River channel formation and response to variations in discharge, sediment and vegetation

PART 2: RIVER PLANFORM

Alessandra Crosato

Tagliamento River, Italy

UNESCO IHE DELFT

TUDelft

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PART 2 RIVER PLANFORM

1. Bars and river planform
2. Bar and planform prediction
3. Comparison with empirical relations
4. Role of floodplain vegetation
5. Summary

1 Bars and river planform

Mow River, Bhutan

River bars are large periodic sediment deposits that emerge during low flows

Missouri River, Nebraska-South Dakota border

canalized Rhine River, Switzerland

But there are also non-periodic bars

Point bars inside river bends

Red River, Texas

Usumachinta River, Guatemala

Periodic alternate bars characterize meandering rivers

Periodic multiple bars characterize braided rivers

Waimakariri River, new Zealand (courtesy M. Hicks)

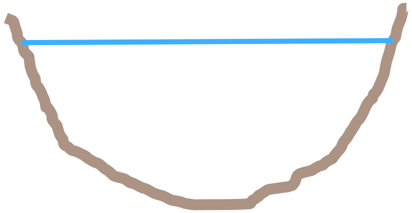
Hii River, Japan (courtesy T. Hosoda)

The river planform is related to bar characteristics, particularly to the number of bars in the cross-section

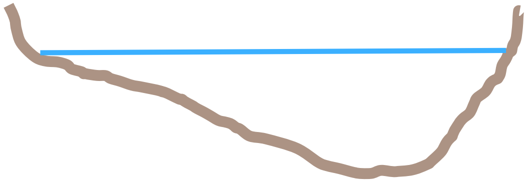
meandering

transition

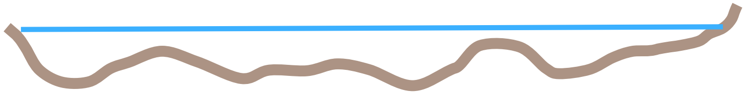
braiding



NO BARS



ALTERNATE BARS



MULTIPLE BARS

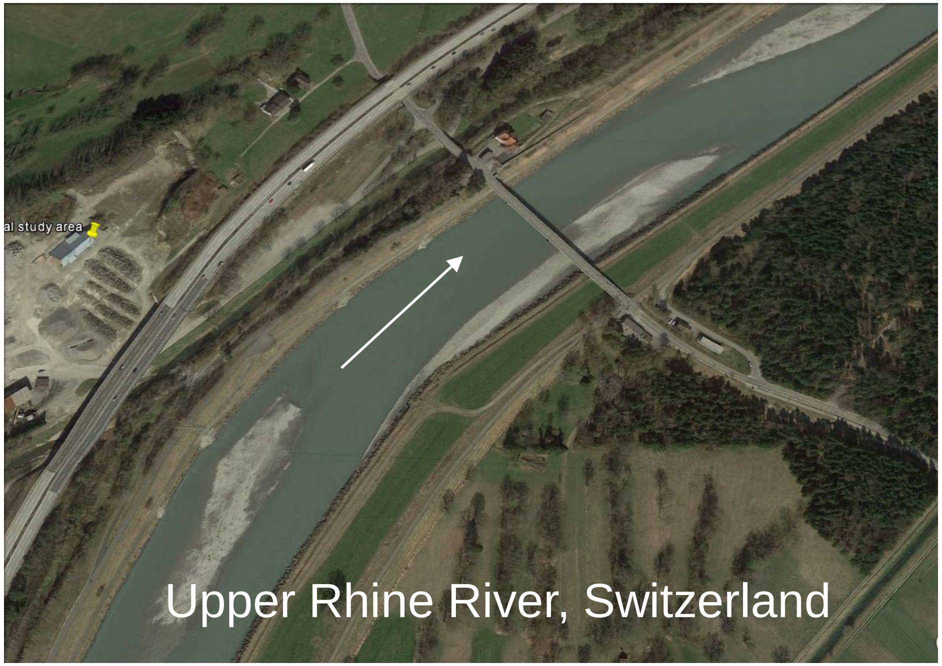
How are bar characteristics related to water, sediment and vegetation?

2 Bar and planform prediction

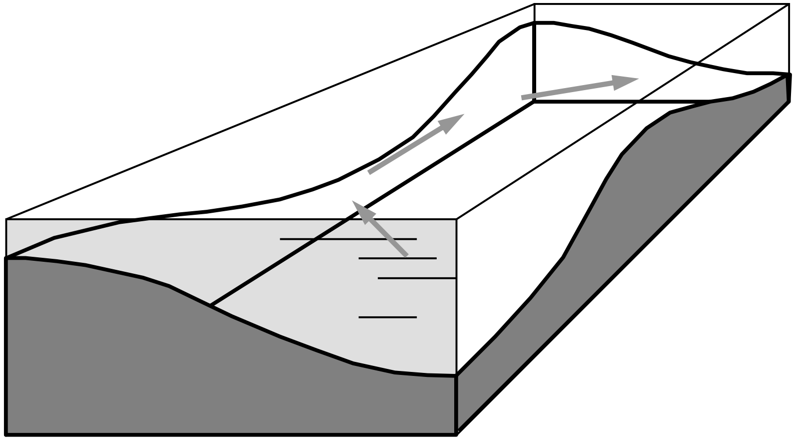
Mow River, Bhutan

Bar characteristics

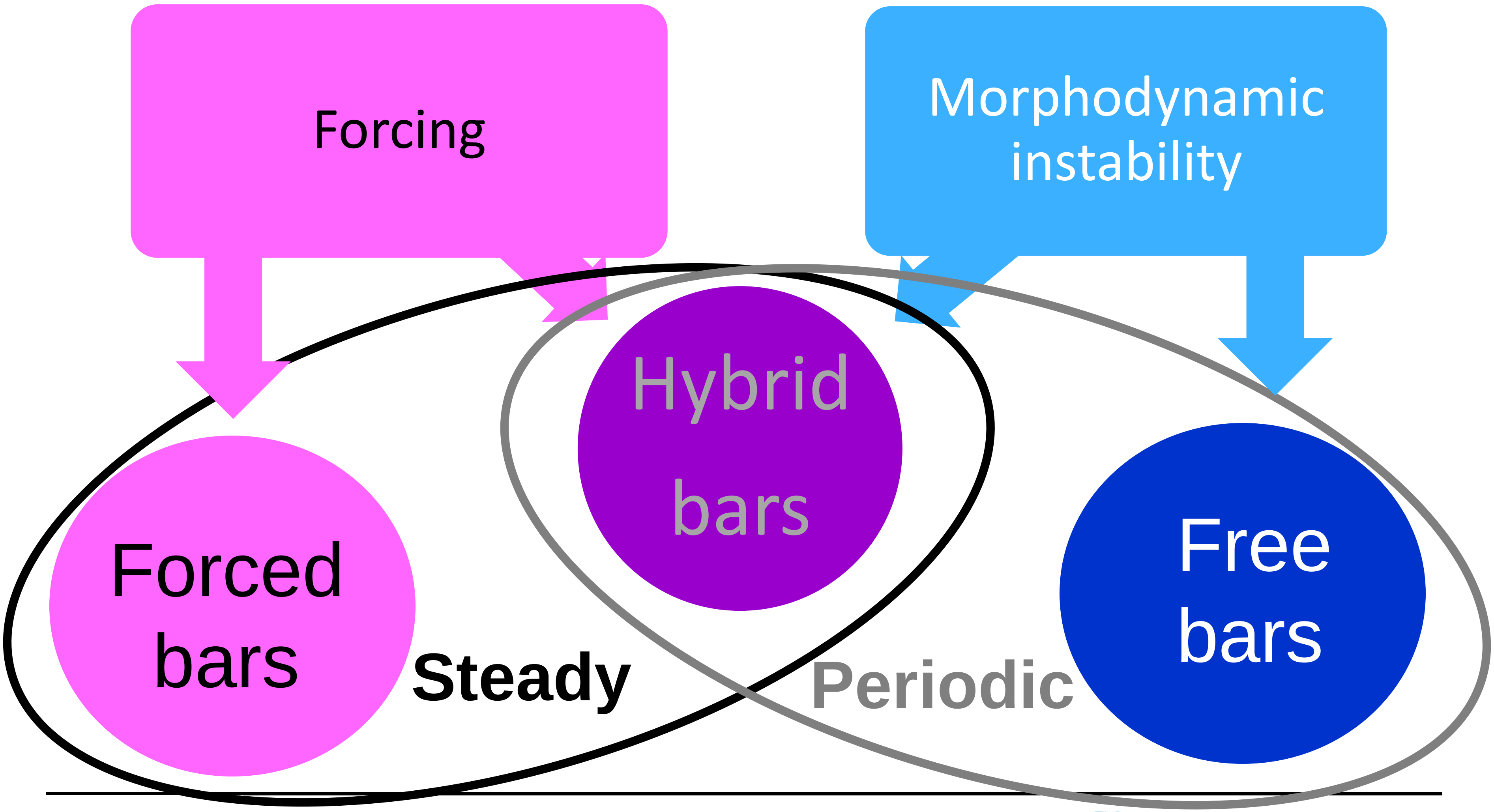
- size in transverse and longitudinal direction
- migration rate
- growth rate
- number of bars per cross-section



Upper Rhine River, Switzerland


Alternate bars

We can distinguish three types of bars, caused by two different mechanisms: forcing and instability



Mechanism

Forcing

Forcing is every geometrical constraint of the river channel that fixes the flow pattern

Forcing can be caused by a bend, a groyne a local narrowing….

