# FAST Danube – Hydraulic and sediment transport modelling with MIKE 21 FM model

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# FAST Danube project

- *"…to identify the technical solutions to be implemented, in order to ensure navigation conditions on the Romanian-Bulgarian common sector of the Danube and safely conducting the transport activities on Danube throughout the entire year, in accordance with the recommendations of the Danube Commission in Budapest."*

FAST DANUBE

***Technical Assistance for Revising and Complementing the Feasibility Study regarding the Improvement of Navigation Conditions on the Romanian-Bulgarian Common Sector of the Danube and Complementary Studies - FAST DANUBE***

# FAST Danube project – objectives

- at the 12 specified critical locations, identify the overall most effective navigation improvement solutions for achieving the recommended navigation fairway parameters at the **ENR** river water level:
  - minimum fairway width of 180 m
  - minimum water depth of 2.5 m
  - minimum fairway radius of 1000 m
- **Étiage navigable et de regularisation** (**ENR**) water level is specified as the "*river water level which is achieved or exceeded for 94% (343 days) of the year*"

# FAST Danube – project area

# Sedimentation problem/solution

- at the ENR water levels parts of the navigation channel become very shallow or completely dry → this can limit the size or loading of vessels that can safely use the fairway
- **cause of problem:** the movement of sediment in the river, which can accumulate within the navigation fairway and act as a physical obstruction during the periods of low flows
- **solution:** the sedimentation problem can be mitigated by:
  i. periodic removal of the deposited sediments through dredging
  ii. prevention of (or reduction in) sedimentation by increasing flow velocities through a variety of engineering measures
  iii. a combination of options (i) and (ii)

# Sedimentation problem/solution

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iii. a combination of options (i)

# Purpose of the modelling

- to help understand the problem of sedimentation in critical areas
- support the process of the selection of solution options by providing a first assessment of the relative performance of the proposed options in maintaining the required navigation fairway parameters
- help to assess the impacts of the proposed solutions on the river navigation (e.g. changes in strength and direction of currents) and on the environment (e.g. changes in currents, changes in bed morphology, changes in water levels)

# Modelling approach

- Factors:
  - project extents: 488 km of river channel, typically ~1km wide, ~10m deep, variable bathymetry, islands
  - 12 critical locations: each 2 to 17 km of river, multiple solution options to be assessed at each location
  - options to be tested: dredging, traditional engineering solutions, nature-based solutions
  - outputs needed: impacts of options on velocities, sediment transport, morphology, environment
  - timescales: 3-4 months after measurement campaigns to build and calibrate models, 3-5 months for option testing

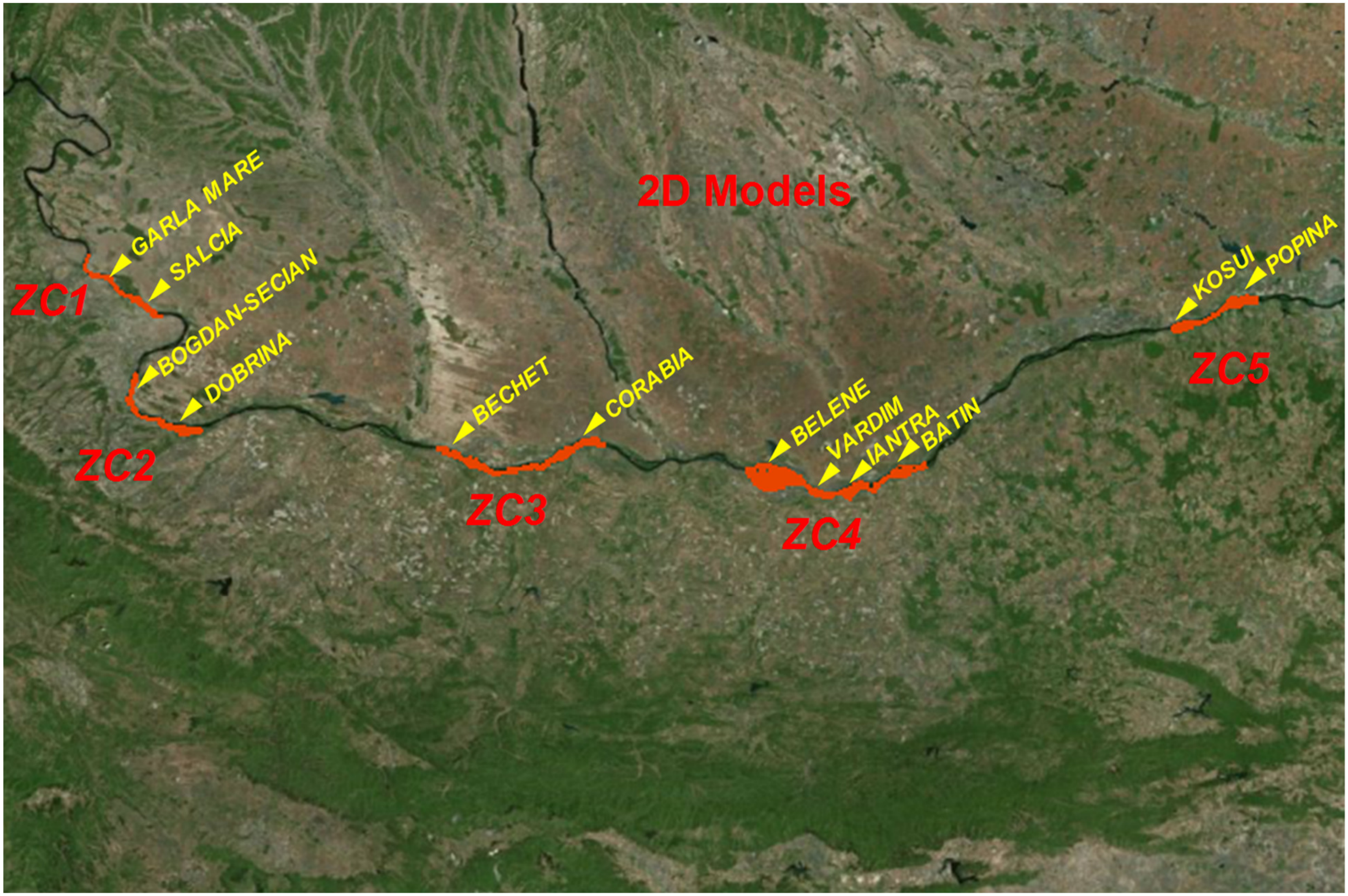
# Modelling approach

- 1D model of entire study reach (488 km) – **1D Flood Modeller Pro model**
  - provides information for whole study area
  - provides boundary data for local models of critical locations
- 2D models of 5 critical zones; 2D options models of 12 critical locations – **2D MIKE 21 FM model**
  - more detailed analysis of behaviour in the critical zones
  - testing of options
- empirical methods using model outputs to inform design for scour and local effects (e.g. bank erosion)

