Bundesanstalt für Wasserbau
Federal Waterways Engineering and Research Institute

Advection and grid effects in river computations

Selling some errors

www.baw.de

Regina Patzwahl and Frank Platzek

12th UnTRIM User Workshop *Trento, May 19th, 2015*

Delft University of Technology

Deltares
Enabling Delta Life

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Numerical diffusion/dissipation in river computations

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Outline

- Background
- Aim
- Comparison of different:
  - Advection schemes
  - Grid structures
  - Resolutions
  - Time steps
- Conclusions and outlook

Background

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River flows; mostly governed by:

- Balance between bed friction and pressure gradient
- Local accelerations mostly due to topography (e.g. weirs, groynes, bed forms)

Background

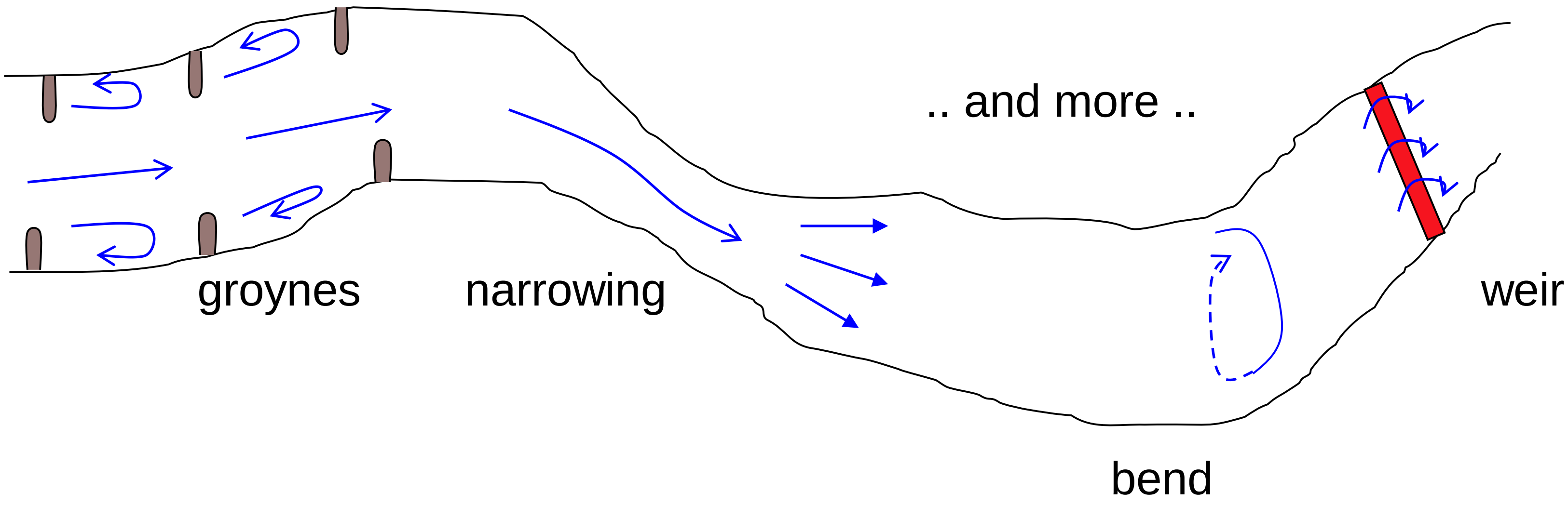
Effect of river training works, e.g.:

- modification of groynes
- parallel dams
- floodplain alterations

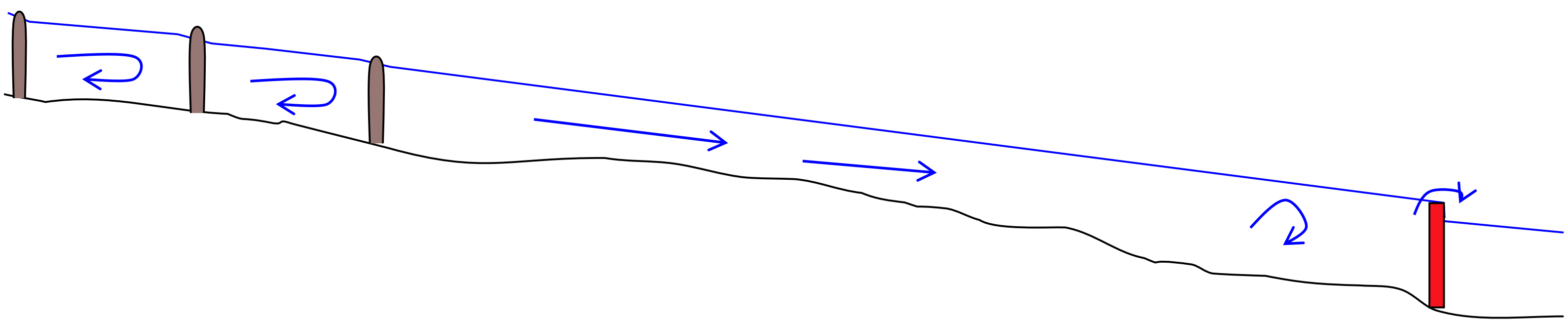
Commonly in *mm-dm* range

A schematic river

Topview of a river with

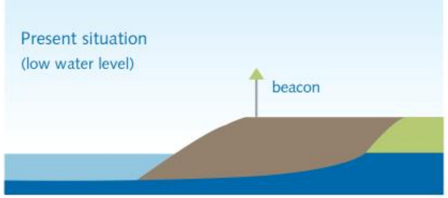


Sideview of the river

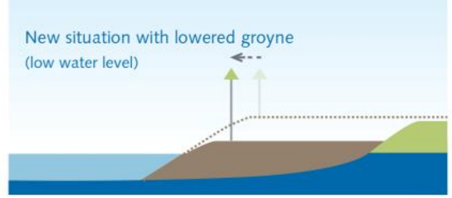


Groyne lowering and dams alongside the Waal River

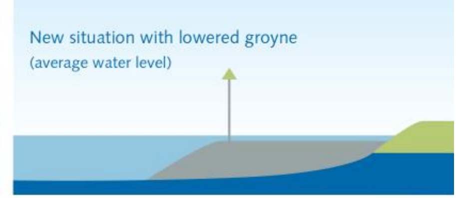
Between Gorinchem and Nijmegen 450 groynes will be lowered and partly replaced by dams alongside. At high tide, the Waal River is then able to flow more easily.