Forced bars

Due to the centrifugal force (inertia) the water flow concentrates near the outer bank

Forcing caused by bend

Mechanism

Morphodynamic instability

A flat river bed surface may be unstable and generate waves of different size: ripples, dunes, periodic bars

Two types of periodic bars

Kander River, Switzerland

Free bars

Periodic:

morphodynamic instability

migrating
(downstream but also upstream)

Two types of periodic bars

Hybrid bars

Periodic:

morphodynamic instability and forcing

steady

Adige River, Italy

Stability analyses: periodic bars

TWO APPROACHES

GENOA

Initial growth in infinitly long rivers

Focus: free bars

DELFT

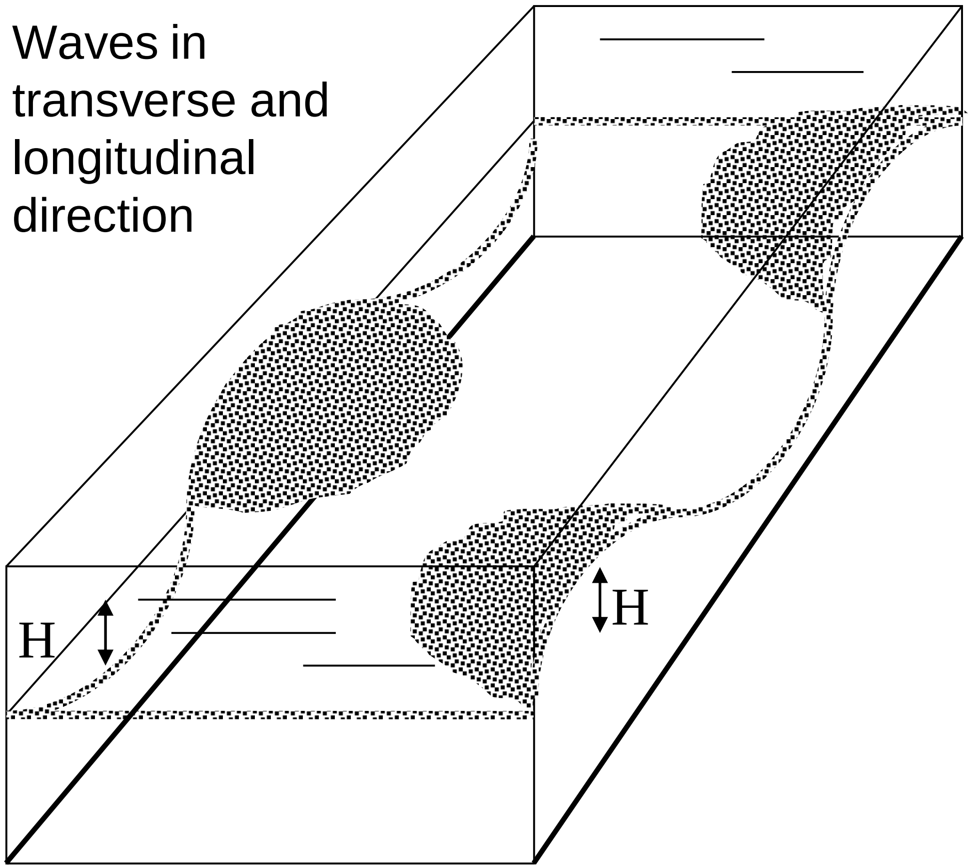
Initial steady bar configuration in rivers with forcing

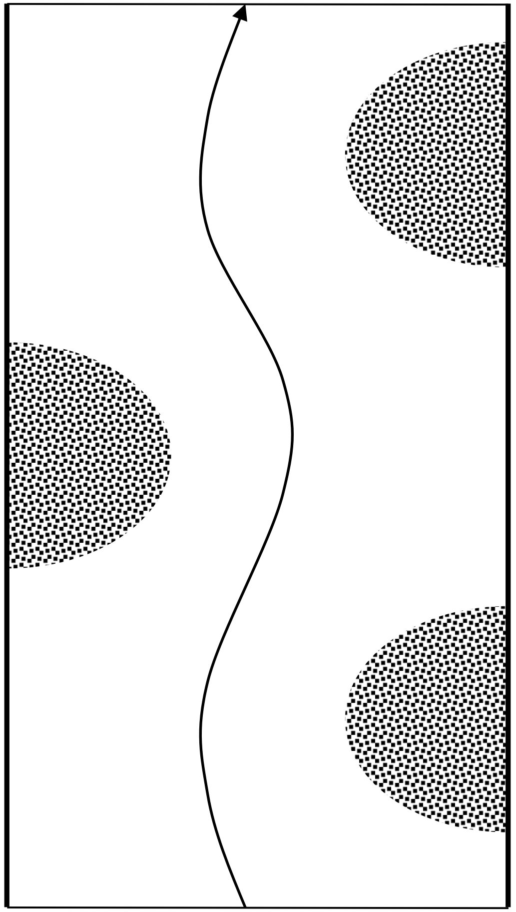
Focus: hybrid bars

(definition “Genoa and Delft schools” after Parker, 1989)

Bar schematization

Waves in transverse and longitudinal direction





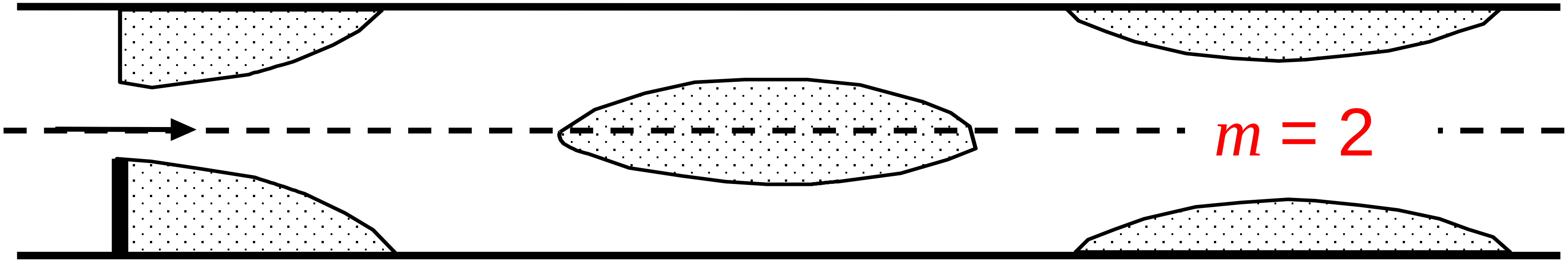
The number of bars per cross section is indicated by bar mode m

$m = 1$ alternate bars

$m = 2$ one bar in the middle/two bars near banks

$m \geq 3$ multiple bars

m indicates the intensity of braiding of the river

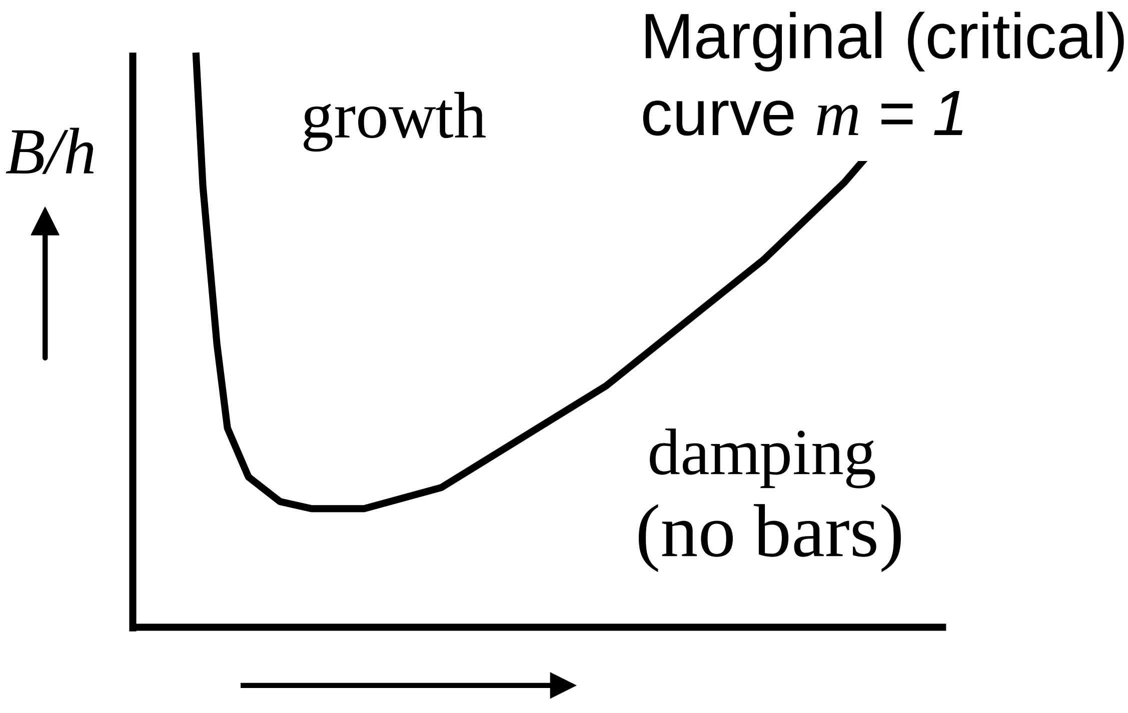


Results for free alternate bars

GENOA

Initial growth in infinitly long rivers

Focus: free bars



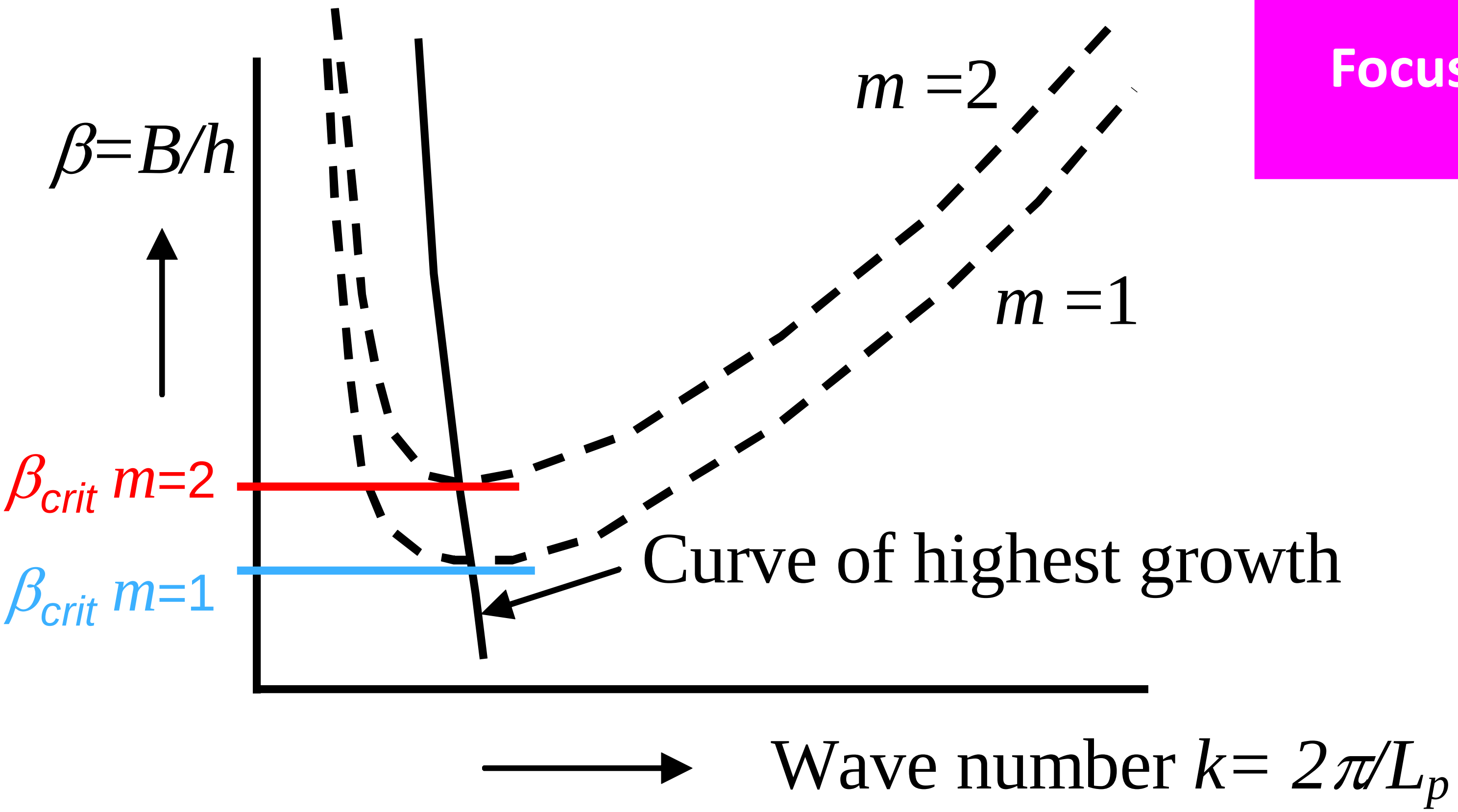
Longitudinal wave number $k = 2\pi/L_p$

Results for periodic free bars

GENOA

Initial growth in infinitly long rivers

Focus: free bars



Bars are governed by the flow width-to-depth ratio

Multiple bars are found in shallow and wide rivers
River channels with no bars have small width-to depth ratios