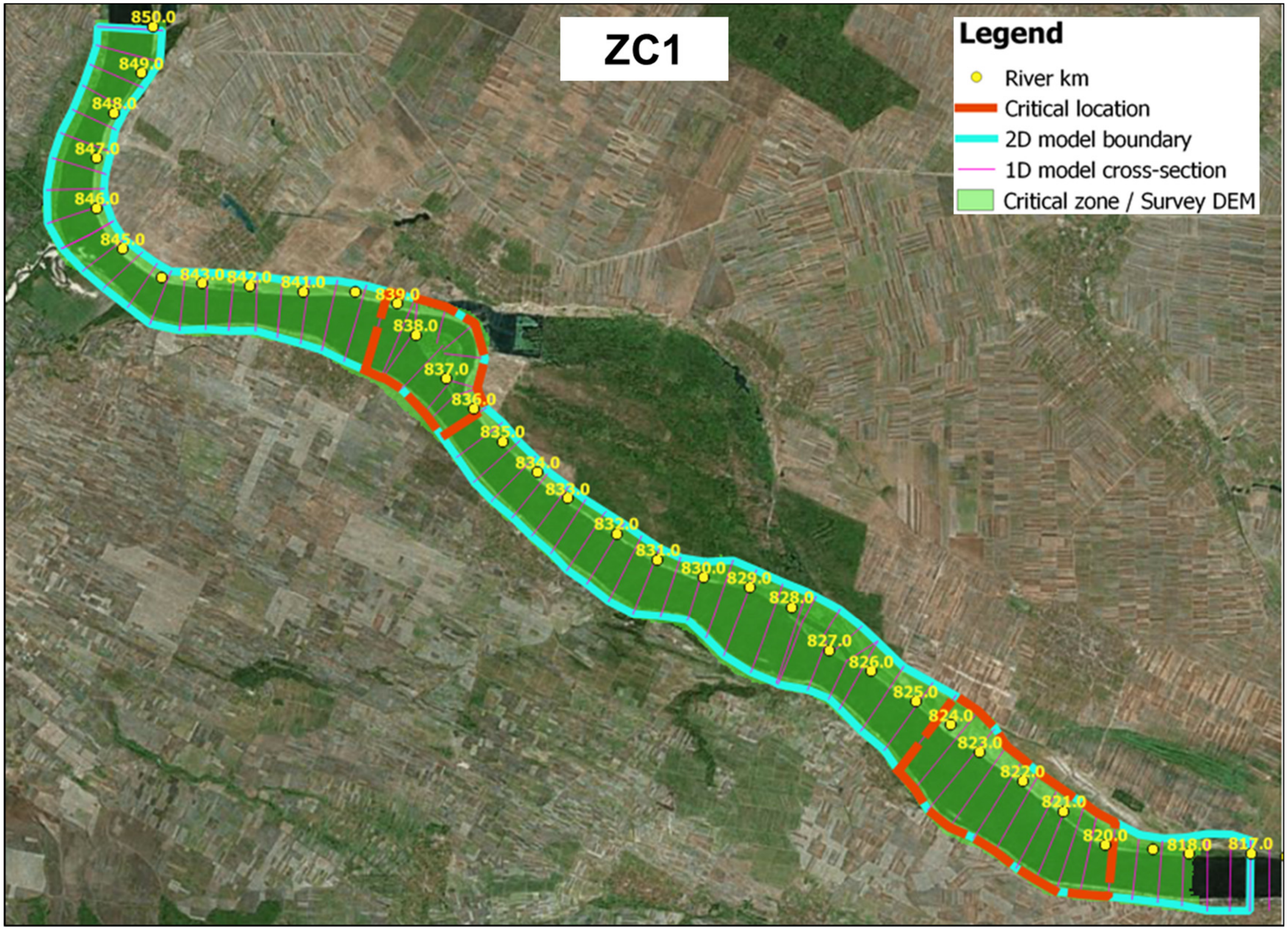
# 2D modelling – why MIKE 21 FM model

- depth-integrated Navier-Stokes equations for free surface flows (velocities, current direction, water levels)
- flexible triangular grid
- simulation of sediment transport (suspended and bed load)
- simulation of geomorphological processes (bed level change) with coupled updating of the river bed levels during the course of the model simulation
- can include the effect of secondary currents (i.e. helical flow) on geomorphological processes
- parallel computing (CPU and GPU)

# 2D modelling – model extents



# 2D modelling – critical zone and critical locations





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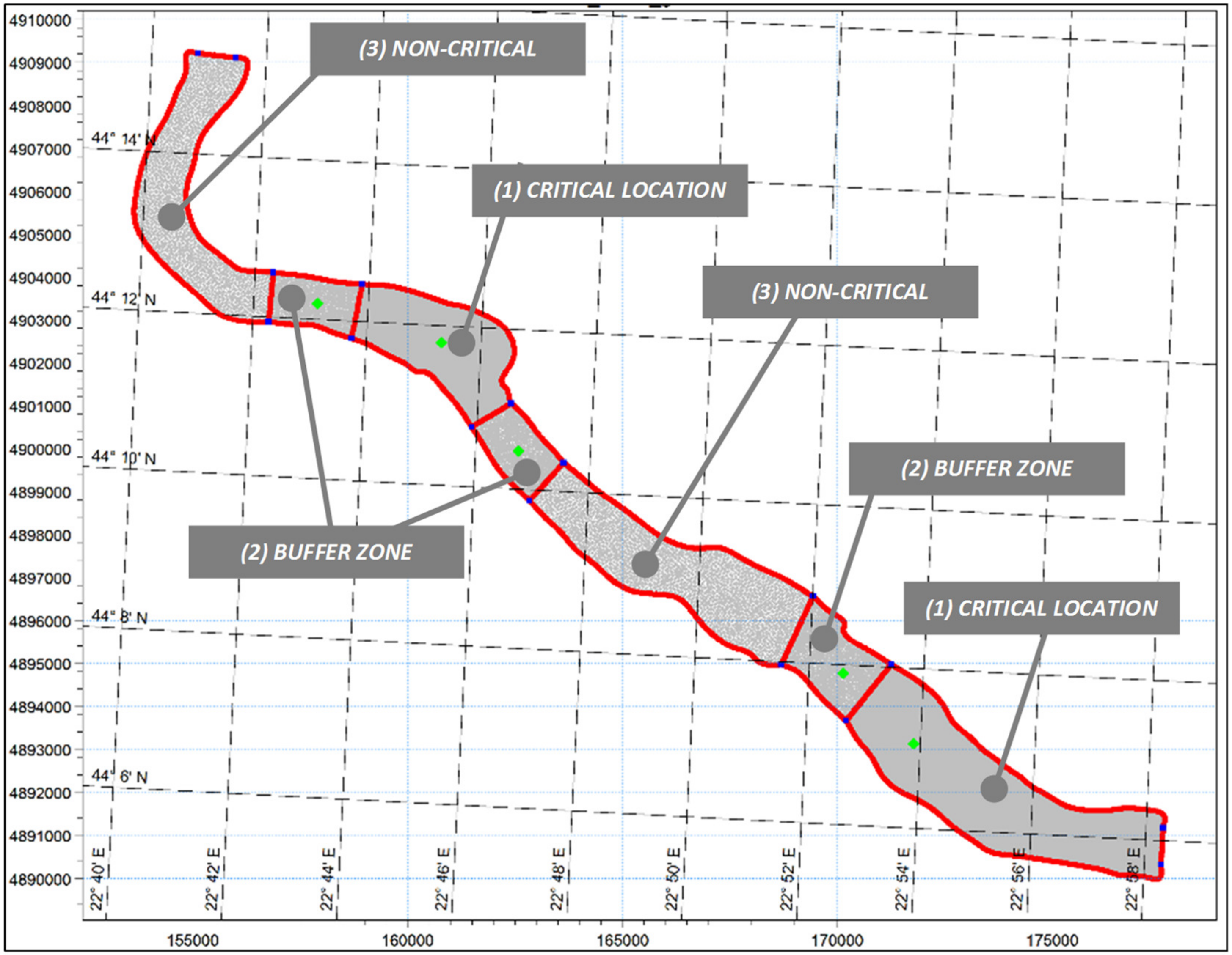
# 2D modelling – model development