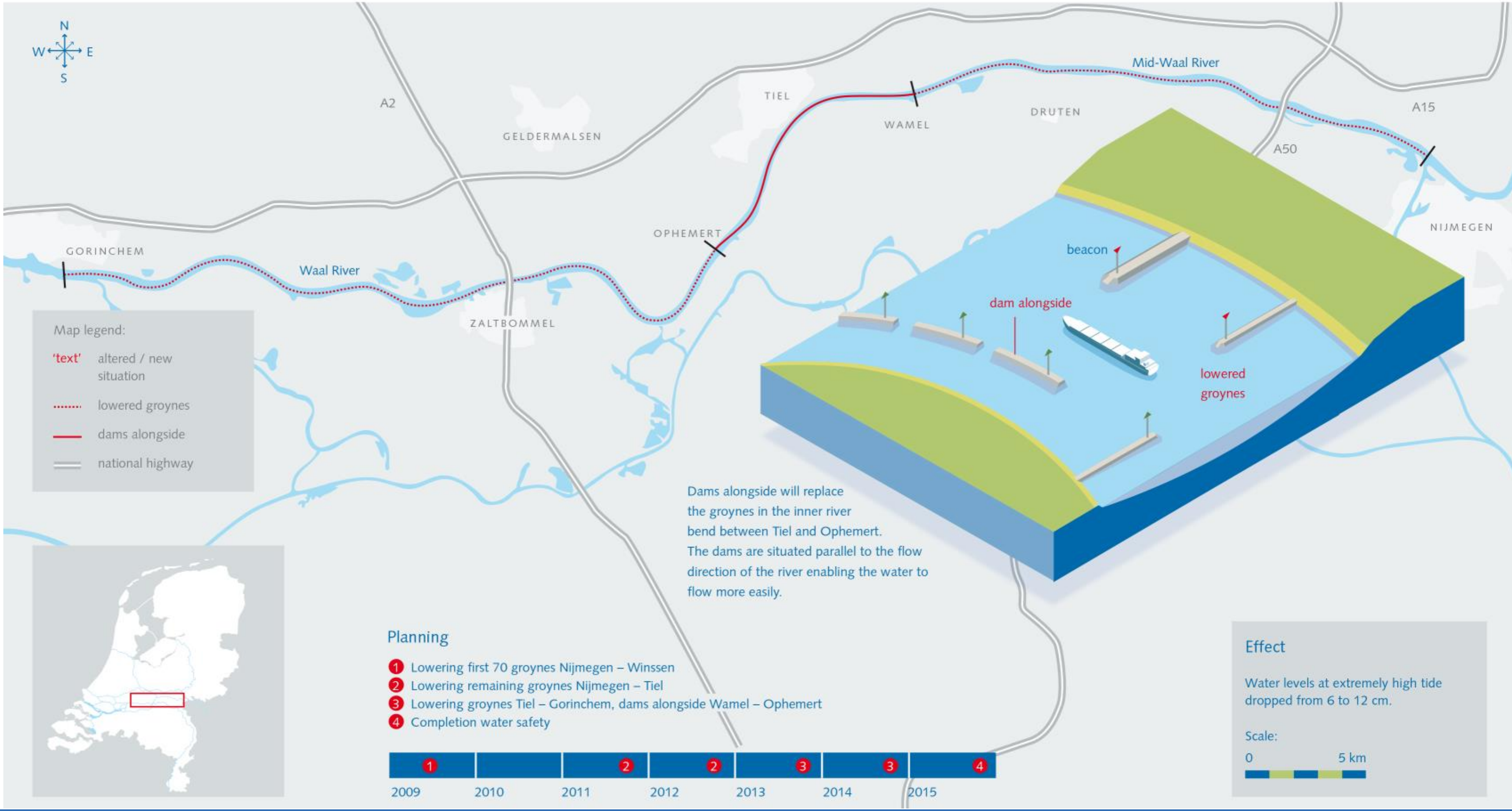
Groyne lowering Waal River (±1 m) will be applied over a distance of approx. 60 km between Gorinchem and Nijmegen.



Shipping beacons are on the groynes. These will be moved and extended.



This will keep the navigation channel visible during high water.



Common aim

Accurately predict the global backwater in rivers

Important for shipping (sufficient depth) and for flooding (limited depth)

So we need to capture both the global balance and the local energy losses, or:

Two key points in a numerical river model:

1. Accurate balance pressure gradient and bed friction
2. Capturing local energy losses, mostly due to topography (e.g. weirs, groynes, bed forms)

Our aim

However, are our approximations good enough to make such accurate predictions?

