BASEMENT

Revision of the sediment transport feature in BASEMENT version 3.1

BASEMENT Users Meeting 2021

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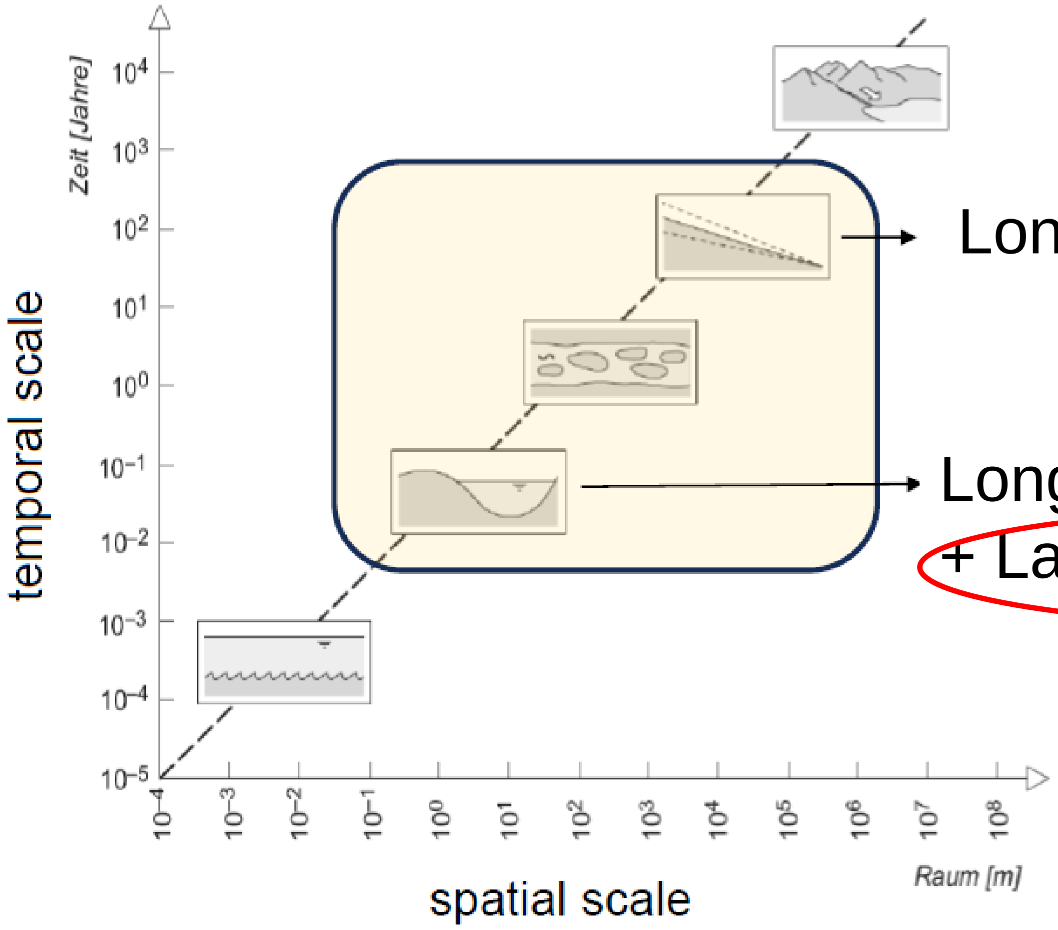
Agenda

- Relevant morphodynamic processes
- Numerical modelling of morphodynamic processes
- Revision of the sediment transport feature in BASEMENT version 3.1
- Morphological simulations with BASEMENT v3.1

Scales of morphodynamic processes



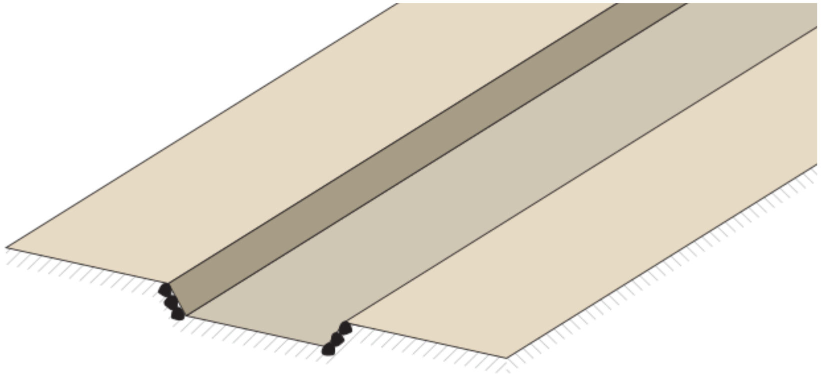
Longitudinal sediment transport → 1D-Modelling

Longitudinal sediment transport
+ Lateral sediment transport → 2D-Modelling

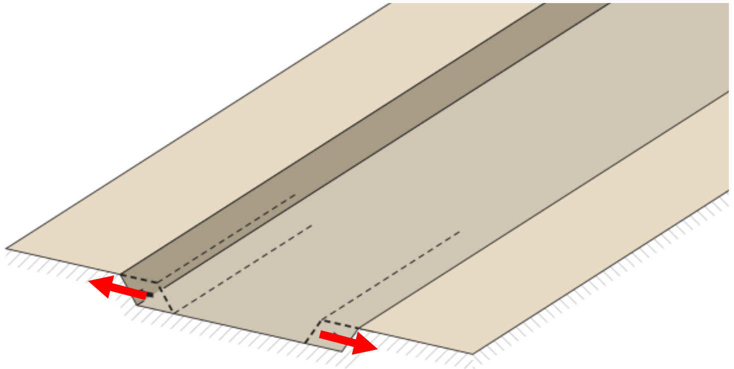
Lateral sediment transport

Anderson et al. (1975) distinguish between primary and secondary erosion:

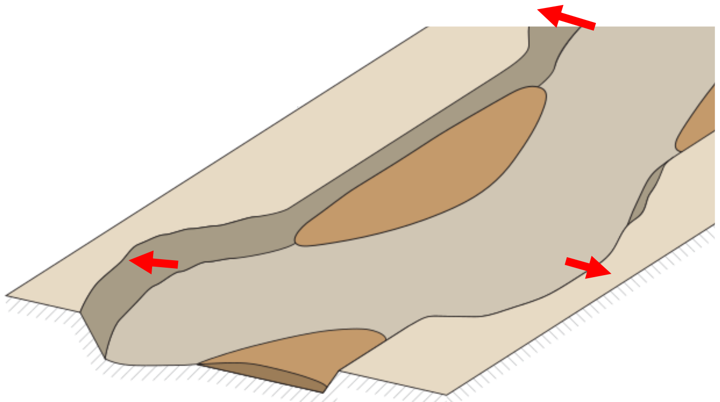
Straight channel



Primary erosion



Secondary erosion



Source: Figures adapted from Requena (2008)

→ Simulation of those erosion processes with a 2D numerical model is not straightforward

Lateral sediment transport

Sediment transport lateral to the main flow direction is key to modelling morphological features such as alternating bars and point bars in bends