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# Navigation improvement solutions

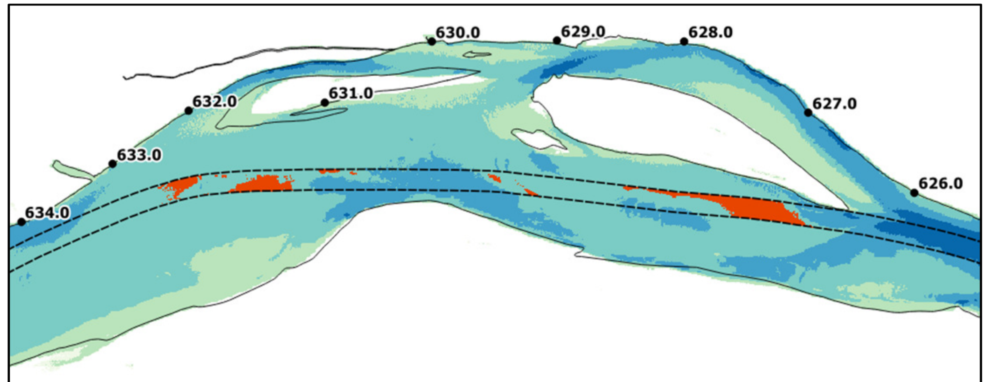
- three types of engineering measures have been considered in identifying the navigation improvement solutions:
  - “**traditional engineering solutions**”, which includes construction of rigid structures, such as groynes and chevrons
  - “**nature-based solutions**”, which includes creation of (self-building) artificial islands and fairway realignment to a more geomorphologically favourable or stable alignment
  - combination of “**traditional engineering**” and “**nature-based**“ types of solution

# Navigation improvement solutions

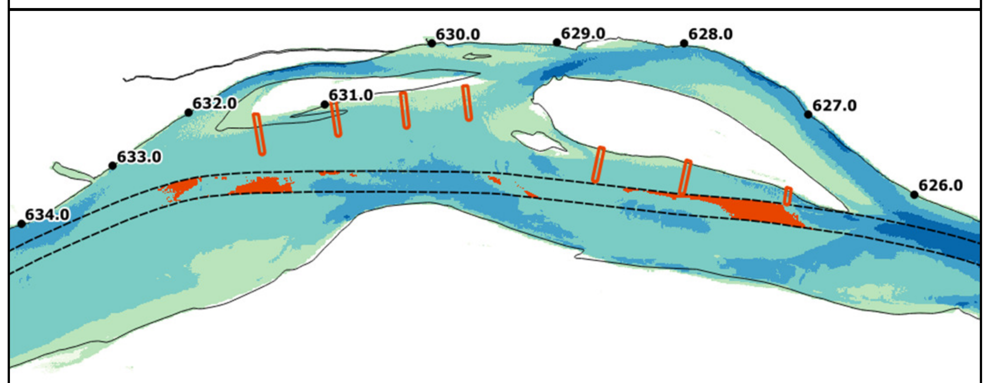
- "**nature-based solutions**", which includes creation of (self-building) artificial islands and fairway realignment to a more geomorphologically favourable or stable alignment
- combination of "**traditional engineering**" and "**nature-based**" types of solution

# 2D modelling – initial options

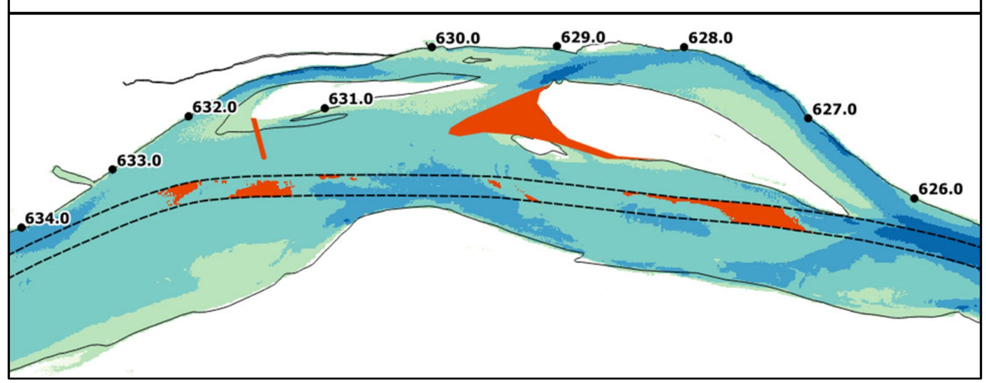
- Corabia:
  - “Dredge only”




  - “Groynes”




  - “Island + Groyne”