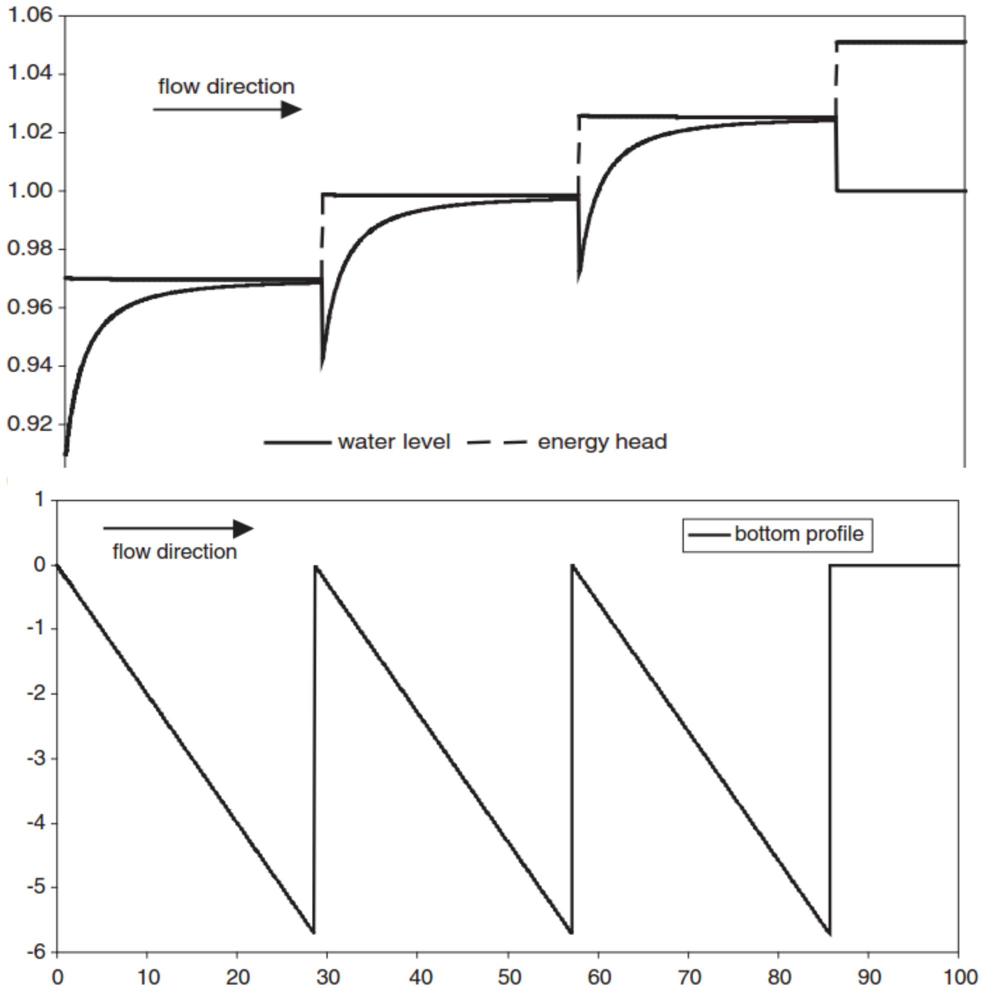
Additionally, can I modify my grid or time step after calibration, without being punished?

So we need:

Three key points in a numerical river model:

1. Accurate balance pressure gradient and bed friction
2. Capturing local energy losses, mostly due to topography (e.g. weirs, groynes, bed forms)
3. No/limited spurious energy losses/gains, or at least insight in these losses!

e.g. Stelling & Duinmeijer (2003)



Not treating the advection right under certain conditions?

A nice solution to the energy problem! ;)

Numerical diffusion?

When do we have numerical / dispersion / dissipation ?