(Engelund, 1970; Tubino and Seminara, 1990)

Important for bars is also sediment mobility

D_{50} = 0.37 mm well sorted	D_{50} =0.50 mm well sorted	D_{50} = 1.00 mm poorly sorted

Same discharge, almost the same B/h, but different sediment

(experiments Roelvink, Lako, Le, Crosato, 2015)

Results for hybrid bars

(Crosato and Mosselman, 2009)

DELFT

Initial steady bar configuration in rivers with forcing

Focus: hybrid bars

bar mode

$$m^2 = 0.17 g \frac{(b-3)}{\sqrt{\Delta D_{50}}} \frac{B^3 i}{C Q_W}$$

b = 4 for sand-bed rivers

b = 10 for gravel-bed rivers

(for width-depth ratio < 100 and assuming uniform flow)

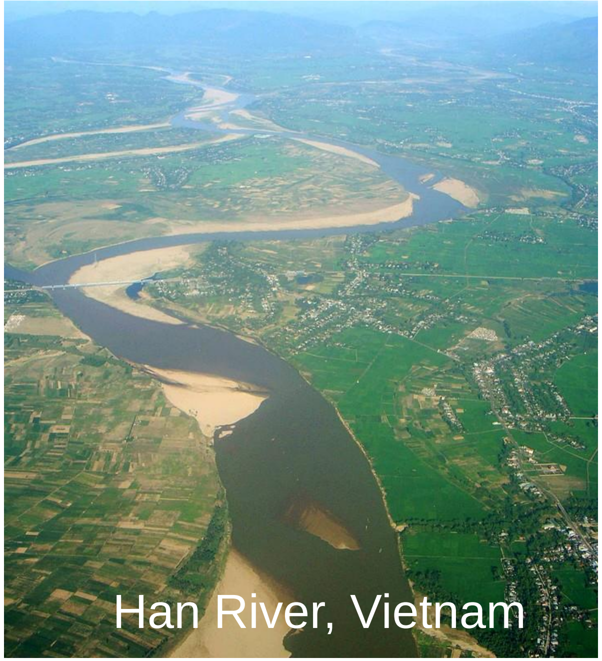
If $m < 0.5$ no alternate bars

If $0.5 < m < 1.5$ alternate bars

} meandering

If $1.5 < m < 2.5$ central bars: transition between meandering and braiding

If $m > 2.5$ multiple bars: braiding



Factors influencing the river planform

$$m^2 \sim \frac{(b-3)}{\sqrt{\Delta D_{50}}} \frac{B^3}{C} \frac{i}{Q_W}$$

Braiding increases with

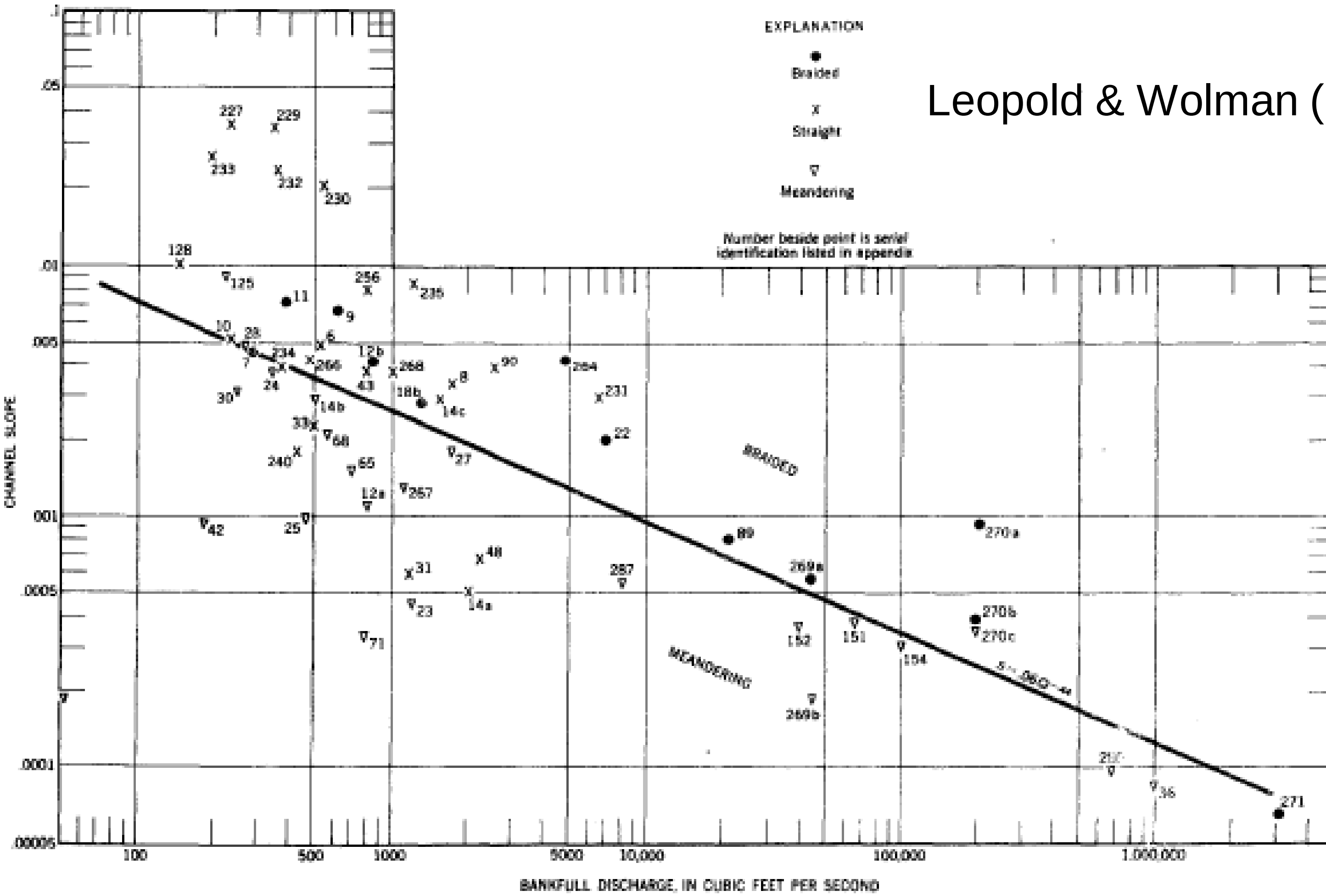
- Channel width: B
- Slope: i
- Sediment transport non-linearity: b (gravel/sand)
- Bed roughness: $1/C$

Braiding decreases with

- Discharge: Q_W
- Sediment size: D_{50} (but in this case b might increase too)

3 Comparison with empirical relations

Leopold & Wolman (1957)



Empirical relations for river planform: braiding if ratio (i/Q_W) exceeds threshold

Leopold & Wolman (1957):
bankfull discharge and slope can discriminate between meandering and braiding

$$i_{crit} = 0.06\ Q_{bf}^{-0.44}$$

Henderson (1963)
added the size of bed material

$$i_{crit} = 0.64 D_{50}^{1.14}\ Q_{bf}^{-0.44}$$

(threshold slope increases if D_{50} increases)

(bankfull is assumed to be the formative discharge)

Parker (1976) accounts for bar formation and relates the critical slope to the channel with-to-depth ratio and Froude number:

$$i_{crit} \sim \left(\frac{h}{B}\right)\frac{u}{\sqrt{gh}}$$

Ferguson (1987): the factors controlling the channel planform are: flow strength, amount and type of sediment load and bank strength.

Millar 2000 includes the bank stabilizing effects by vegetation through the bank friction angle (bank strength)

$$i_{crit} = 0.0002 D_{50}^{0.61} \phi'^{1.75} Q_{bf}^{-0.25}$$

Threshold based on bar mode

Imposing m = n as threshold:

$$i_{crit} \sim \frac{\sqrt{\Delta D_{50}}}{(b-3)} \frac{u}{\sqrt{gh}} \frac{Q_W}{B^3}$$

Formative discharge

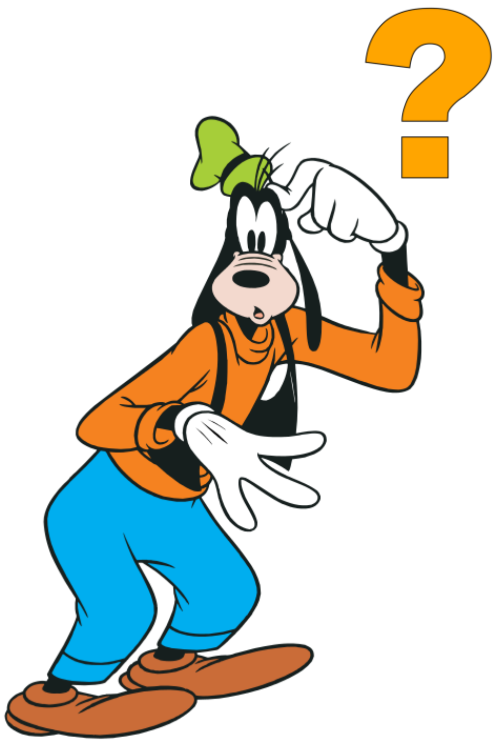
Channel width

Sediment
and sediment transport characteristics

Froude number

Some aspects of Parker's (1976)
The width is assumed to be known

By affecting the width, what is the role of vegetation?