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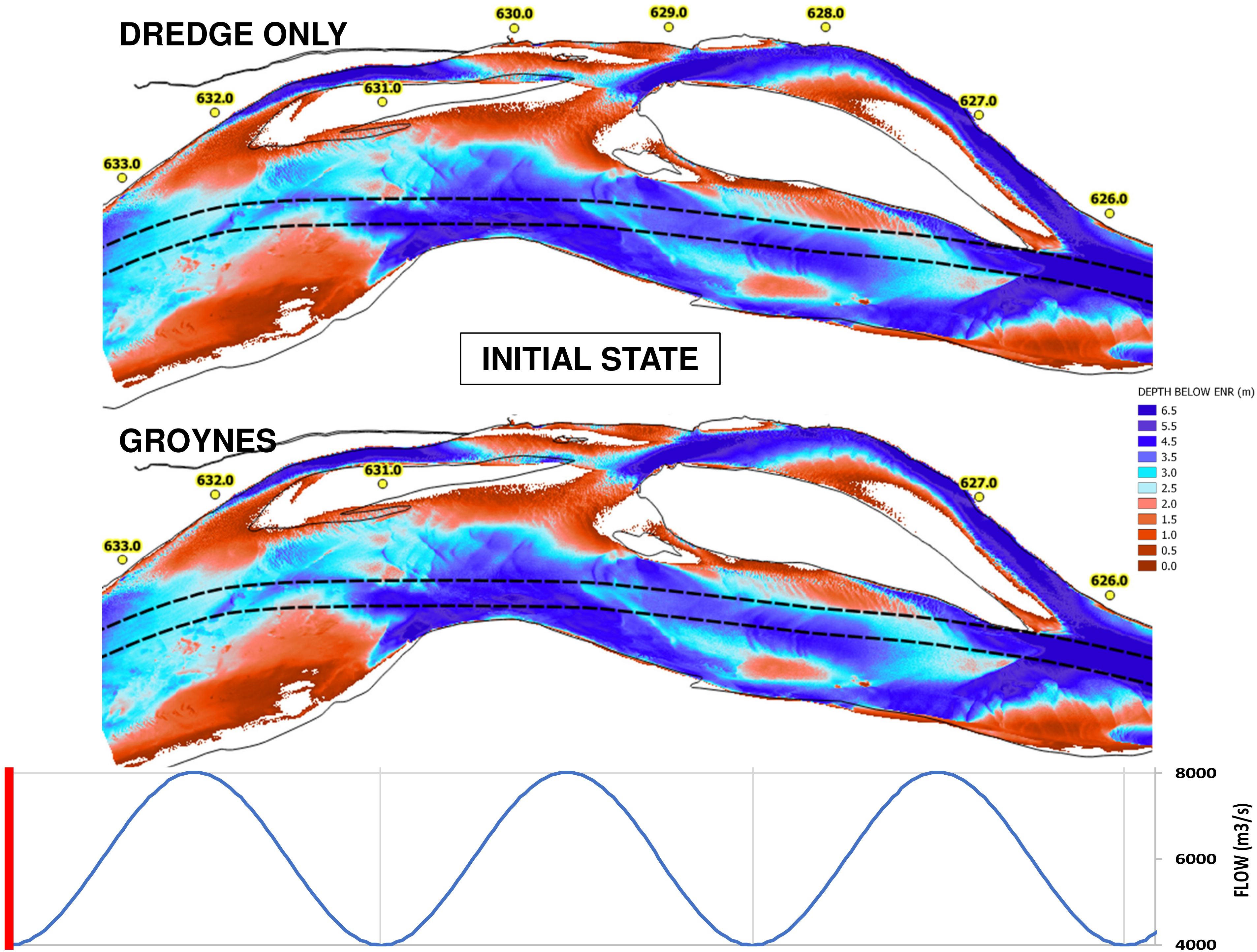
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INITIAL STATE
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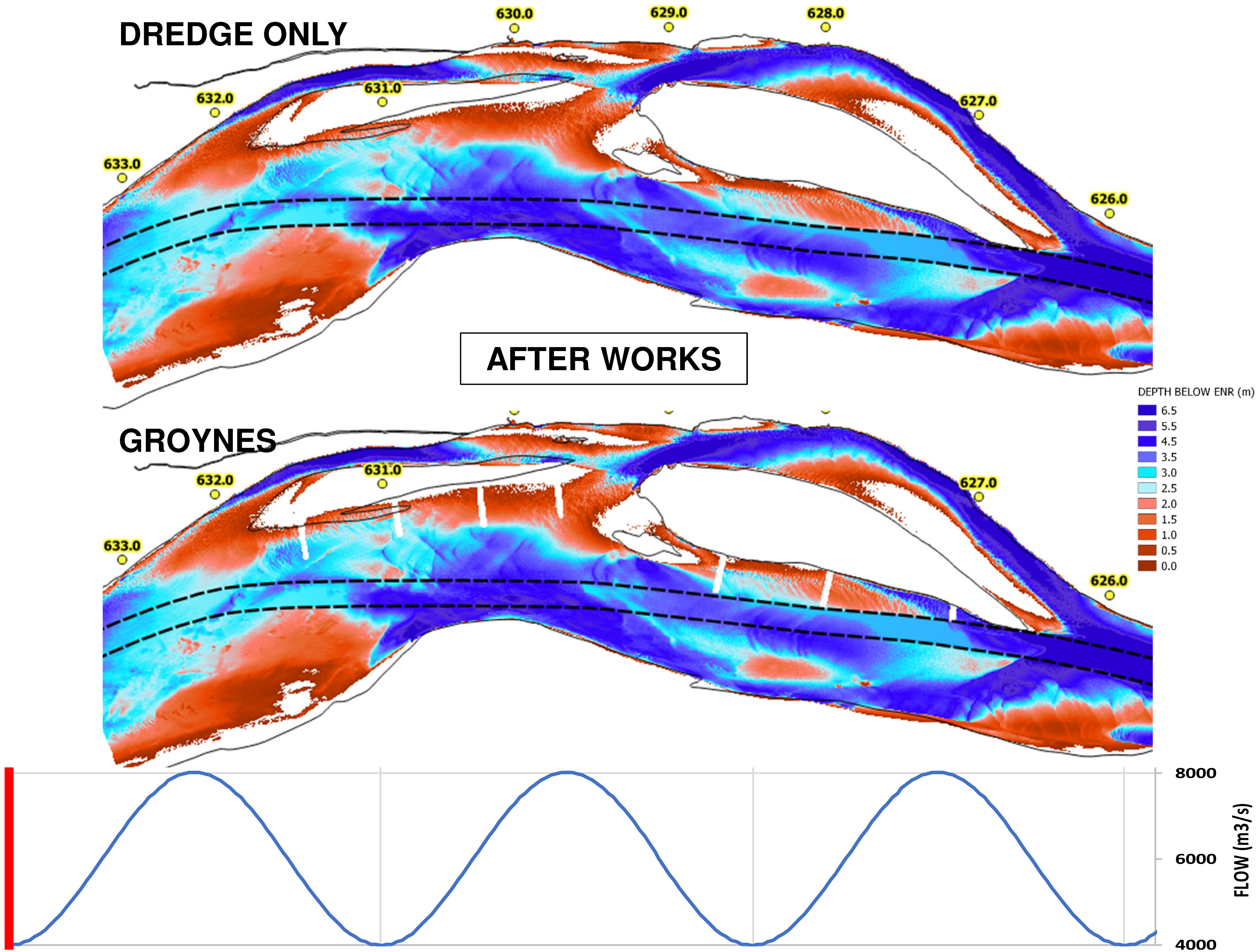

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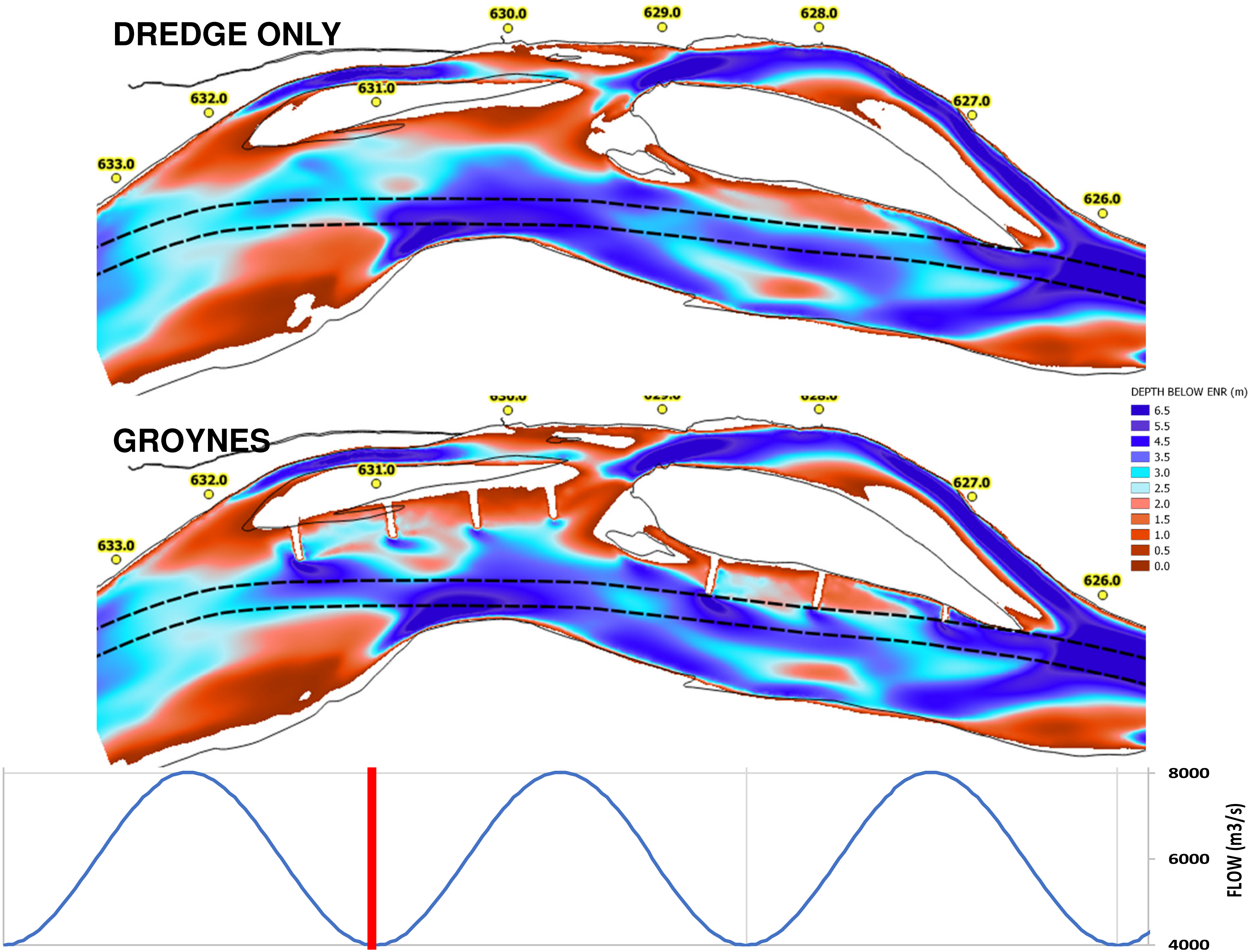