Numerical modelling of morphodynamic processes

Mathematical model

$$\frac{\partial h}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0$$

shallow water eqn.s*

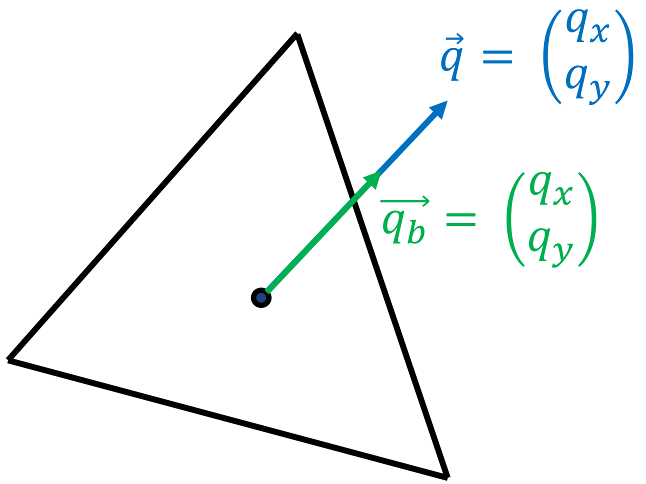
$$\frac{\partial q_x}{\partial t} + \frac{\partial}{\partial x}\left(\frac{q_x^2}{h}\right) + gh\frac{\partial h}{\partial x} + \frac{\partial}{\partial y}\left(\frac{q_x q_y}{h}\right) = -gh\left(\frac{\partial z_B}{\partial x} + S_{fx}\right)$$

$$\frac{\partial q_y}{\partial t} + \frac{\partial}{\partial y}\left(\frac{q_y^2}{h}\right) + gh\frac{\partial h}{\partial y} + \frac{\partial}{\partial x}\left(\frac{q_x q_y}{h}\right) = -gh\left(\frac{\partial z_B}{\partial y} + S_{fy}\right)$$

$$(1-p)\frac{\partial z_B}{\partial t} + \frac{\partial q_{Bx}}{\partial x} + \frac{\partial q_{By}}{\partial y} = 0$$

Exner eqn.

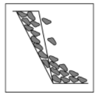
Assumption: Vector of sediment discharge has the **SAME DIRECTION** as the vector of liquid discharge



→ Requires closure relation for sediment transport capacity q_b, e.g. Meyer-Peter and Müller (1948)

Numerical modelling of morphodynamic processes

Additional model requirements

1. Local bed slope effect on threshold for incipient motion 
2. Deviation of sediment discharge direction from water discharge direction
   a. Lateral bed slope effect 
   b. Curvature effect 
3. Slope collapse by gravitational transport 

Numerical modelling of morphodynamic processes

1. INFLUENCE OF LOCAL BED SLOPE ON INCIPIENT MOTION: gravitational effect $\theta_c \updownarrow$

E.g. approaches of van Rijn (1989) or Chen et al. (2010):

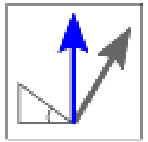
$$\theta_{cr,\delta} = k \cdot \theta_{cr}$$

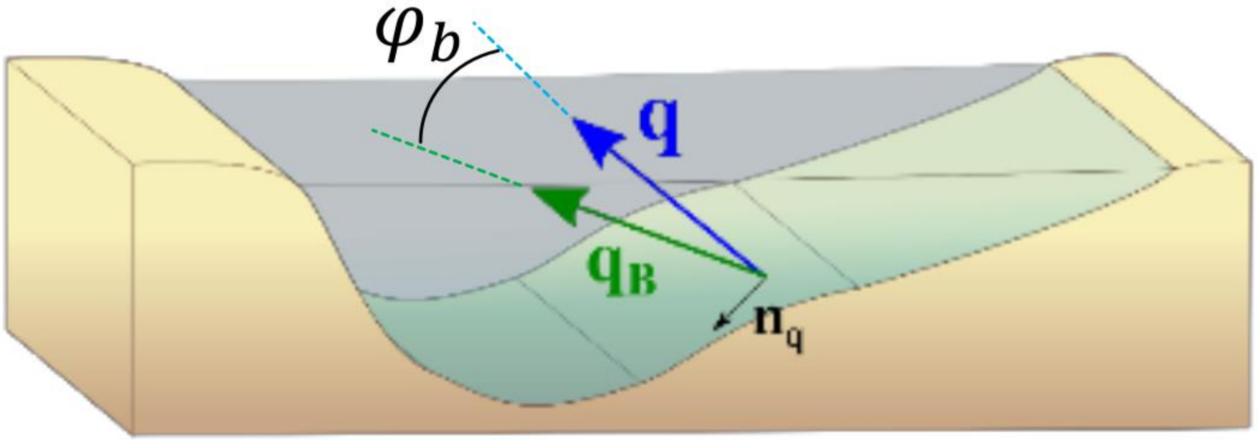
$$k = \mathrm{f}(\gamma, \delta_l, \delta_t)$$

γ: Angle of repose of the sediment
δ_l: Angle between the horizontal and bed slope in longitudinal direction
δ_t: Angle between the horizontal and bed slope in transversal direction
θ_{cr}: Non-dimensional critical bed shear stress (θ_{cr} = 0.047)
$\theta_{cr,\delta}$: Non-dimensional critical bed shear stress corrected for the local bed slope

Numerical modelling of morphodynamic processes

2.a. LATERAL BED SLOPE: gravitational effect





Source: Vetsch et al. (2020)

E.g. Talmon et al. (1995):

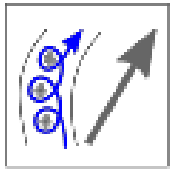
$$\tan \varphi_b = -f(\theta) \cdot \vec{s} \cdot \vec{n}_q \quad \text{for} \quad \vec{s} \cdot \vec{n}_q < 0$$

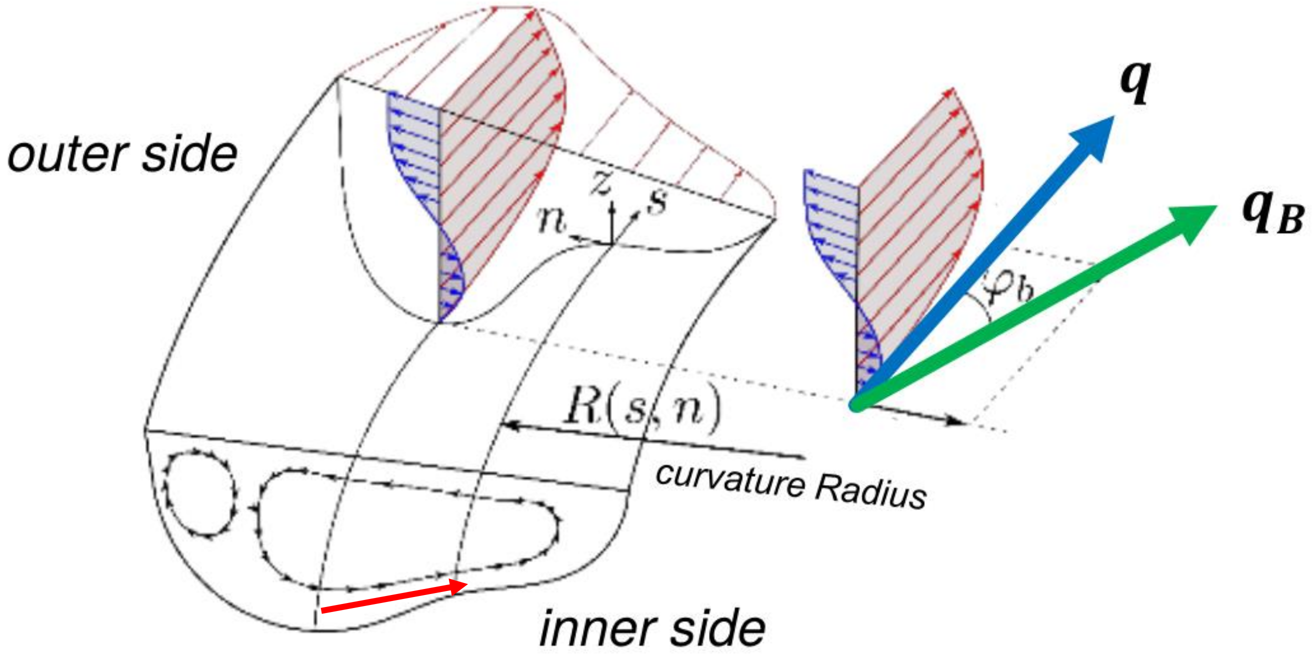
$$f(\theta) = N_l \left(\frac{\theta_{cr}}{\theta} \right)^{M_l}$$

