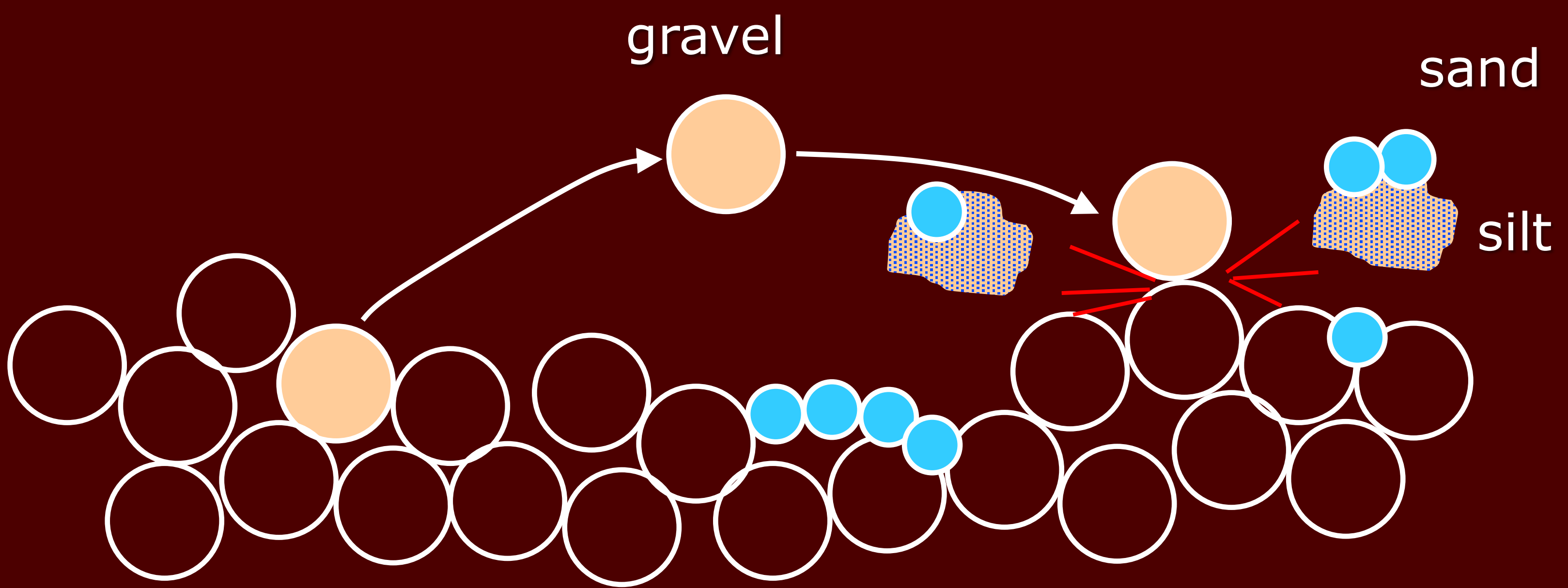
Coarser unisize grains are harder to move