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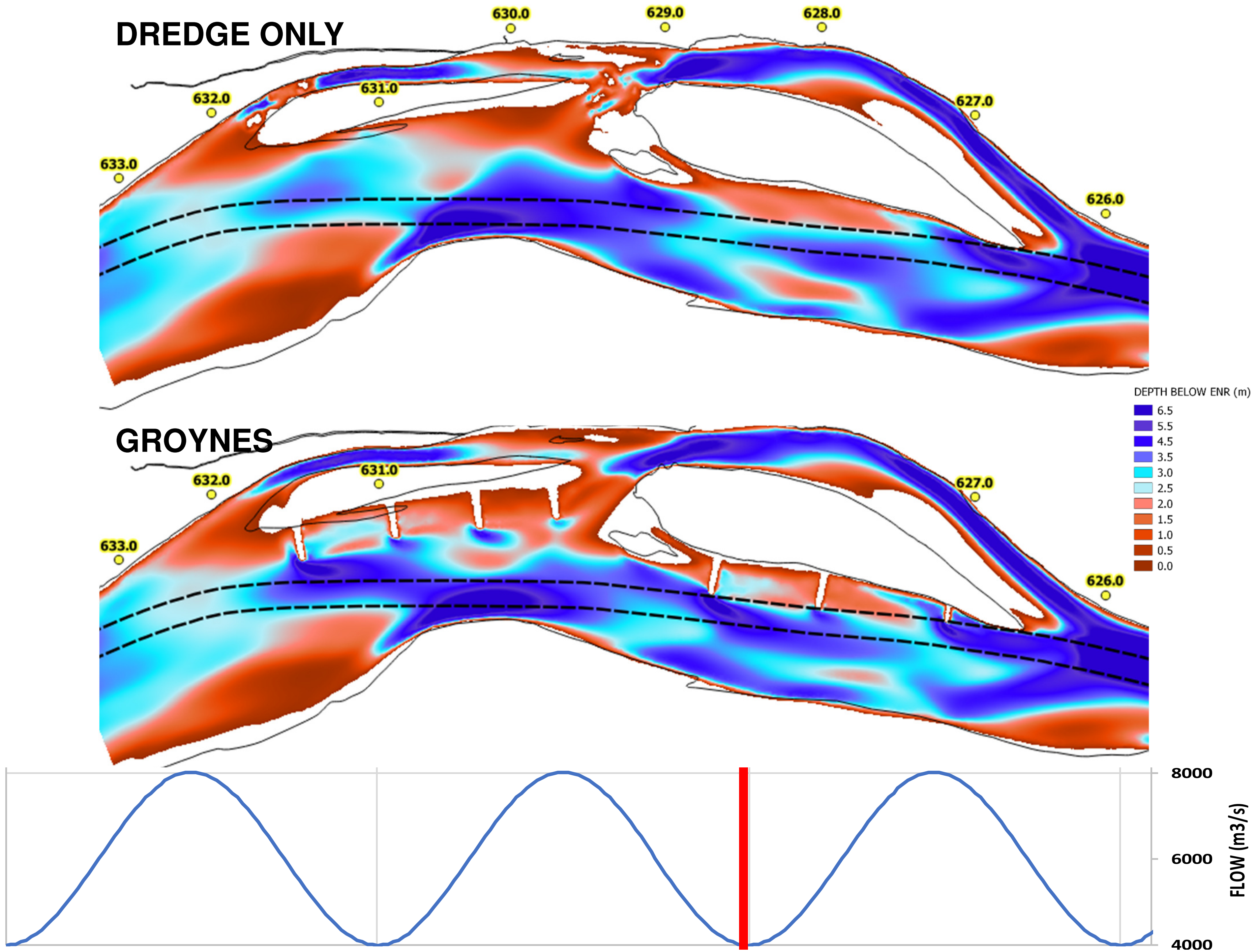
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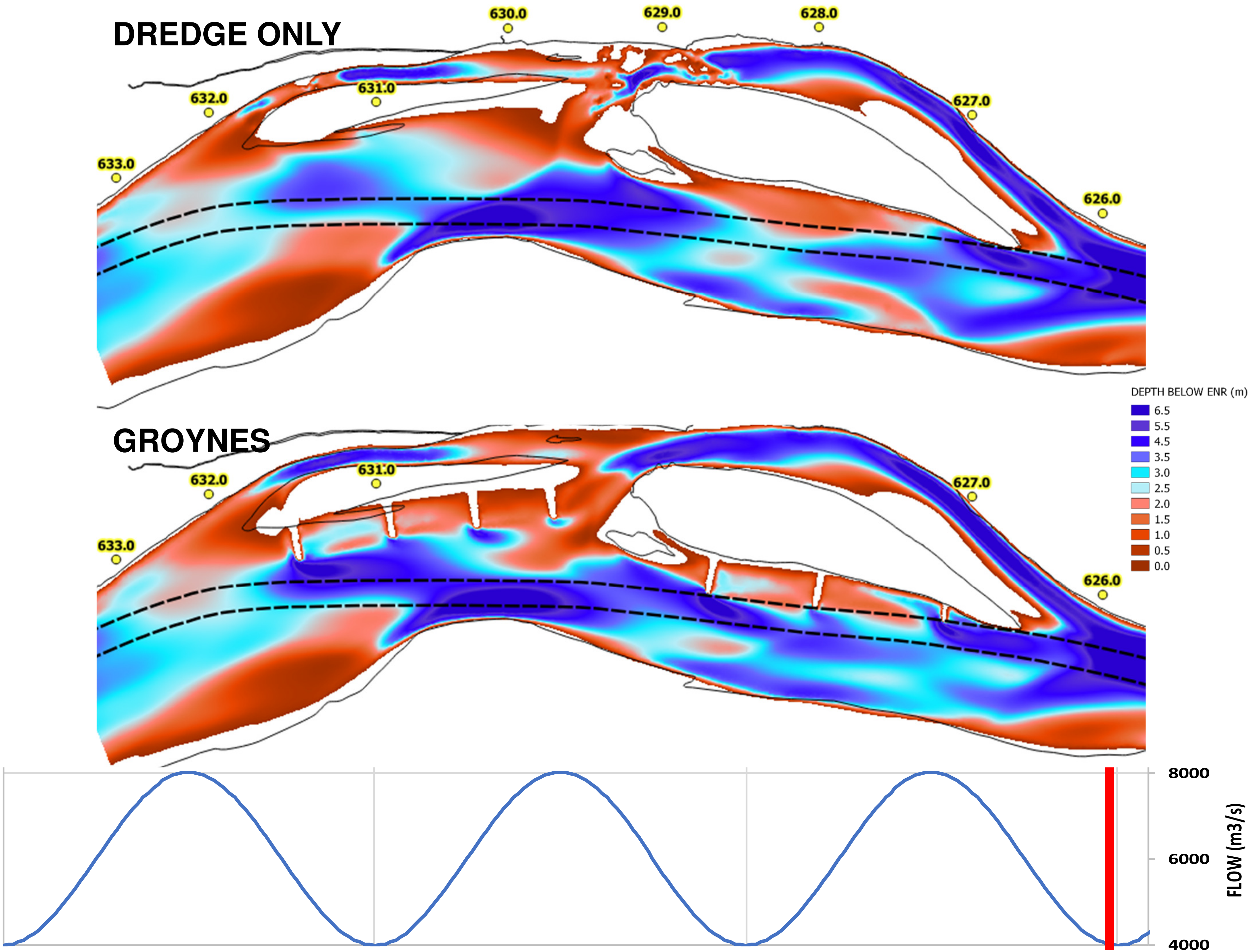