$\vec{s}$: Bed gradient
$\overrightarrow{n_q}$: Normal vector to flow direction
N_l: lateral transport factor $N_l \in [0.75, 2.63]$
M_l: lateral transport exp. ($M_l \approx 0{,}5$)
θ: non-dimensional bed shear stress
θ_{cr}: critical non-dimensional bed shear stress

Numerical modelling of morphodynamic processes

2.b. CURVATURE EFFECT: hydrodynamic effect





Source: Vetsch et al. (2020)

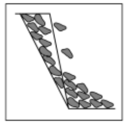
Engelund (1974):

$$\tan \varphi_c = -N_* \frac{h}{R}$$

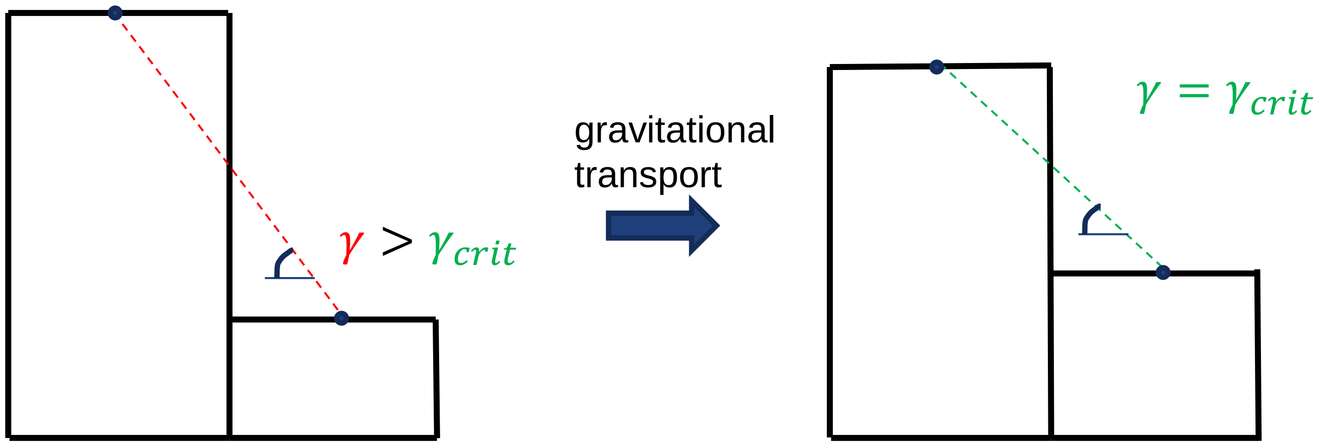
N_*: Curvature factor ($N_* \approx 7$)
R: Radius of channel bend
h: Flow depth

Numerical modelling of morphodynamic processes

3. GRAVITATIONAL TRANSPORT

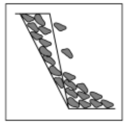


- Simplified geometrical approach with slope failure when a critical slope between two elements is exceeded



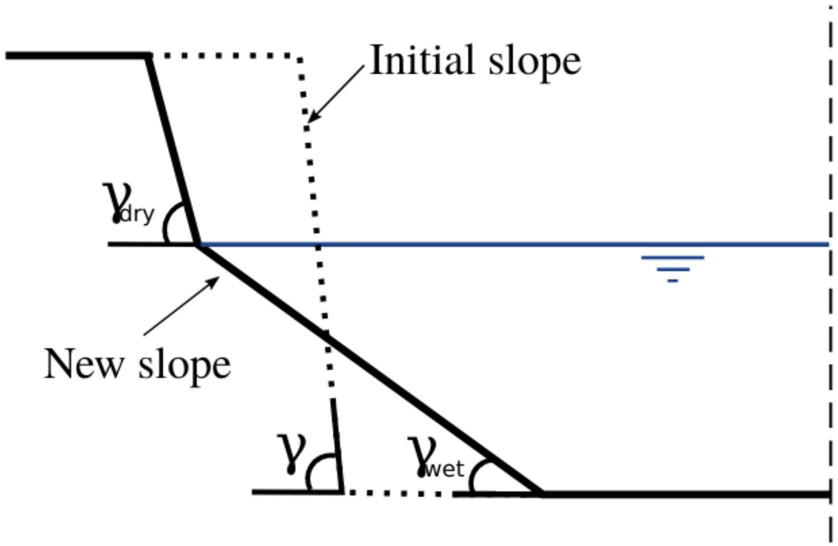
Numerical modelling of morphodynamic processes

3. GRAVITATIONAL TRANSPORT



- Simplified geometrical approach with slope failure when a critical slope between to elements is exceeded

- Critical angle can be defined for wet and dry sediment



Source: Vetsch et al. (2020)