4 Role of floodplain vegetation

Results of some recent studies

River Atrato, Colombia
(courtesy A. Montes Arboleda)

By decreasing the width and increasing the depth, Floodplain vegetation is expected to affect the bar mode and thus the river planform

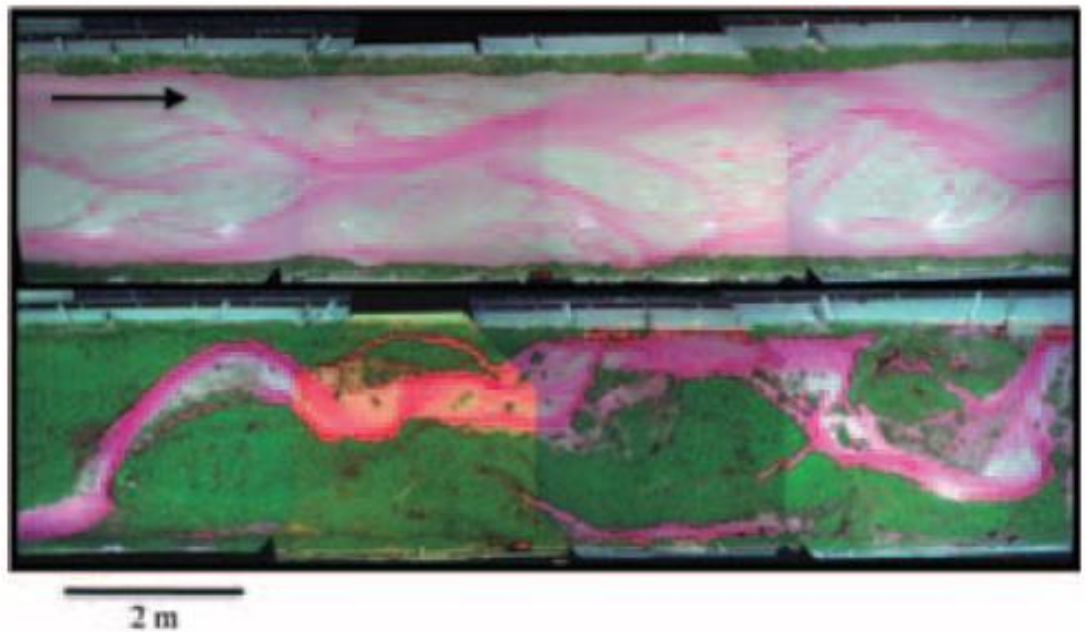
Observation: meanders are dominant within luxuriant forests and braids are dominant within scarce vegetation

Meandering river in the Amazon

Effects of vegetation on river planform
- Experimental study

(Tal and Paola, 2010)

Unvegetated baided channel transforms in predominantly single-channel



(no flows on floodplains, no colonization by plants of emerging deposits)

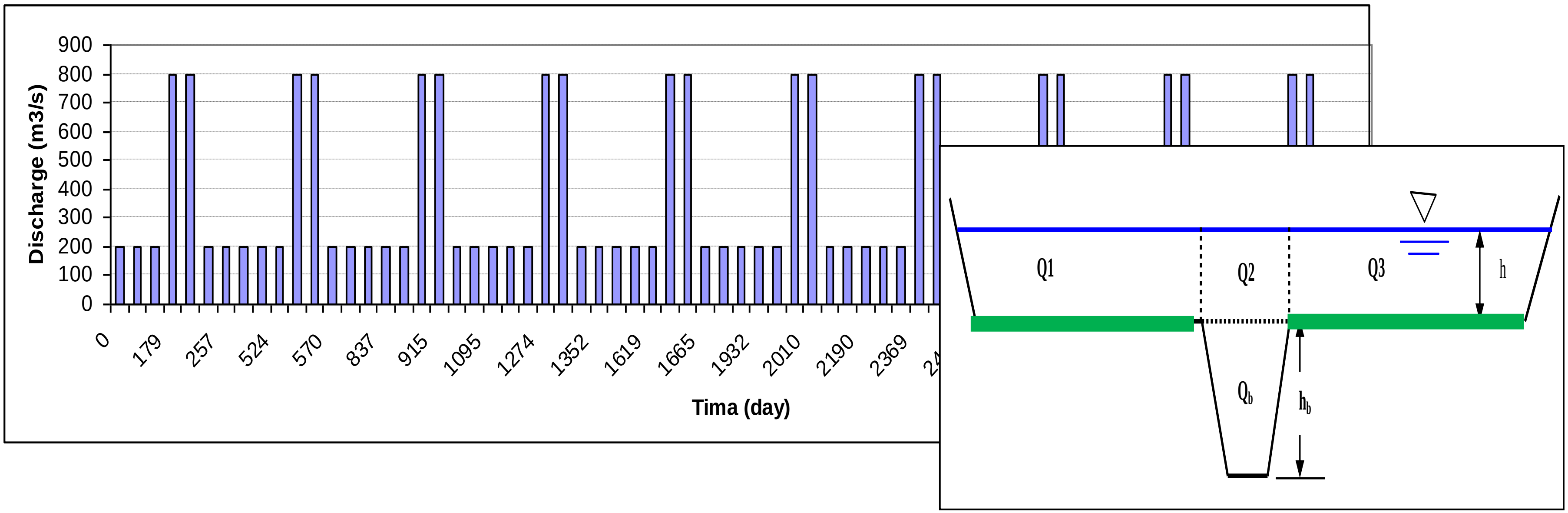
Effects of vegetation on river planform
Numerical study: floods + colonization

(Crosato and Samir Saleh, 2011)

2D morphodynamic model inspired by the Allier River (France)

Straight channel with high/low flow sequences

Colonization by vegetation of bed surfaces that emerge during low flows



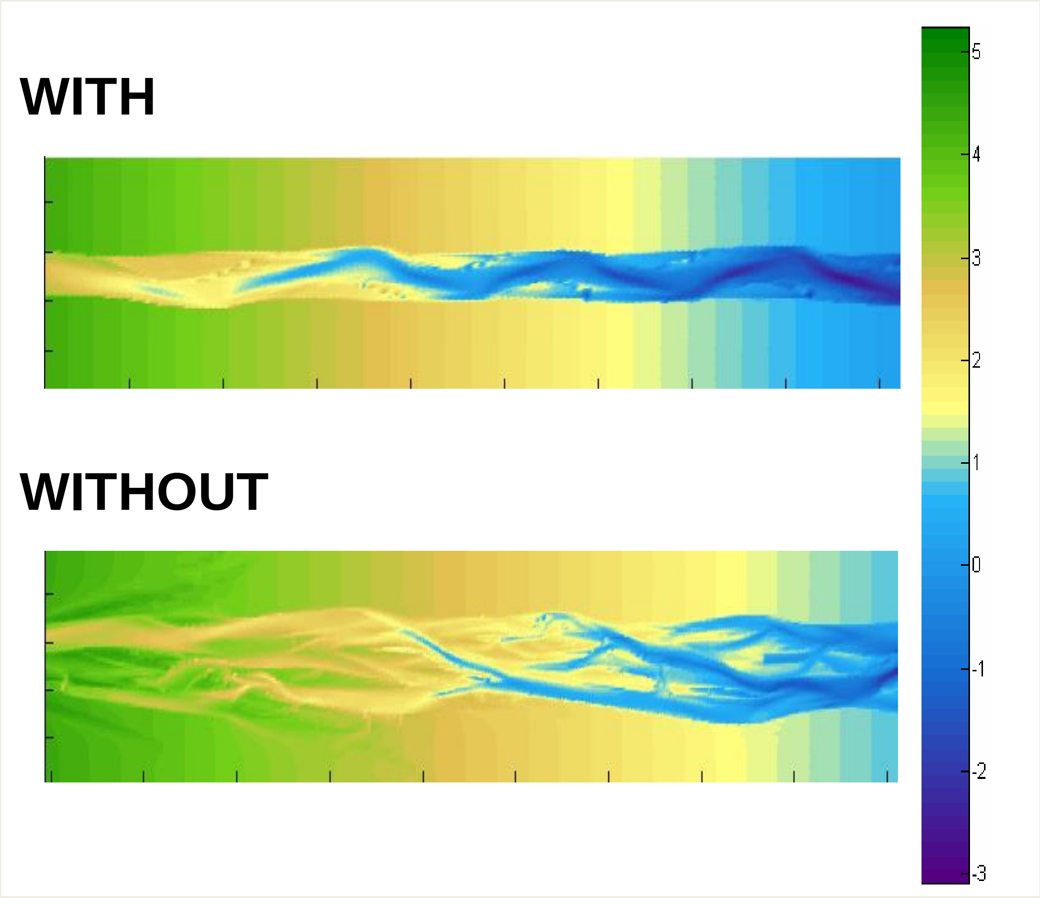
Results: river planform

With vegetation:

Colonization of bars stabilizes accreting banks and pushes the flow toward the opposite bank

Bank erosion decreases

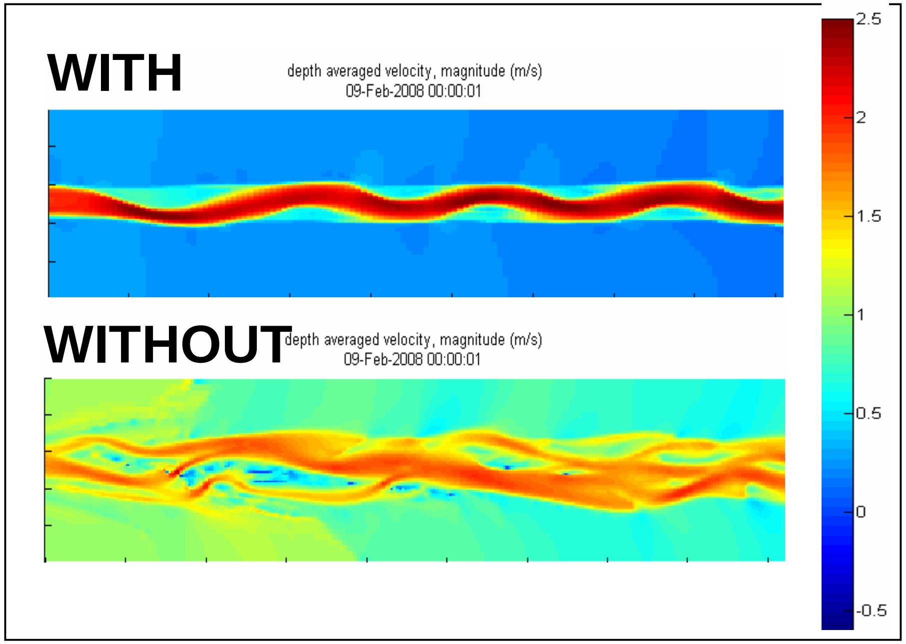
The river tends to have a single channel and a meandering pattern