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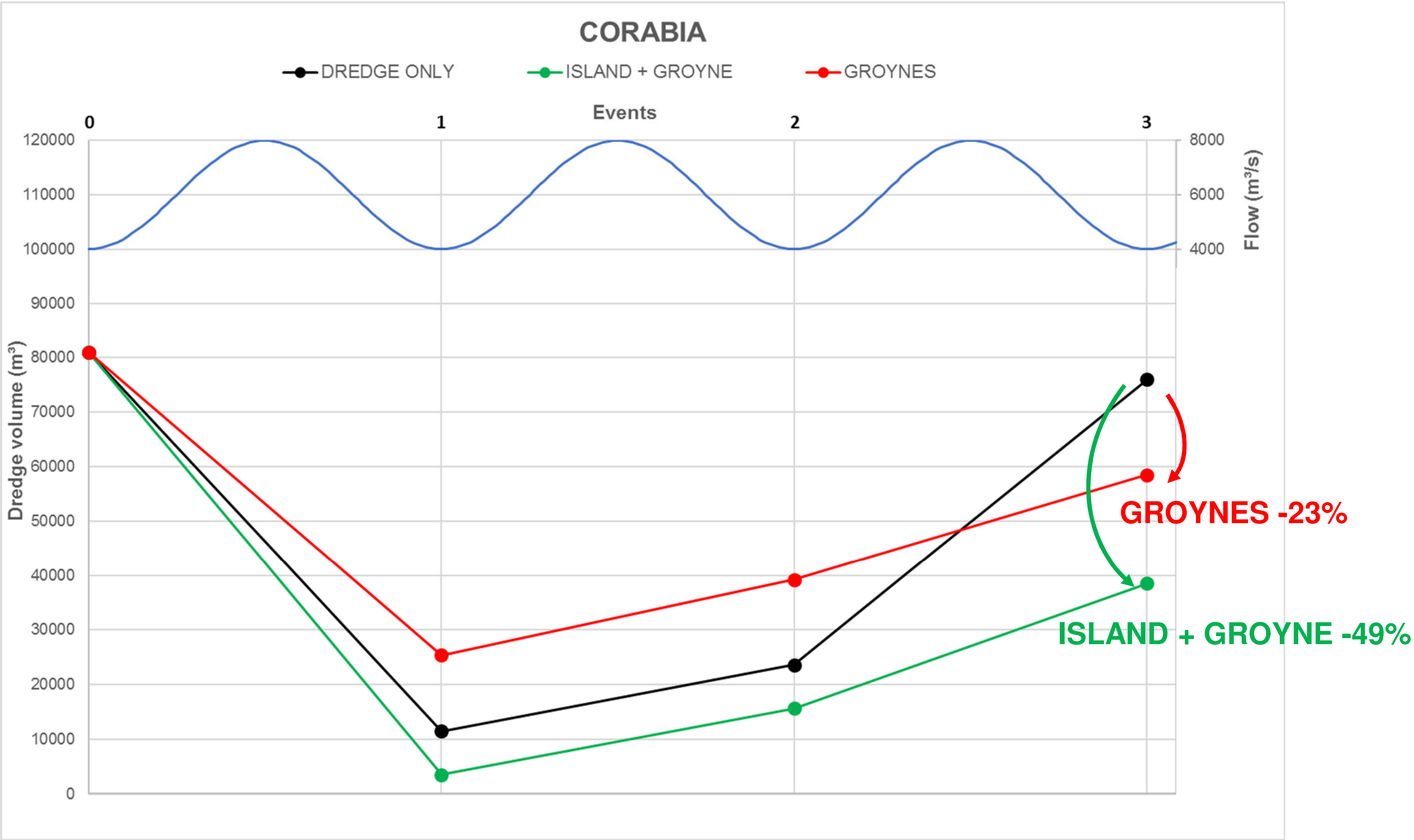
FLOW (m3/s)

# Effectiveness of options



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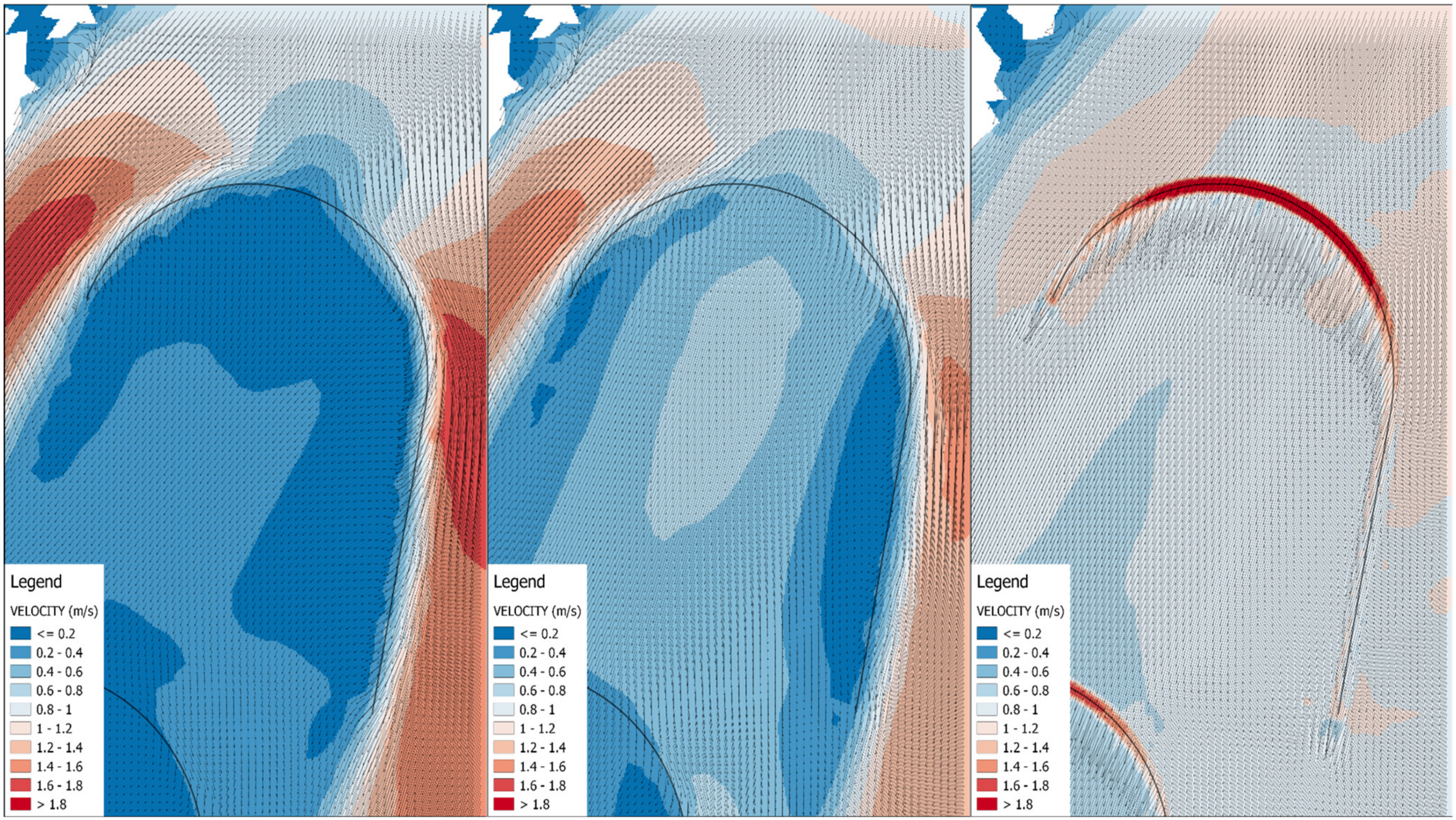
# 2D modelling – structure representation