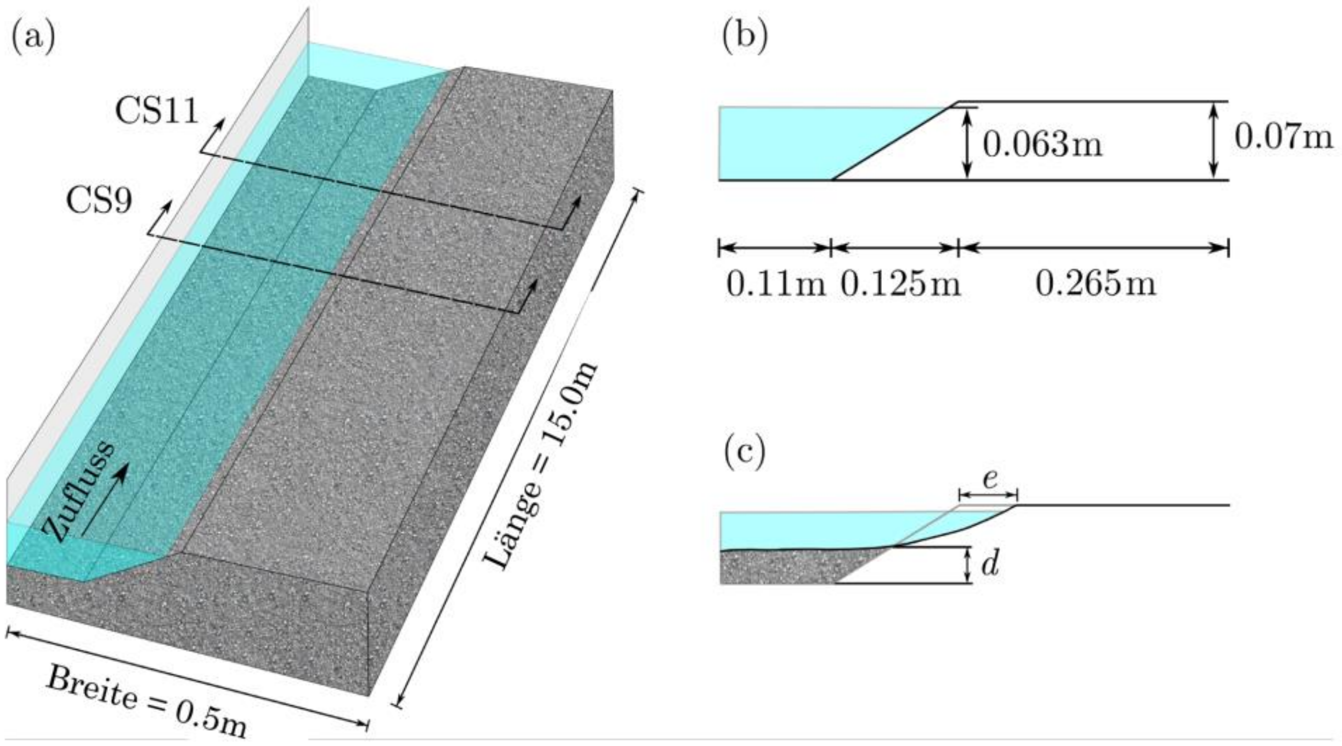
Numerical modelling morphodynamic processes

Revision of sediment transport feature in BASEMENT Version 3.1

- Bugfixes in curvature and lateral bed slope effects
- New calculation method for gradients (e.g. bed gradient, velocity gradient) significantly improved prediction of the curvature and lateral bed slope effects
- Improved gradient calculation also benefits the critical shear stress correction due to local bed slope
- Implementation of gravitational bedload transport to simulate bank erosion

Morphological simulations with BASEMENT v3.1

BANK EROSION IN A STRAIGHT TRAPEZOIDAL CHANNEL (IKEDA 1981)

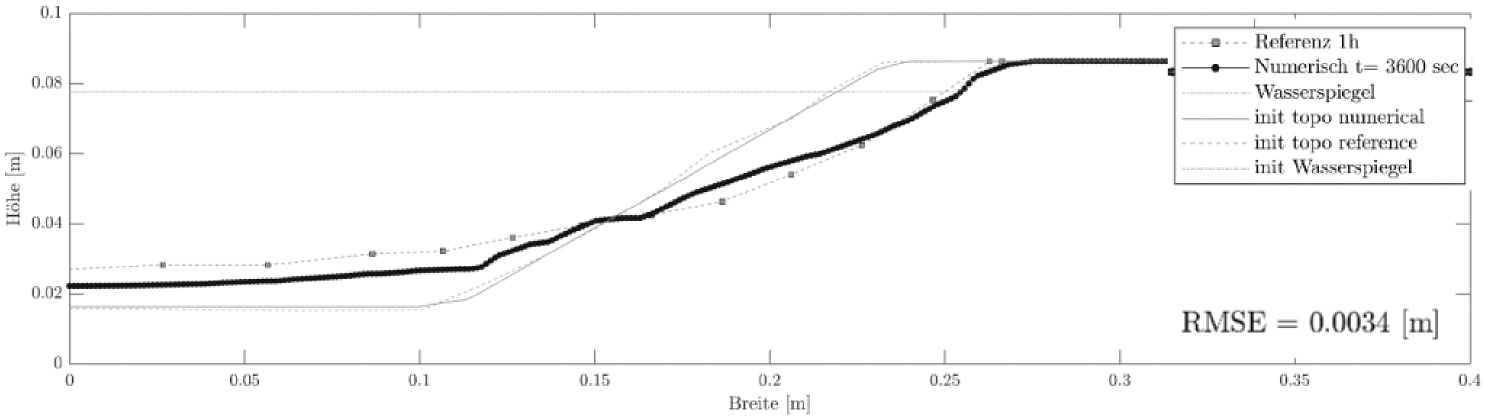


Source: Vonwiller, Vetsch und Boes (2018), adapted by Stadtmann (2020)

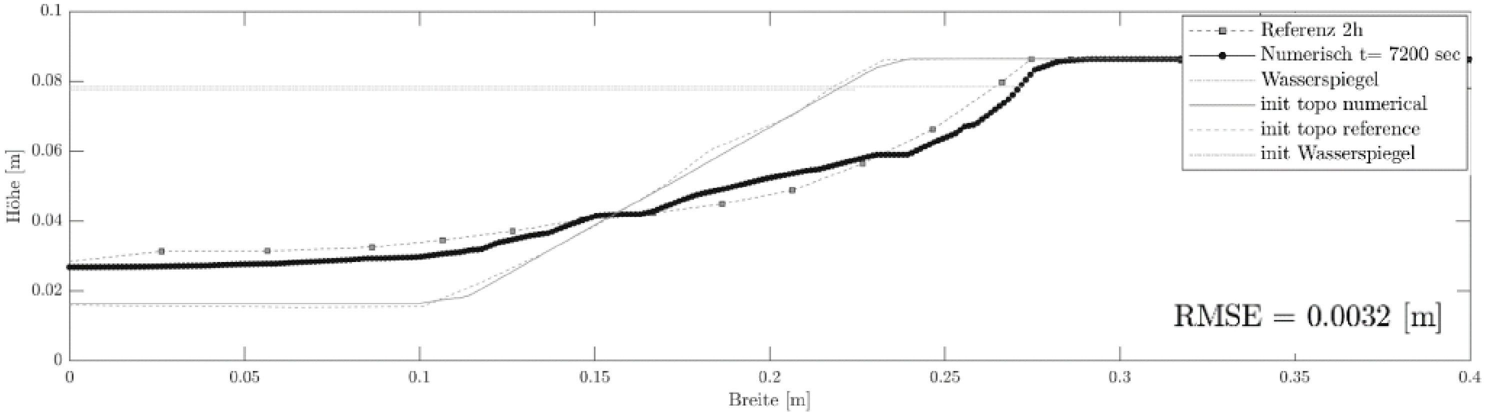
Morphological simulations with BASEMENT v3.1

BANK EROSION IN A STRAIGHT TRAPEZOIDAL CHANNEL (IKEDA 1981)