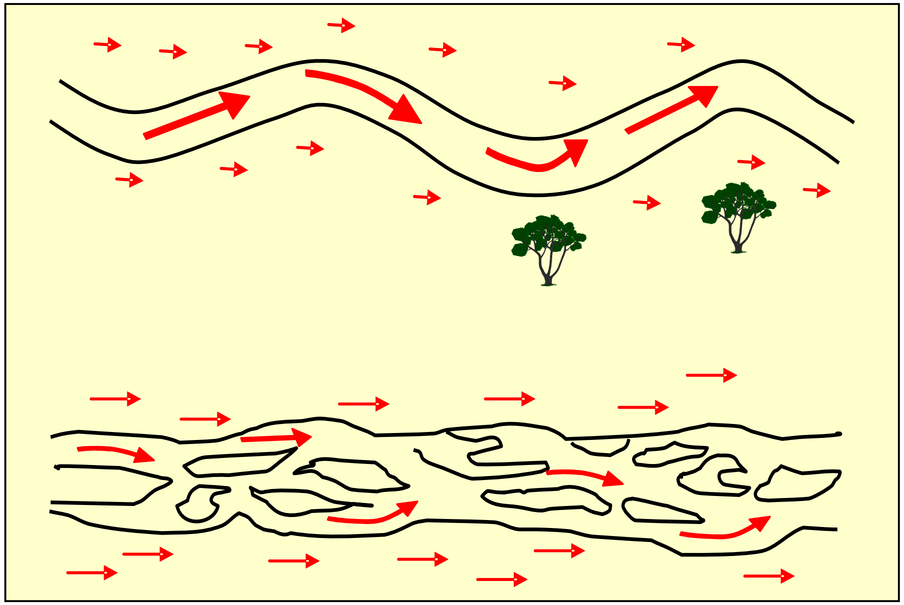


Results: flow velocity

With vegetation:

- High plant roughness diverts the flow into the main channel
- Higher flow velocity in the main channel
- Lower flow velocity at channel edges and on floodplains

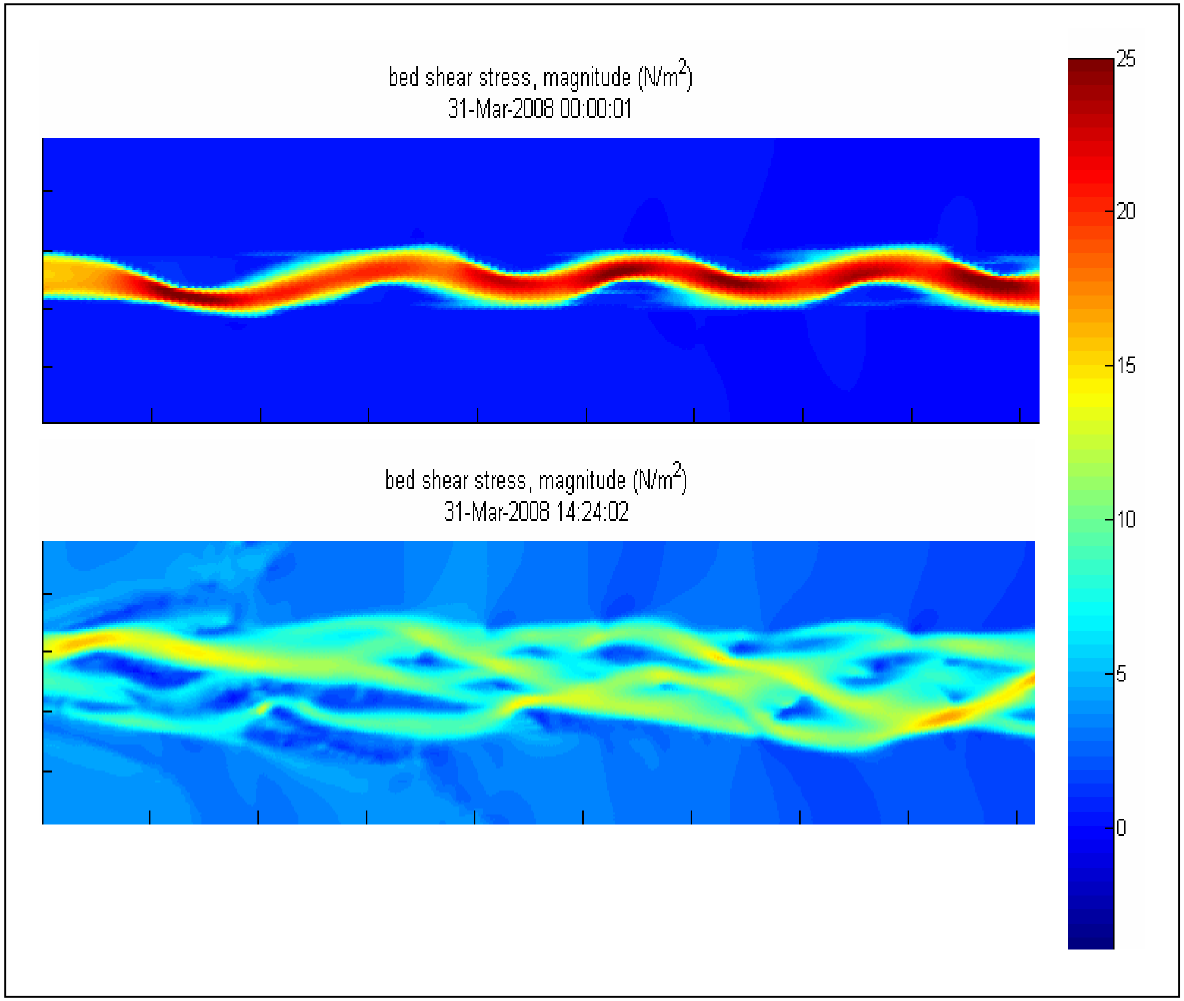




Results: bed shear stress plan view

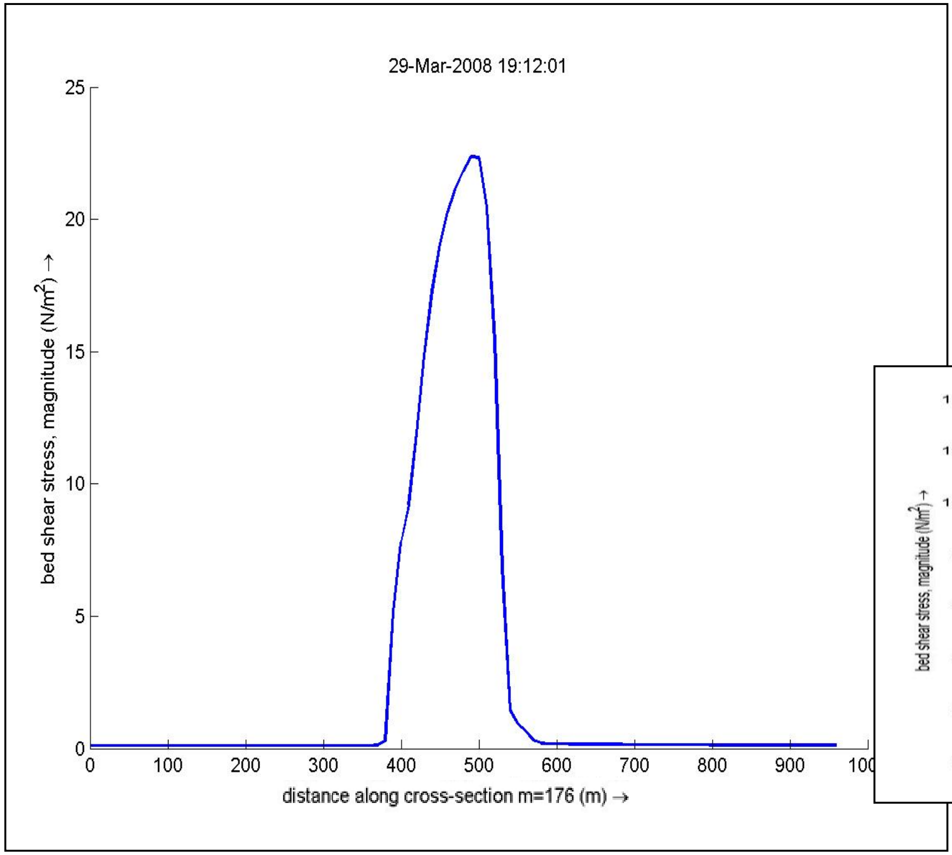
WITH

WITHOUT

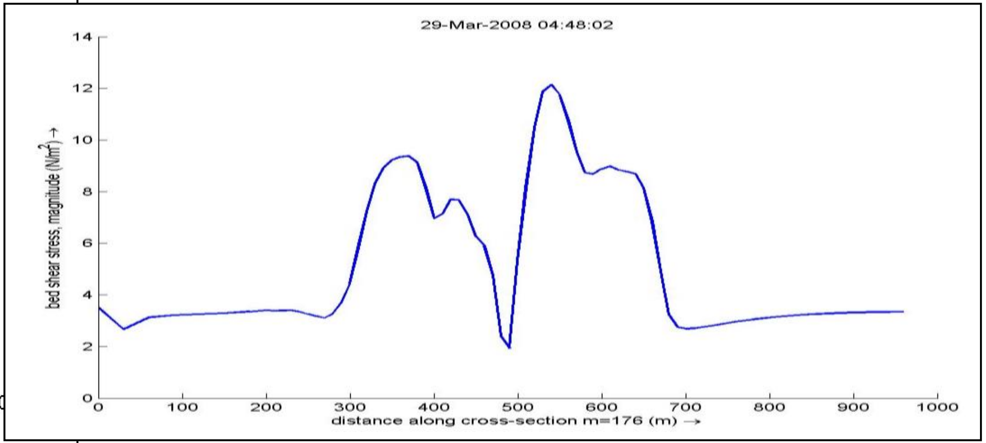


Results bed shear stress (cross-section)