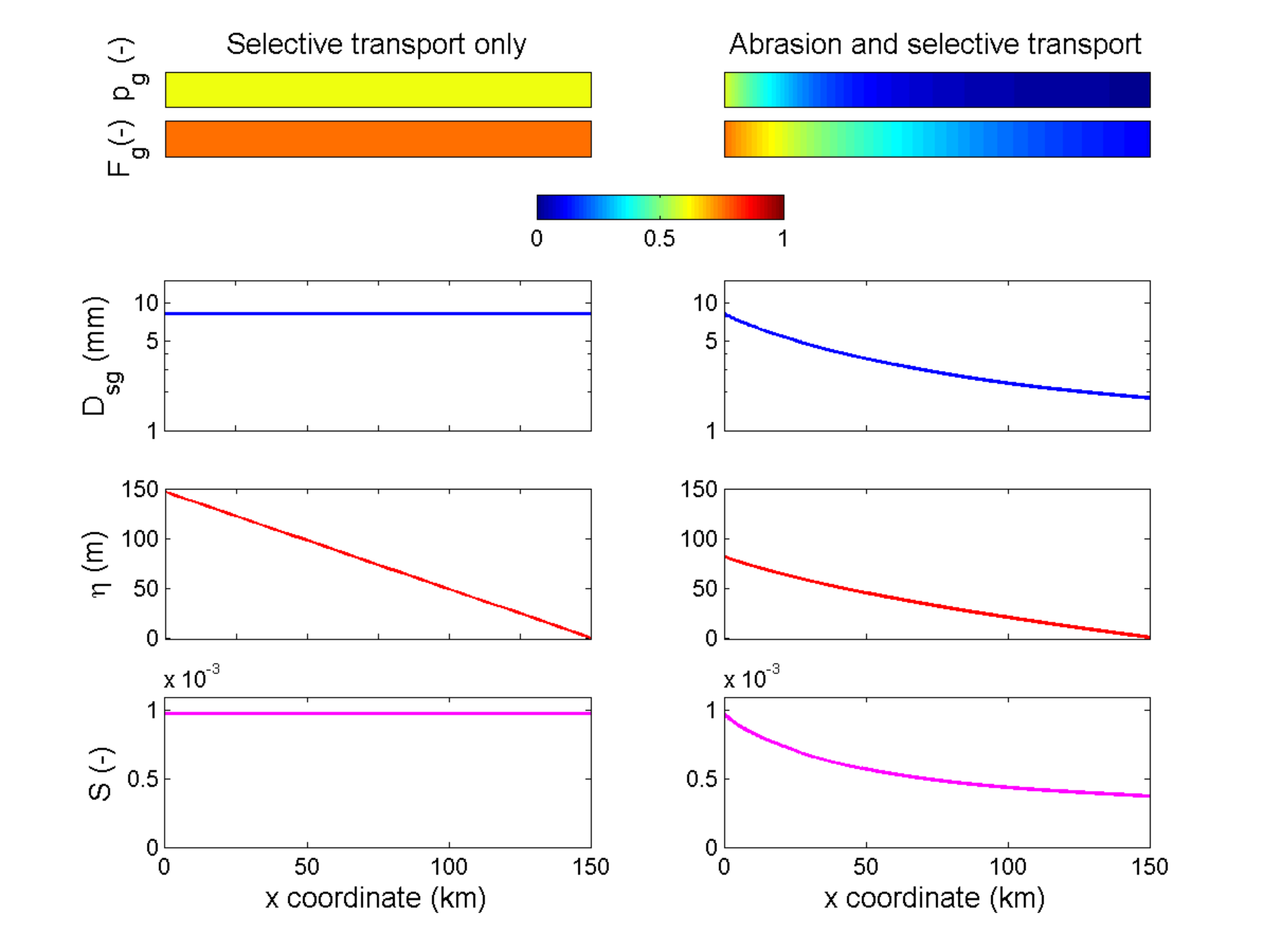
After Wilcock & Crowe, 2003

Egiazaroff (1965)

Particle abrasion

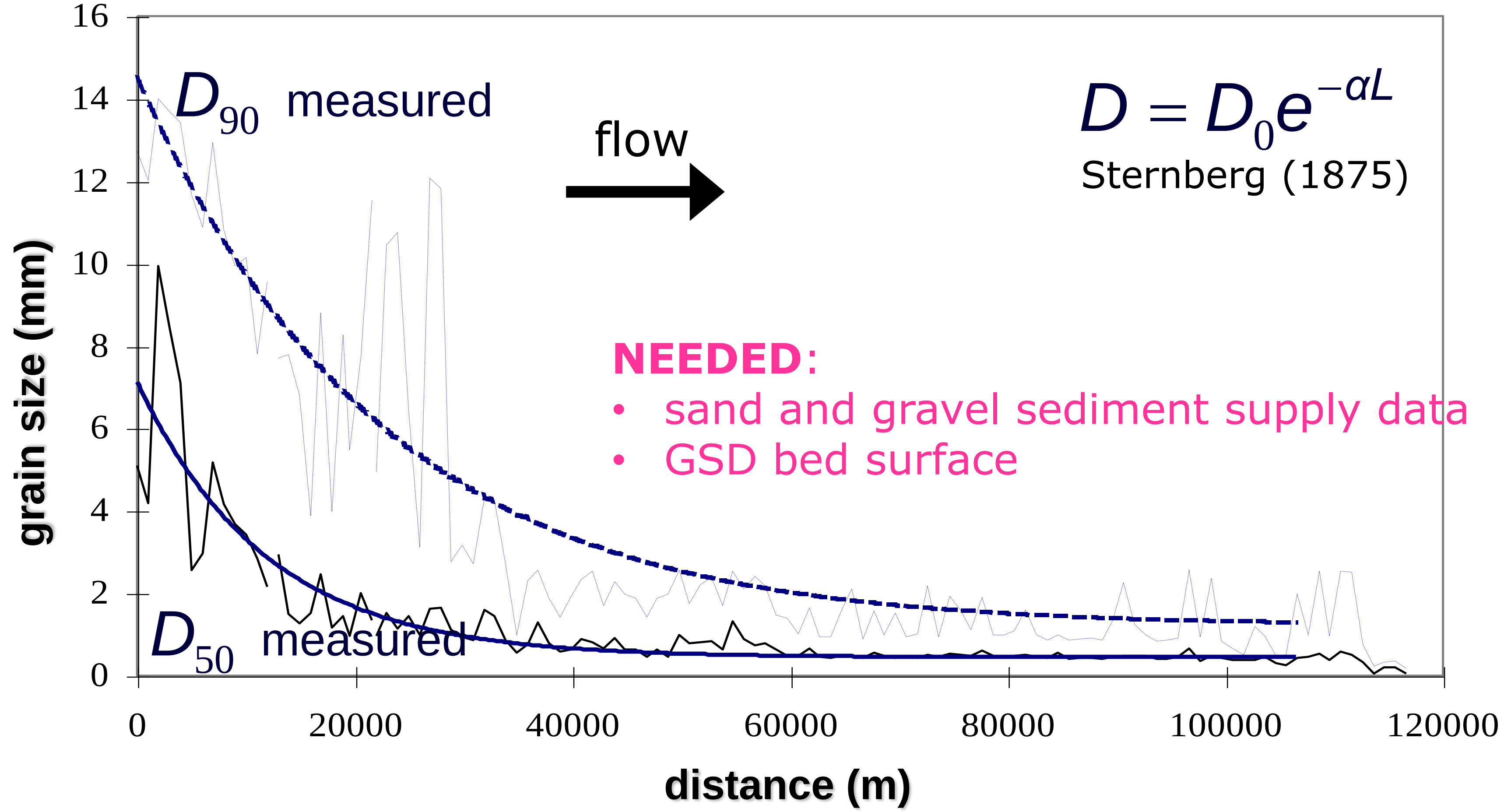


Abrasion acts as a trigger for profile concavity and so downstream fining



Ongoing work: comparison between model results and field data

IJssel branch of the Dutch Rhine



NEEDED:

- sand and gravel sediment supply data
- GSD bed surface

Workshop on Modelling Mixed-Sediment River Morphodynamics

27-28-29 May 2015

Delft – The Netherlands

www.sortingworkshop2015.nl