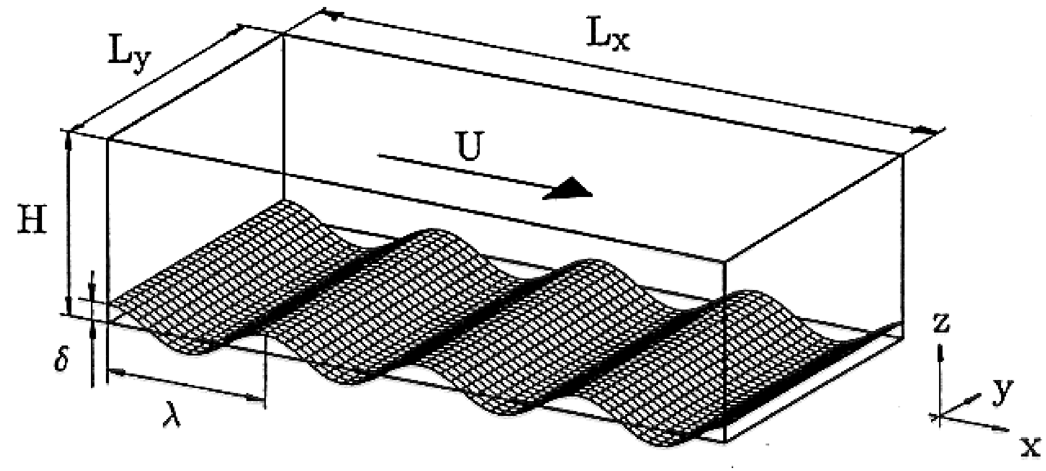
$$Diff: \quad C_1 \frac{d^2u}{dx^2}$$

$$Disp: \quad C_2 \frac{d^3u}{dx^3}$$

Diss: due to spatial variation of the above

Other flow situations?

Flow over bed forms →



← Flow over groynes

Energy losses?

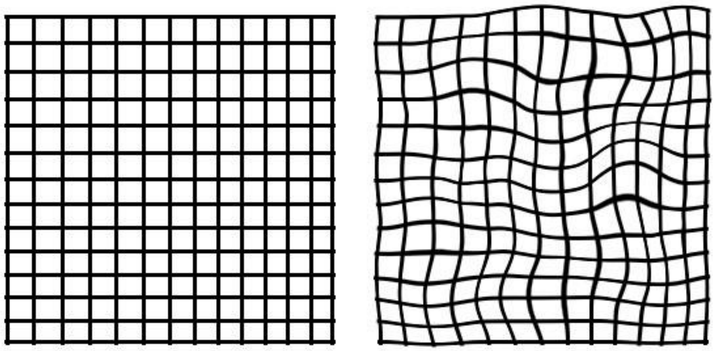
Approach

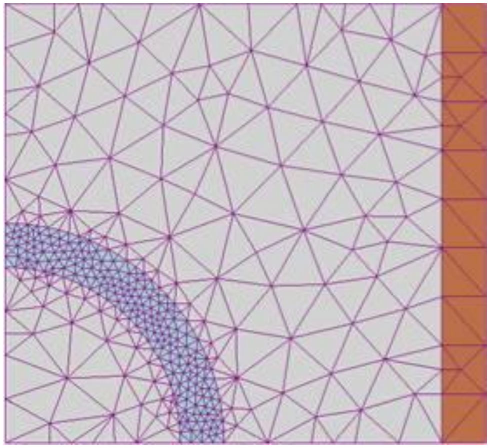
We investigate the backwater due to common obstacles in rivers

Physics: Energy losses due to:
- skin friction drag
- turbulent dissipation in expansions ("form drag")

= 0

Numerics: Errors due to:
- grid structure or irregularity
- discretization errors (e.g. in nonlinear advection)





Approach

So we investigate:

Inviscid flow over a wavy bottom (no energy losses)

Focus on the (numerical) backwater, as a function of the:

1. Grid structure (quads / triangles, regular/irregular)
2. Grid resolution
3. Advection scheme (different numerical models, with different schemes)
4. Time step

To see whether the effect of river training works can be accurately quantified!

Preliminary results only in 2D!