Weir | Dike | Through bathymetry



# Submerged weir discharge – empirical relations

| Study | Discharge reduction coefficient formula | Empirical coefficients used |
|---|---|---|
| Villemonte (1947) | $C_d = (1 - S^P)^{0.385}$ | P = 1.5 |
| Fritz and Hager (1998) | $C_d = \left(1 - \frac{\left(\frac{H_2}{H_0} - y_L\right)}{(1 - y_L)}\right)^{\frac{1}{n}}$ | Max limit: $y_L$ = 0.85, n = 7<br>Min limit: $y_L$ = 0.35, n = 4 |
| Azimi et al. (2014) | $C_d = \left(1 - \left(\frac{H_2}{H_0}\right)^m\right)^n$ | m = 10<br>n = 0.95 |
| Ali and Uijttewaal (2014) | $d_0^* - \left(d_1^* + \Delta^* + \alpha_1 \frac{1}{2d_1^{*2}}\right) d_0^{*2} + \frac{1}{2}\alpha_0 = 0$<br>$d_1^{*3} + 2\Delta^* d_1^{*2} + \left(\Delta^{*2} - d_2^{*2} - \beta_2 \frac{2}{d_2^*}\right) d_1^* + 2\beta_1 = 0$<br>$C_d = \frac{3q}{2 \cdot \sqrt{\frac{2}{3} g H_0^{\frac{3}{2}}}}$ | / |



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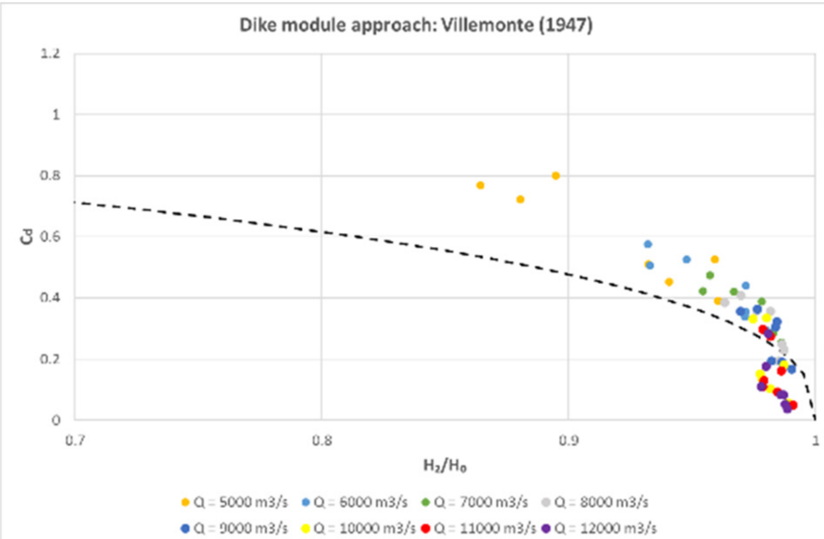
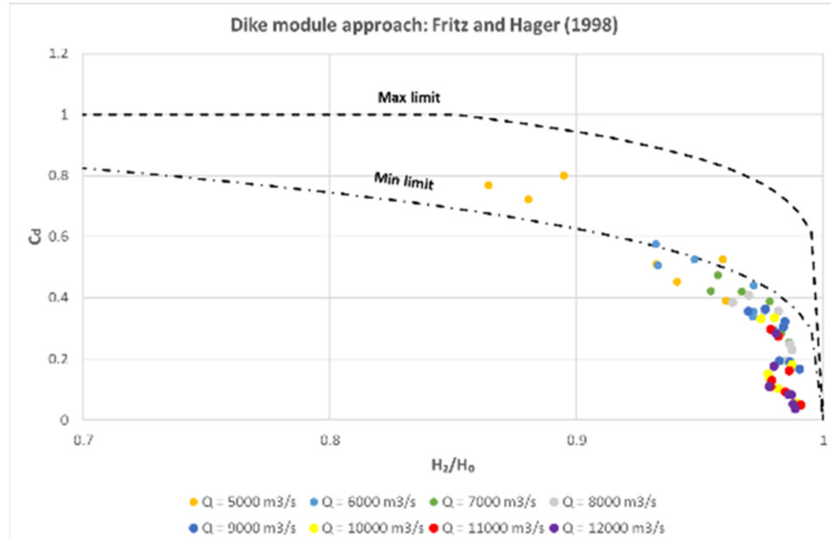
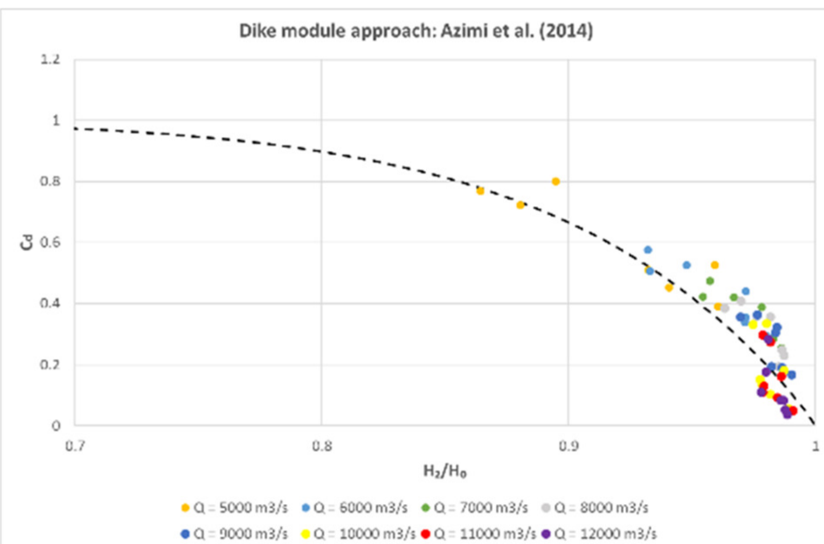
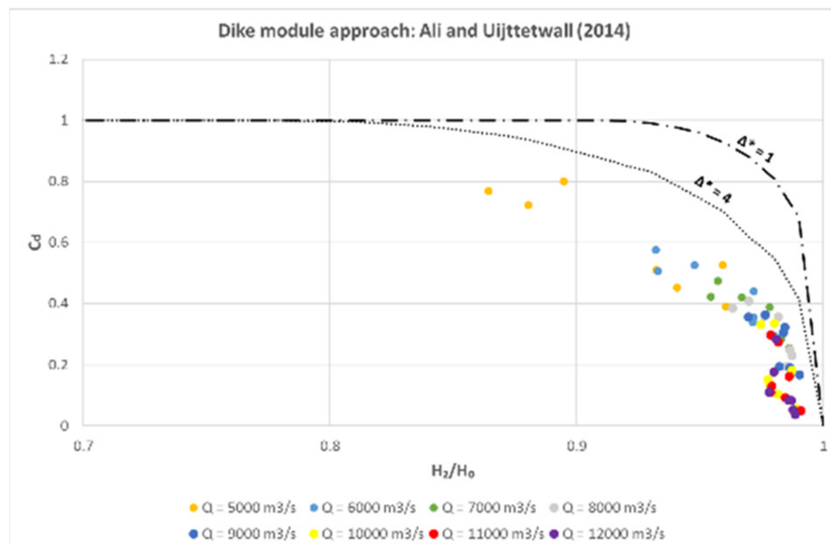
# Submerged weir discharge – dike module