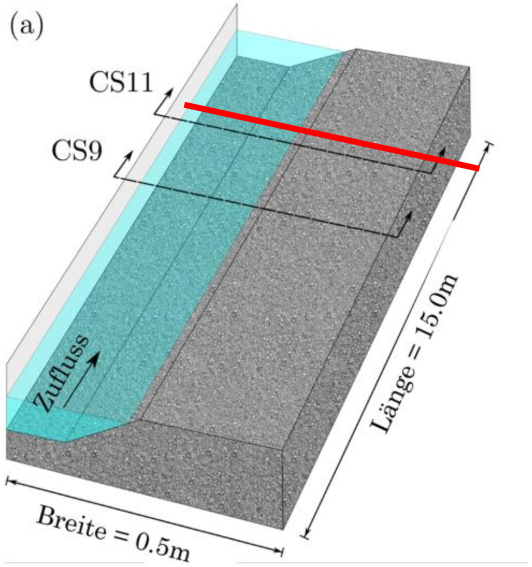
1h



2h



Source: Stadtmann (2020)

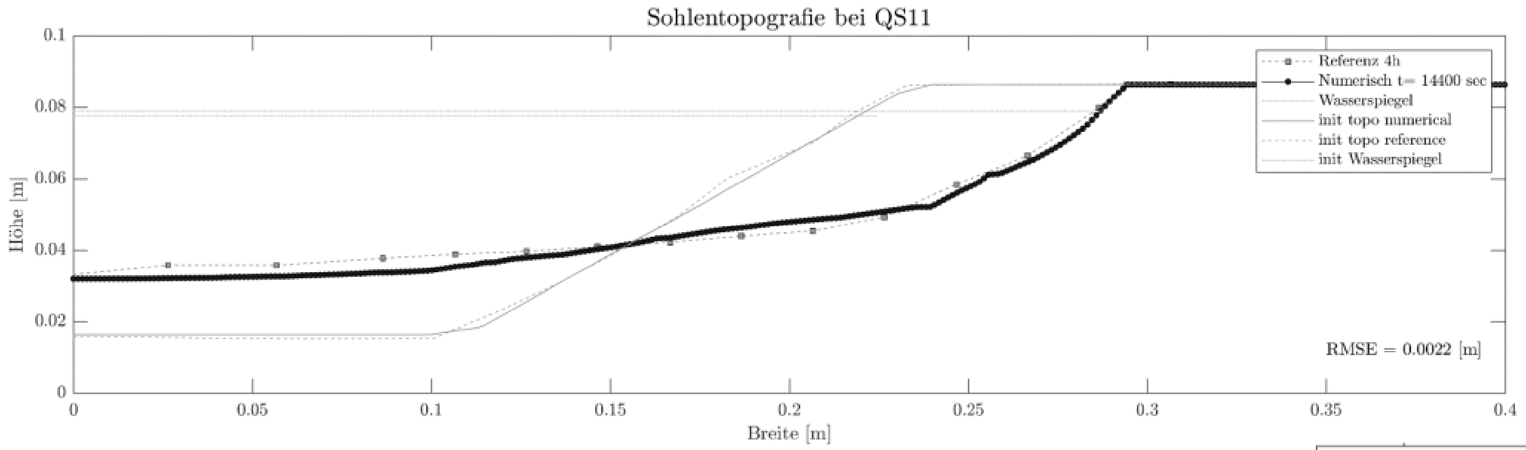


Source: Vonwiller, Vetsch and Boes (2018), adapted by Stadtmann (2020)

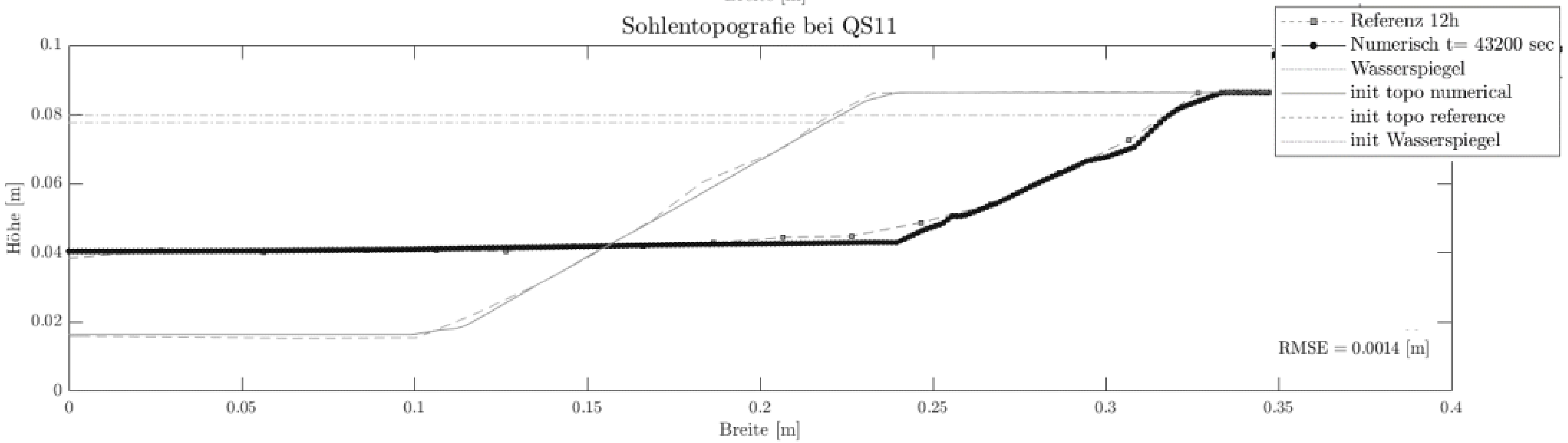
Morphological simulations with BASEMENT v3.1

BANK EROSION IN A STRAIGHT TRAPEZOIDAL CHANNEL (IKEDA 1981)

4h



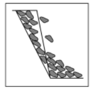
12h



Source: Stadtmann (2020)

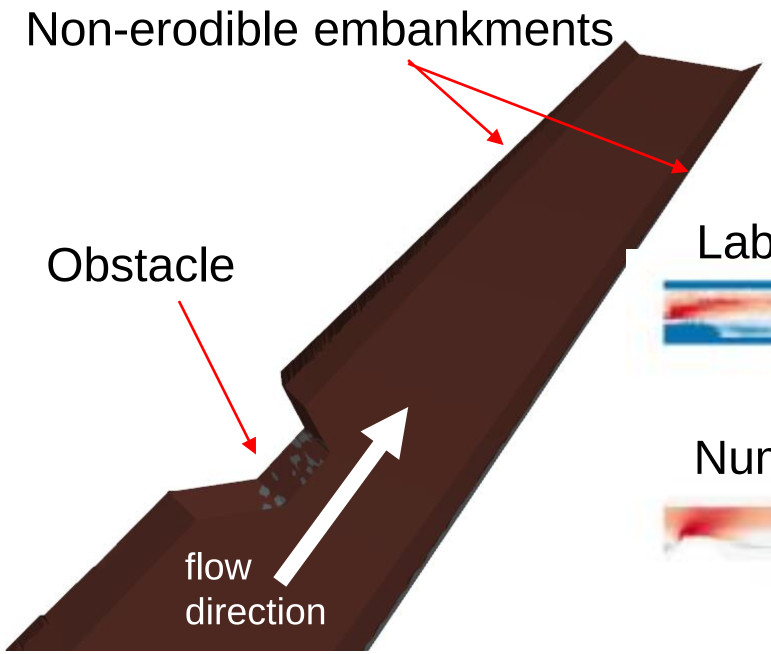
Requires:

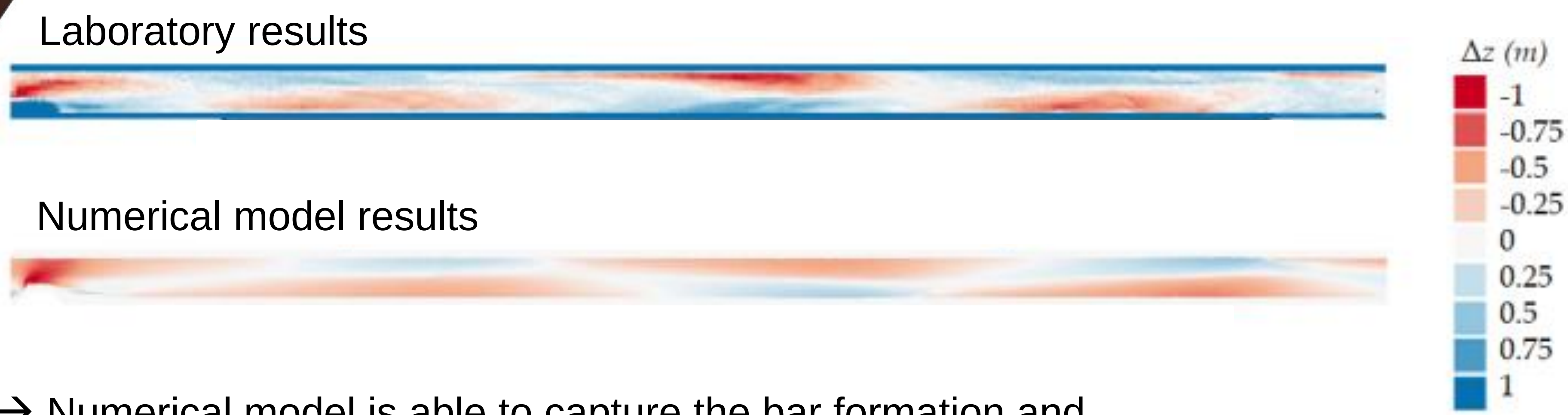
- Lateral slope effect 
- Local slope effect 

- Slope collapse 

Morphological simulations with BASEMENT v3.1

ALTERNATE BAR FORMATION IN A TRAPEZOIDAL CHANNEL



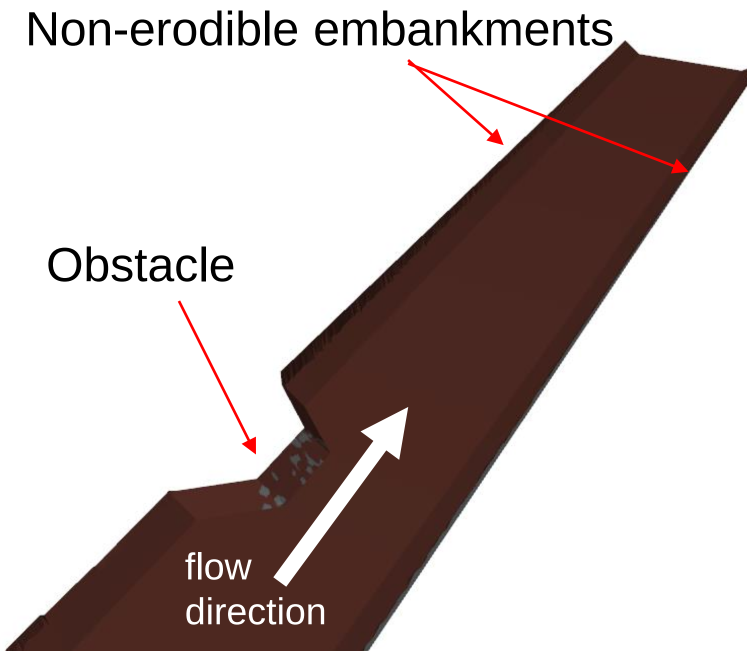


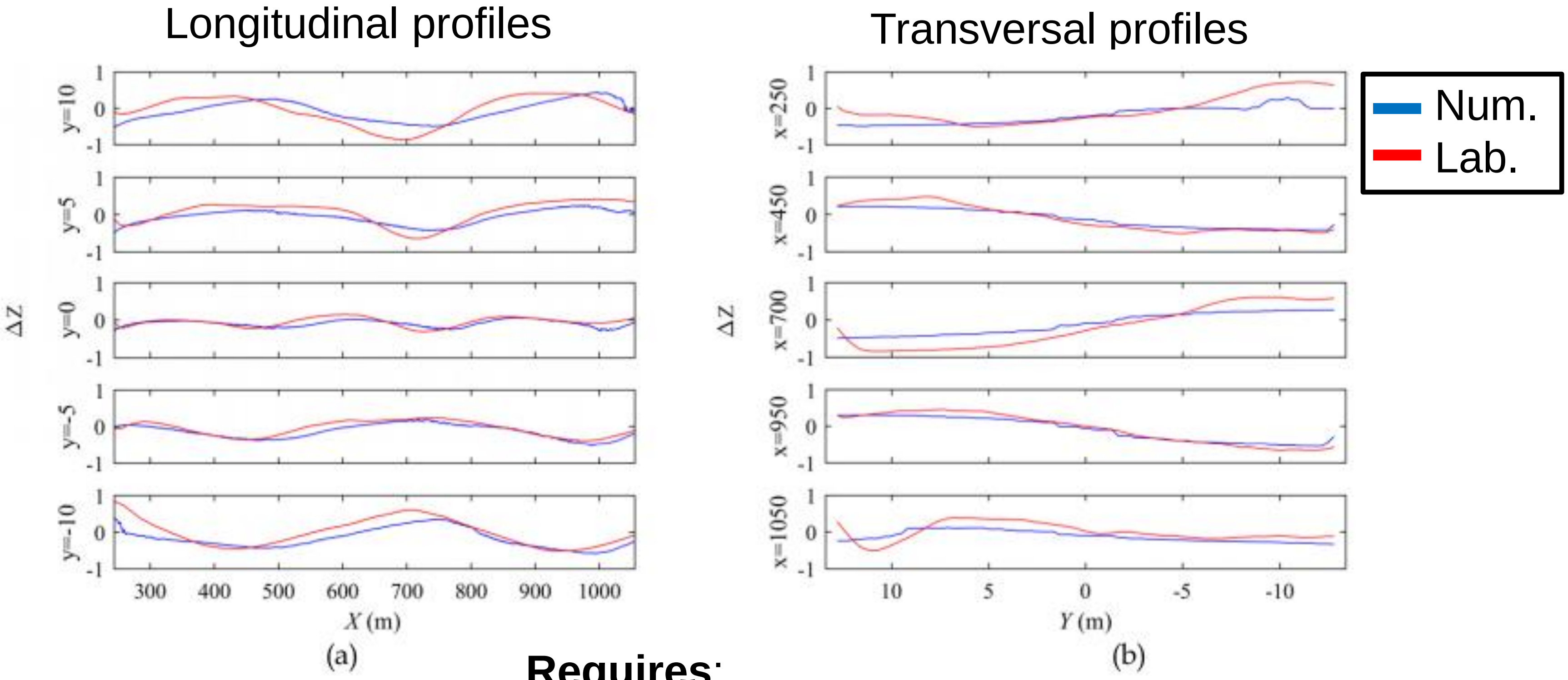
→ Numerical model is able to capture the bar formation and location of bars in good agreement with laboratory results