Inviscid flow over a wavy bottom

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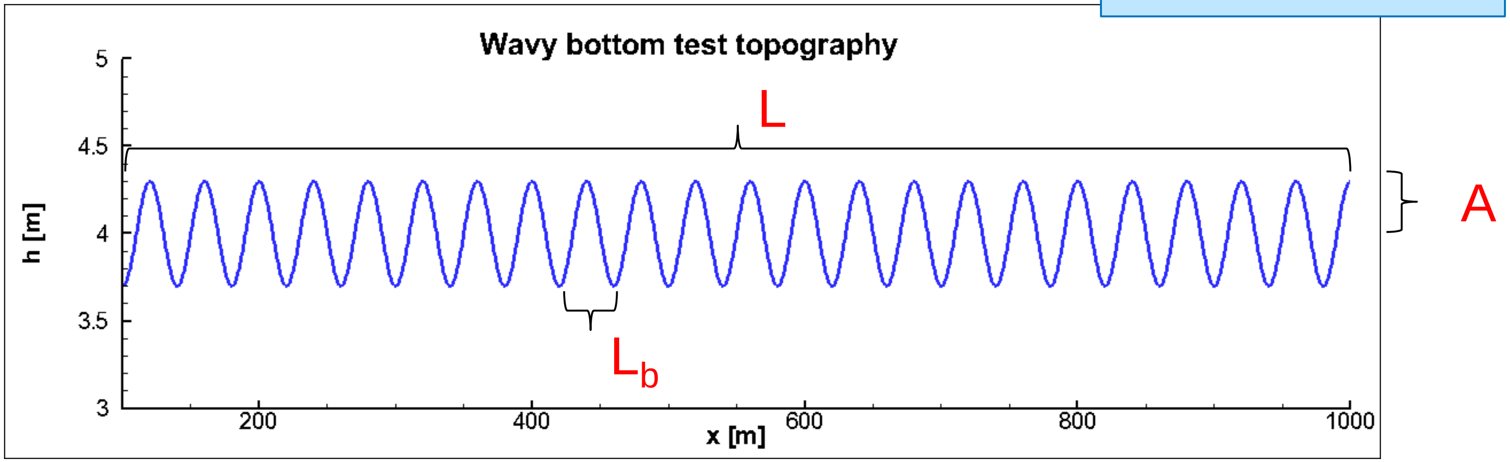
Straight channel

Length	L	= 1000	[m]	
Width	W	= 240	[m]	
Bottom wave length	L_b	= 40	[m]	
# of bed forms	n_b (L/L_b)	= 25	[-]	
Bottom level	h	$= 4 + 0.3 \sin(2\pi n_b/L - \pi/2)$	[m]	(amplitude A = 0.3 m)
Total water depth	H	~ 4	[m]	
Discharge	Q	= 960	[m^3/s]	
Velocity	U	~ 1	[m/s]	(Fr ~ 0.16)
Friction coefficient	c_f	= 0	[-]	

Low-land rivers



Inviscid flow over a wavy bottom

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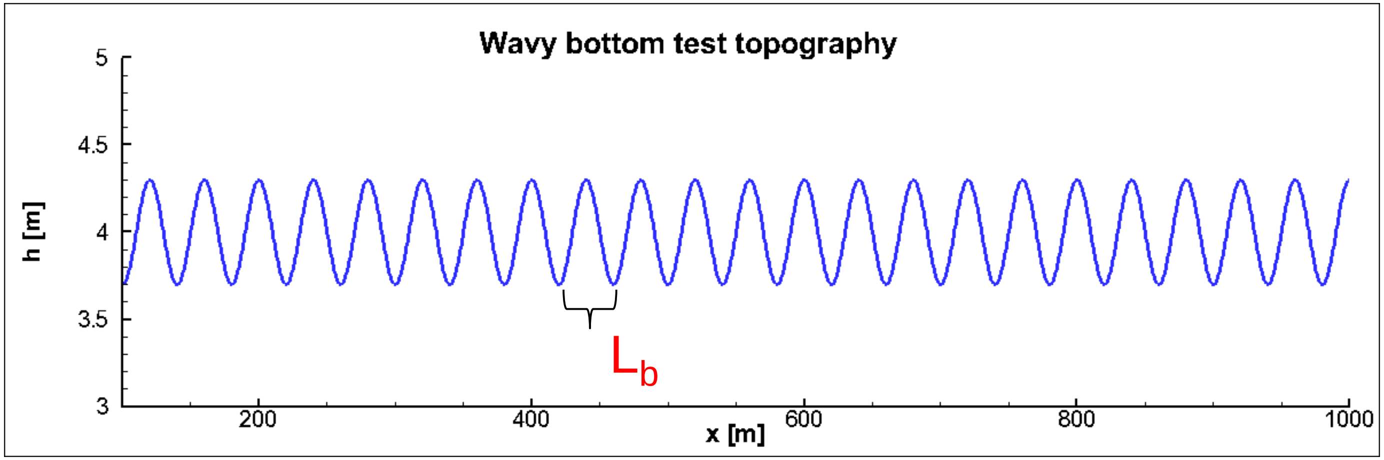
*** 5 Different advection schemes
(from 3 different numerical models, that like to remain anonymous)