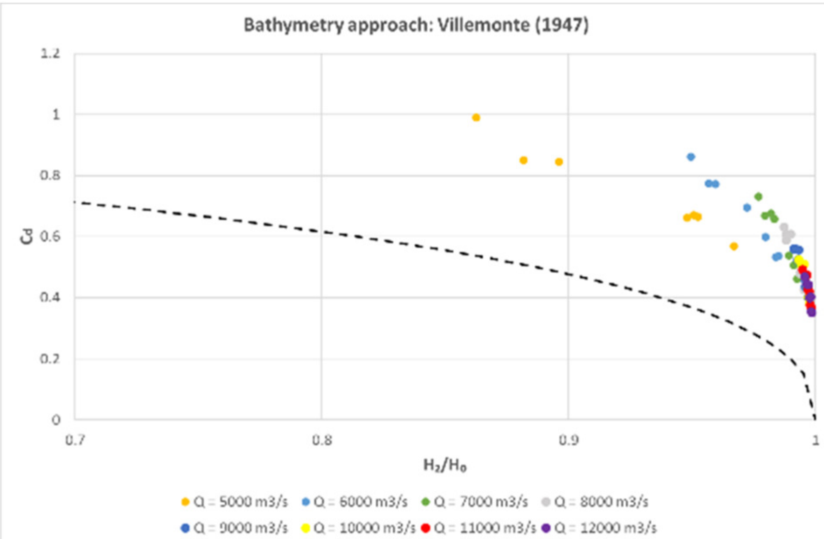


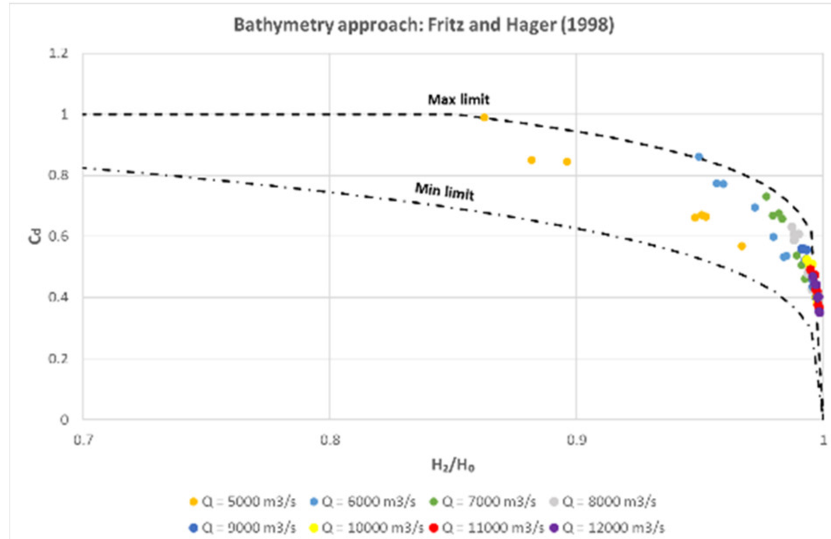



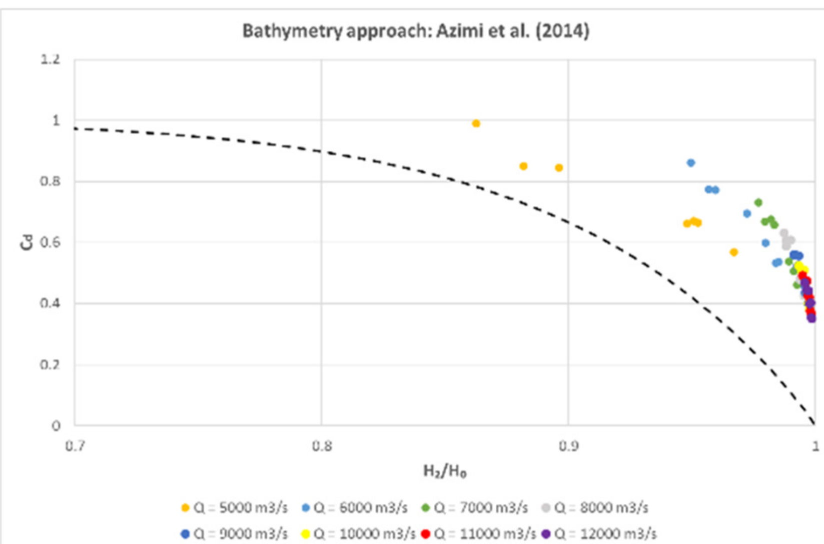



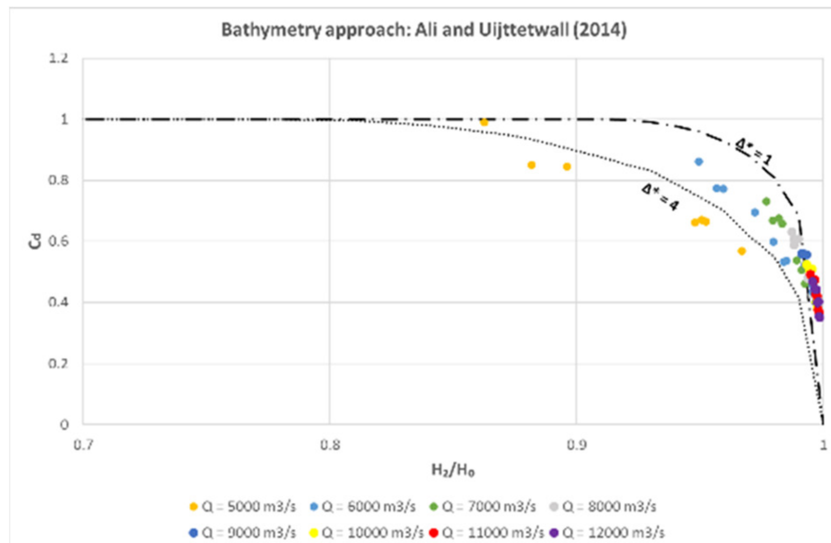



# Submerged weir discharge – bathymetry method



# ADCP velocity measurements – St. Louis Harbor





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# Summary

- MIKE 21 FM model has been used to assess the technical performance of the proposed navigation improvement solutions for the FAST Danube project
- modelling results are used in the options design process, environmental impact assessment and economic appraisal
- key elements: flexible mesh and parallel computing
- model clarity and simplicity → important for future knowledge transfer



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# Thank you

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