Sources:
M. Nieto Medina (2020)

Morphological simulations with BASEMENT v3.1

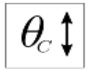
ALTERNATE BAR FORMATION IN A TRAPEZOIDAL CHANNEL





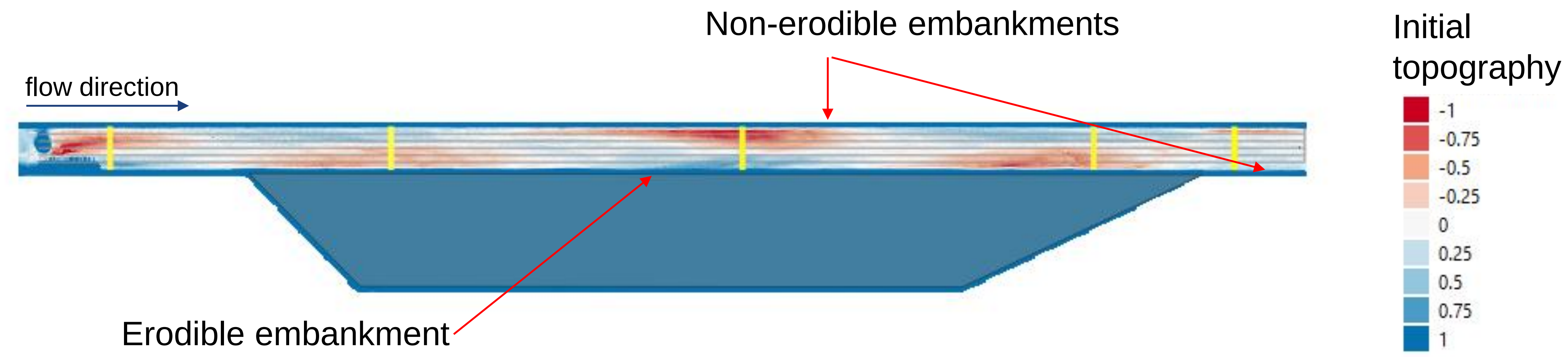
Sources:
M. Nieto Medina (2020)

Requires:

- Lateral slope effect 
- Local slope effect 

Morphological simulations with BASEMENT v3.1

DYNAMIC CHANNEL WIDENING

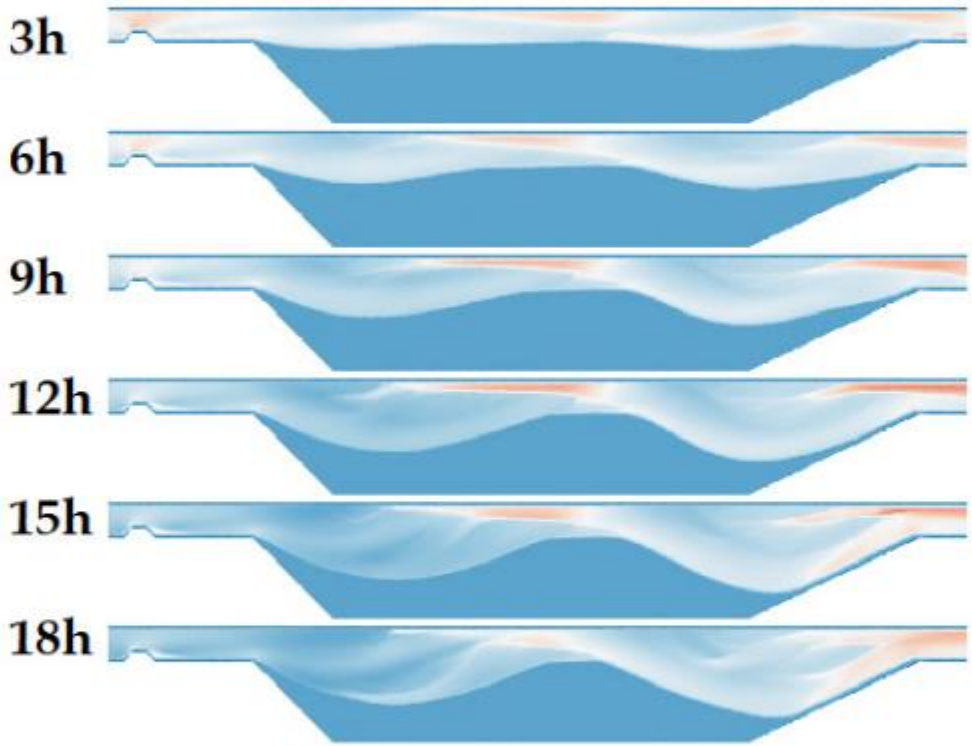


Source:
M. Nieto Medina (2020)

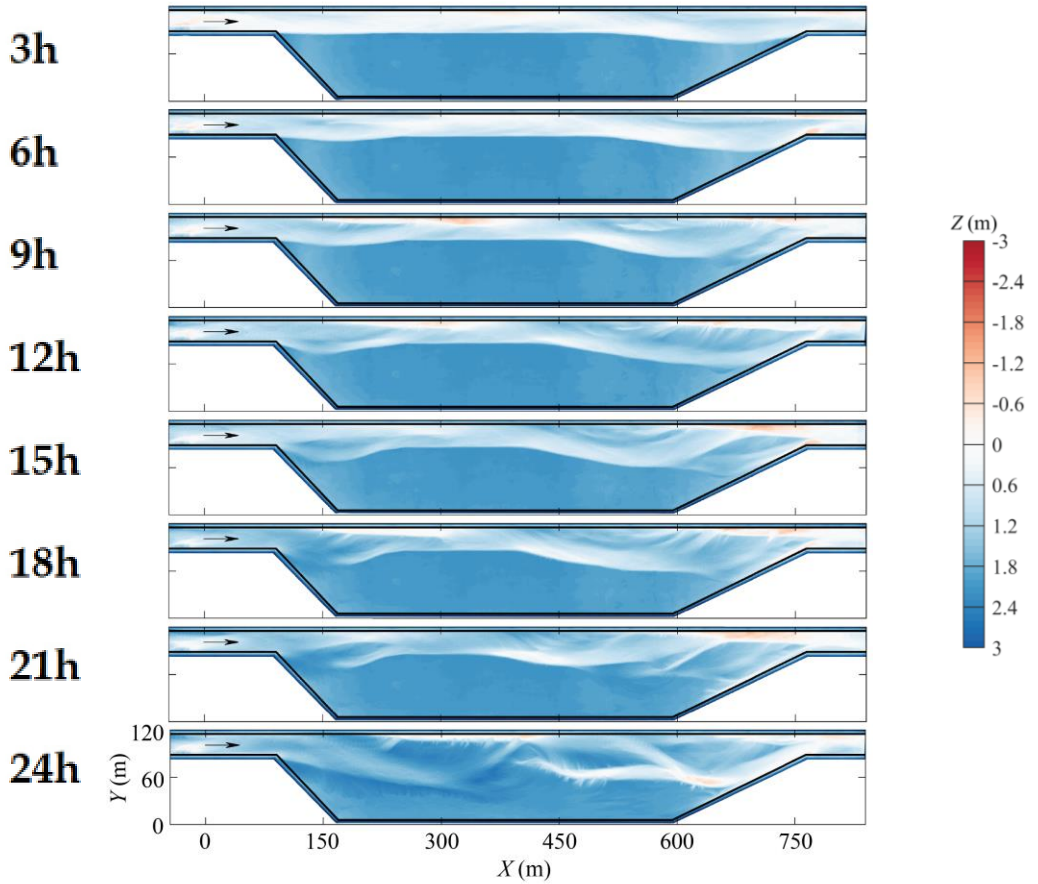
Morphological simulations with BASEMENT v3.1