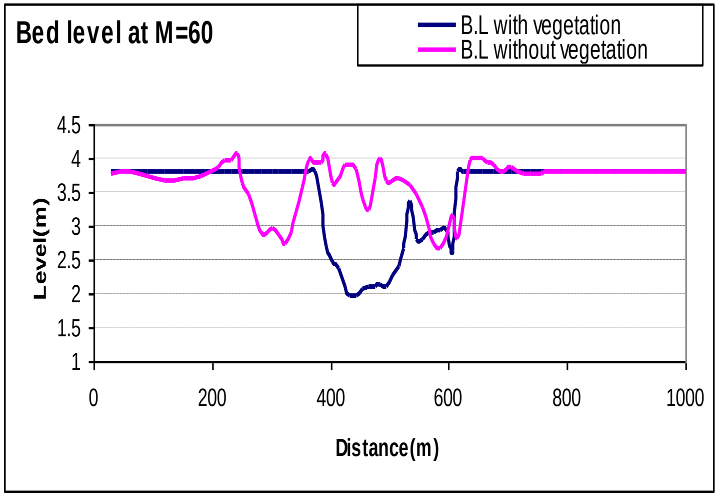
WITH VEGETATION

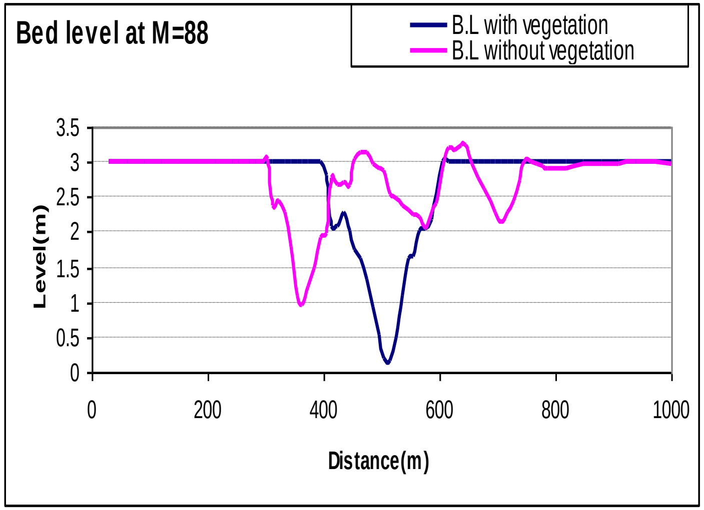


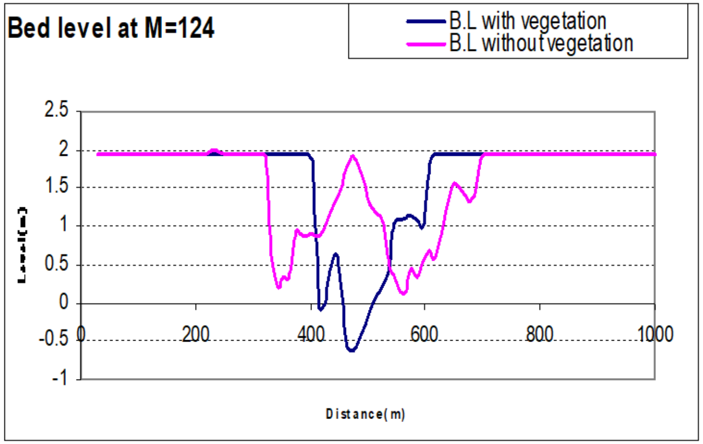
WITHOUT VEGETATION

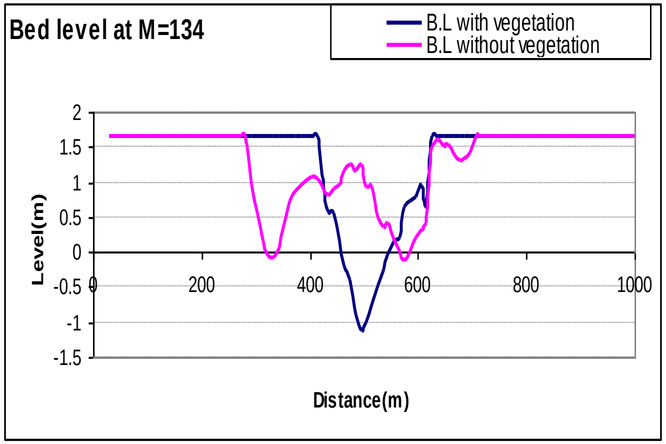


Results: cross-sections

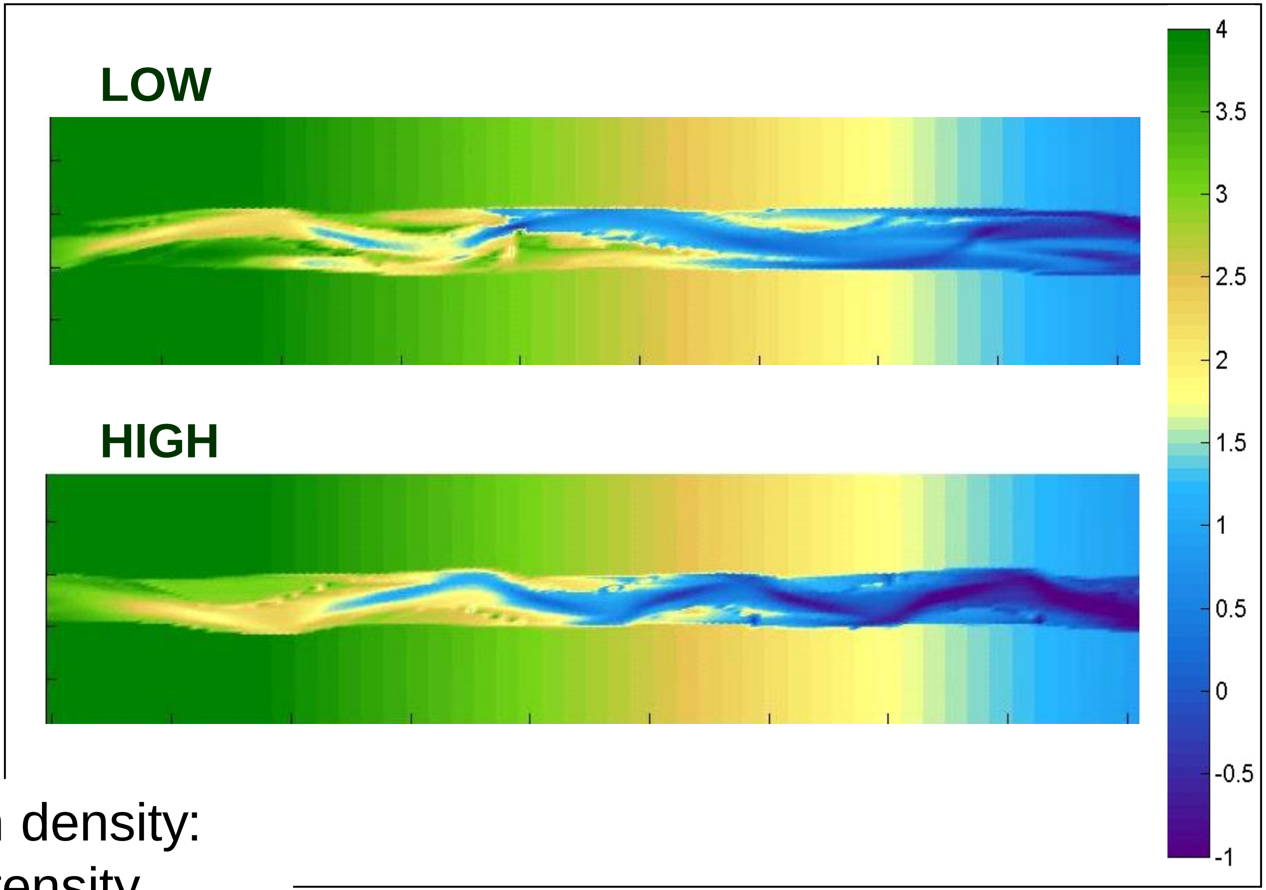








Results high vs. low vegetation density



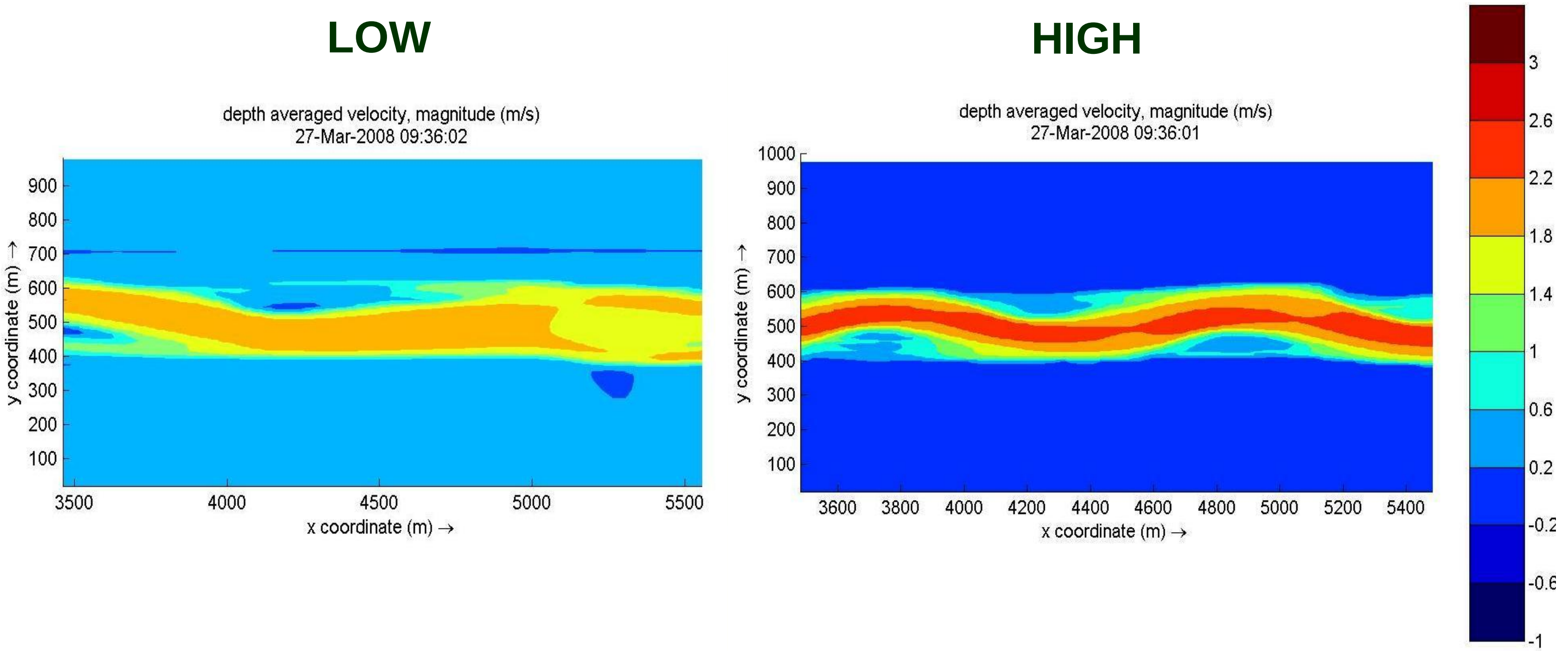
With lower vegetation density:

- Higher braiding intensity
- Longer meander wave length

Results high vs. low vegetation density

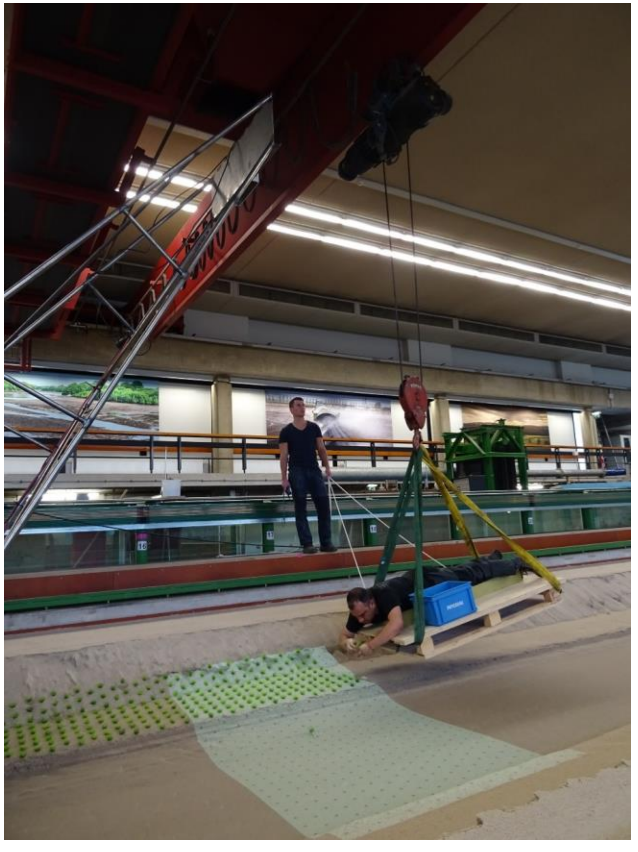
With lower vegetation density:

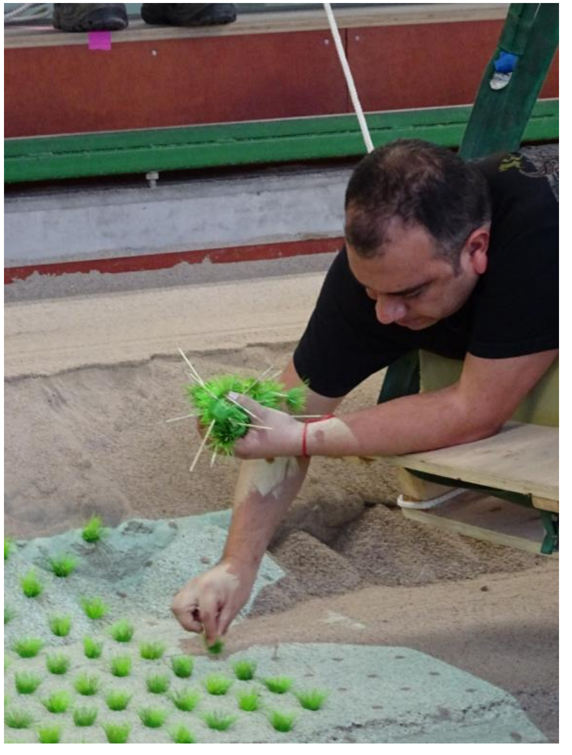
- higher flow velocity on vegetated zones
- lower flow velocity in non-vegetated zones



Effects of bar colonization by plnts on river planform - Experimental study

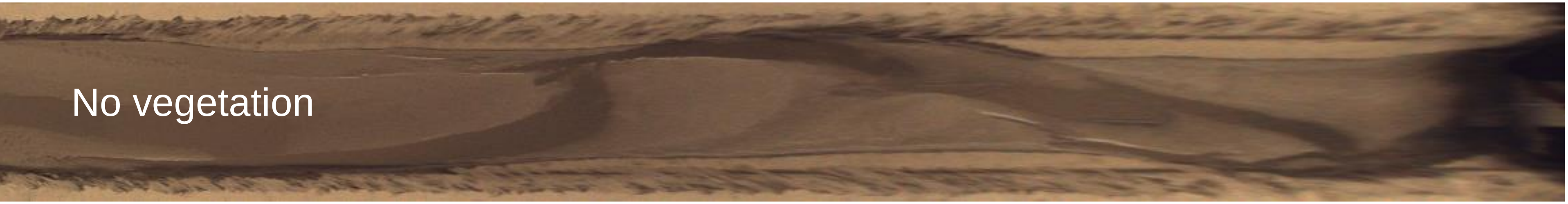
(Vargas-Luna, Duró, Crosato, Uijttewaal 2019, in review)

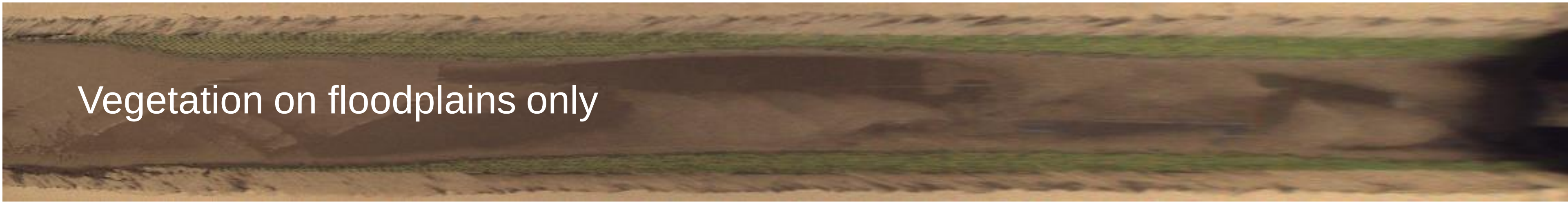




Large flume: 50x5 m
10,000 plastic plants

Results with and without vegetation: three scenarios

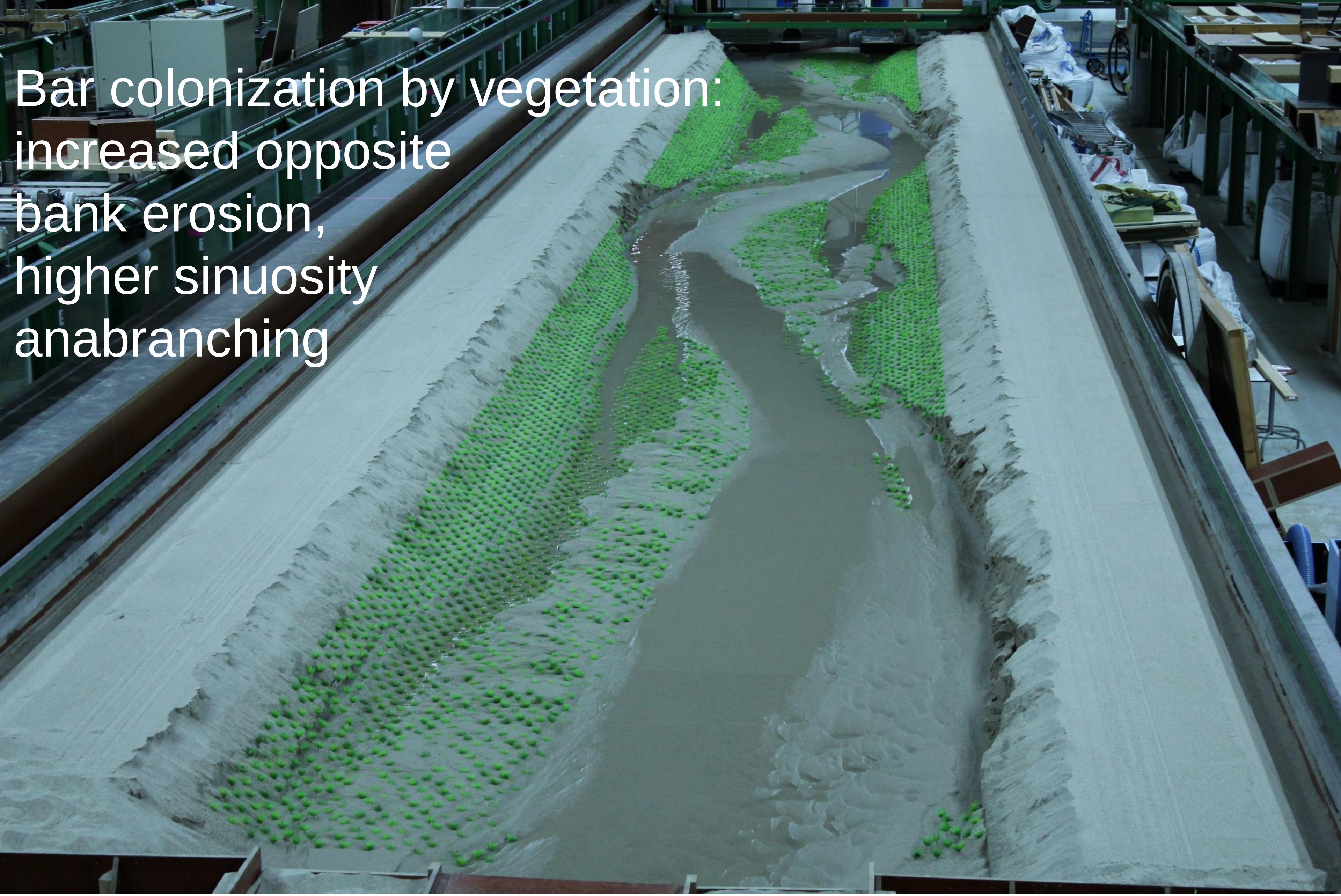




No vegetation:
Channel at transition between meandering and braiding

Vegetation on floodplains only: reduced bank erosion narrower channel

Bar colonization by vegetation:
increased opposite
bank erosion,
higher sinuosity
anabranching

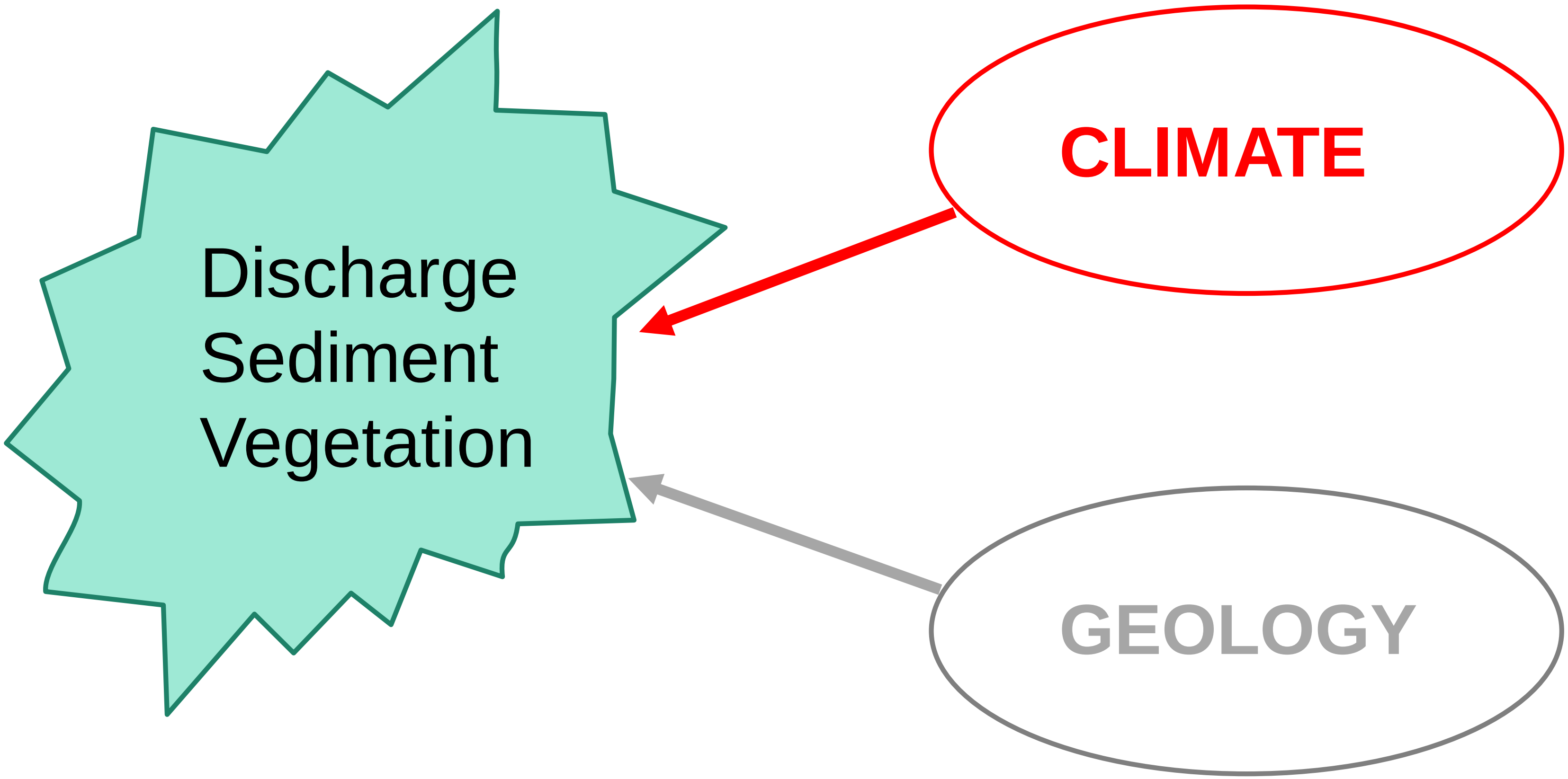


Results

Colonization by vegetation results in meandering and anabranching

Waterpark Bosscherveld along Border Meuse River, the Netherlands

5 Summary



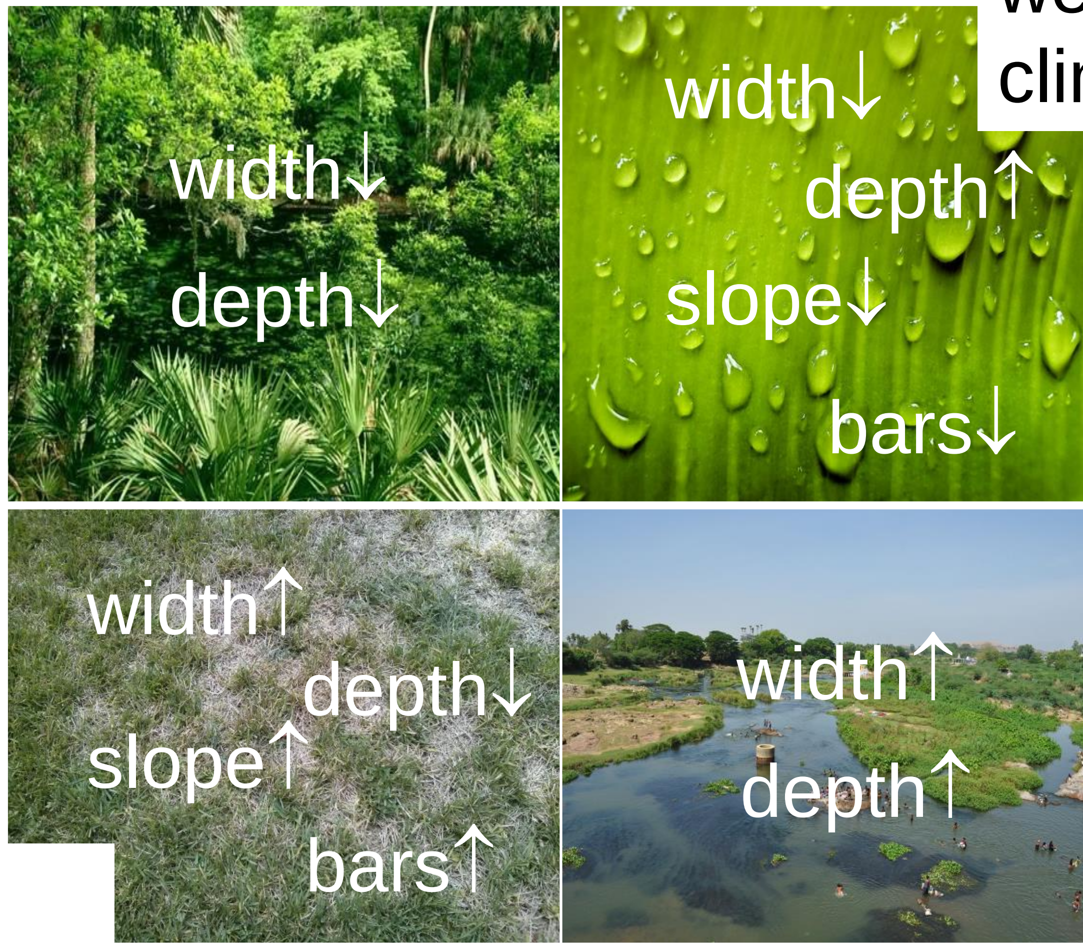
If sediment load and size remain constant

wetter climate

HIGHER

Floodplain vegetation density

LOWER



drier climate

LOWER

HIGHER

Discharge

If the discharge remains constant

HIGHER

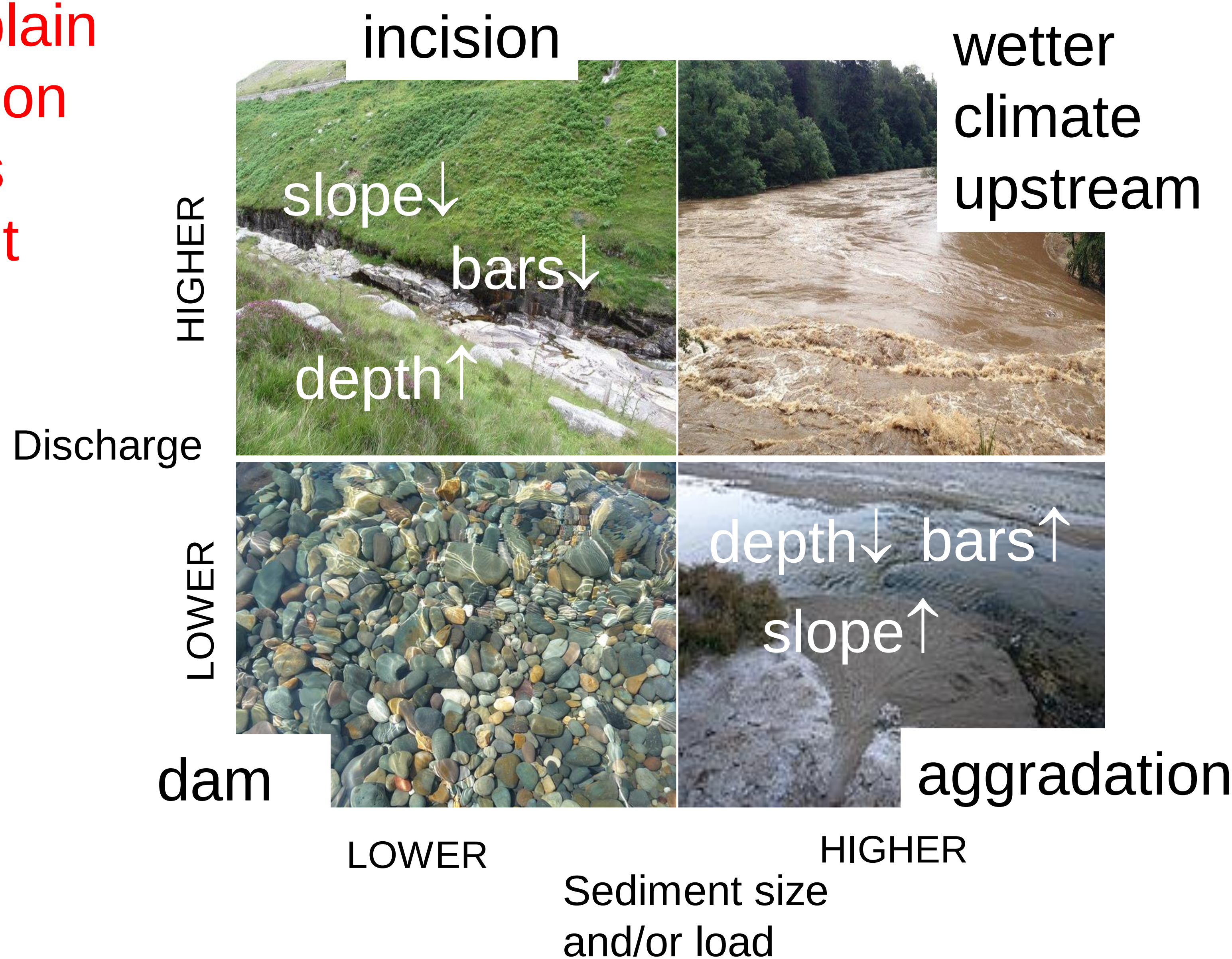
Floodplain vegetation density

LOWER

LOWER HIGHER

Sediment size and/or load

If floodplain vegetation remains constant



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THANK YOU

Questions?