DYNAMIC CHANNEL WIDENING

Numerical model



Laboratory



Source:
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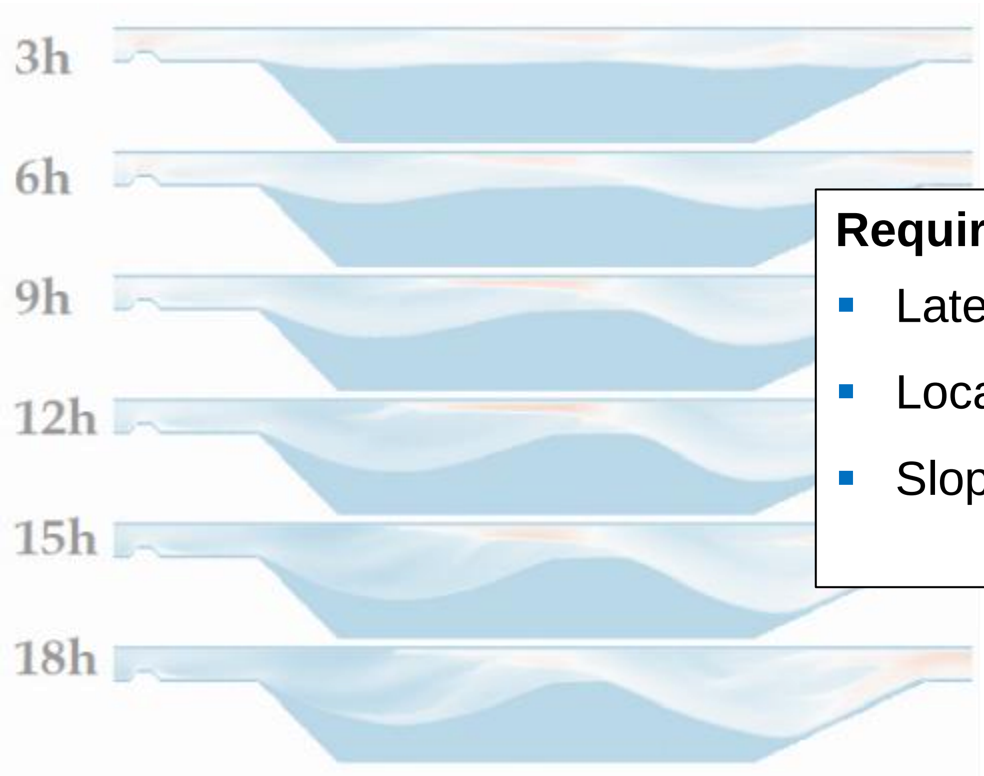
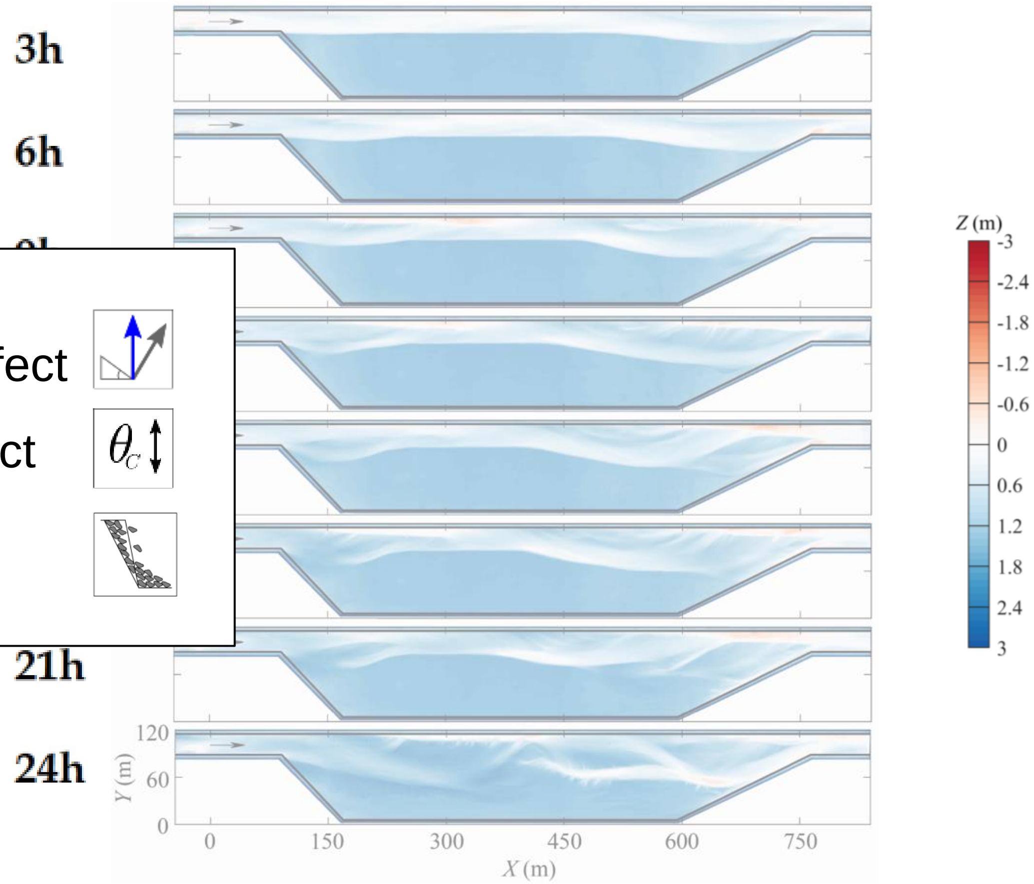
Morphological simulations with BASEMENT v3.1

DYNAMIC CHANNEL WIDENING

Numerical model



Laboratory



Requires:

- Lateral slope effect
- Local slope effect
- Slope collapse

Source:
M. Nieto Medina (2020)

Conclusion

- Extensive revision of the sediment transport feature in BASEMENT v3.1, including bug fixes, improved calculation methods for spatial gradients and gravitational transport
- Successful application BASEMENT of v3.1 for modelling:
  - Lateral bank erosion
  - Alternating bar formation
  - Dynamic widening
  - Bend flow with point bar formation

Thanks to Patrik Stadtmann, Michel Nieto Medina and Cristina Rachelly!

Literature (i)

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Literature (ii)

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