*** 4 Different grid structures:
- Regular / Irregular quads
- Regular / Irregular triangles

*** 3 Different grid resolutions
Dx ~ L_b / 4, L_b / 8, L_b / 16
(10 m) (5 m) (2.5 m)

*** 3 Different time steps / Courant numbers
C ~ 0.3, 1, 3
(C > 1 only for those schemes that remain stable)

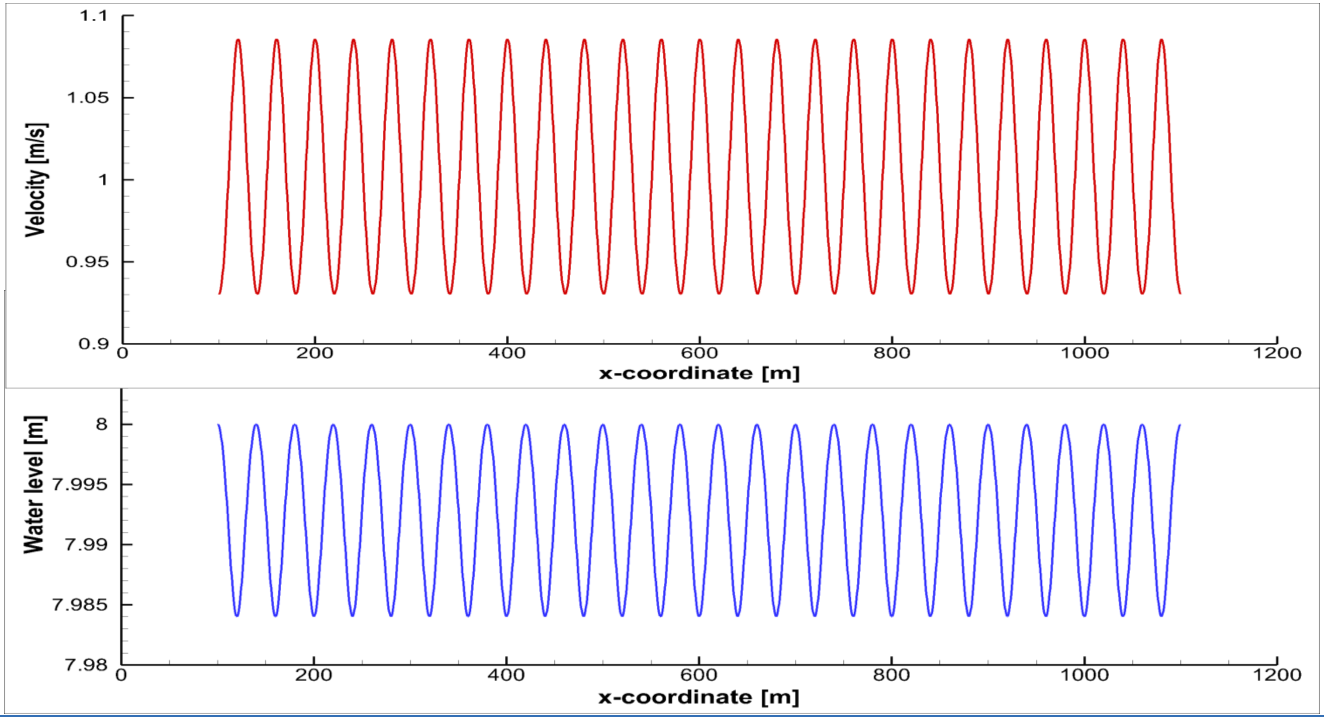


Inviscid flow over a wavy bottom

Analytical solution from 1D stationary continuity and momentum conservation:

$$hu = \frac{Q}{B}$$

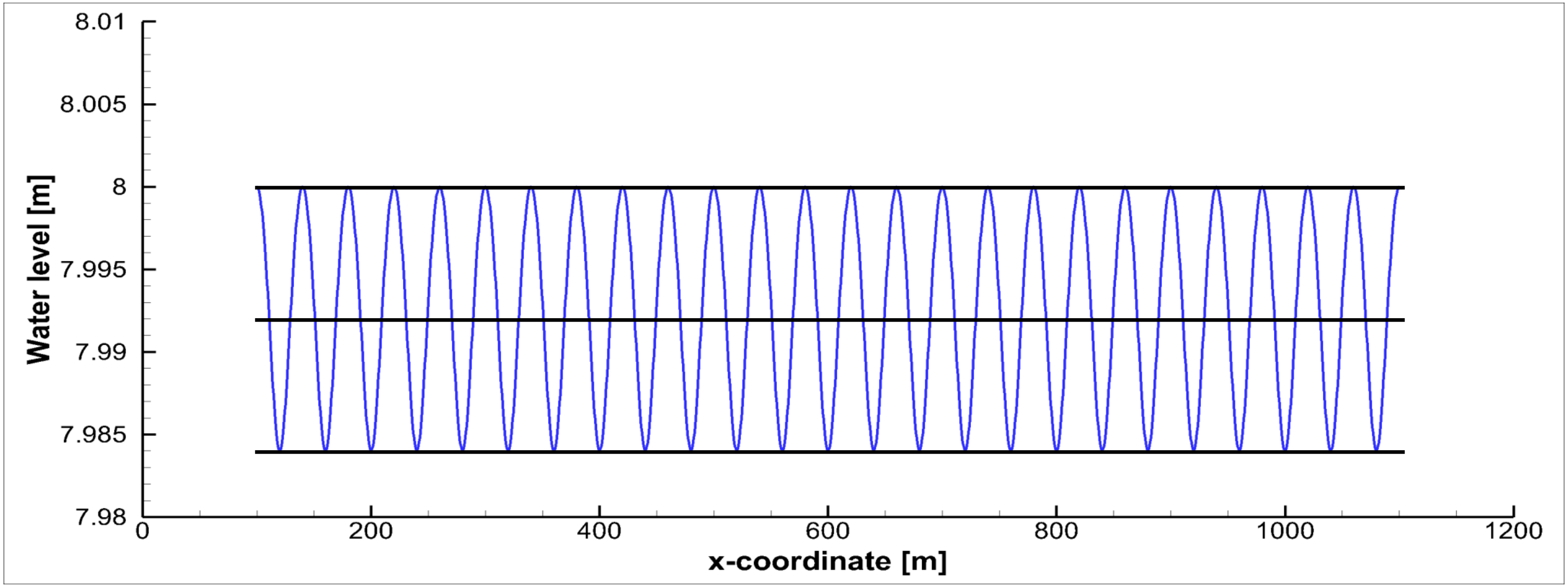
$$\frac{u}{2g} + \zeta = H^e$$



Inviscid flow over a wavy bottom

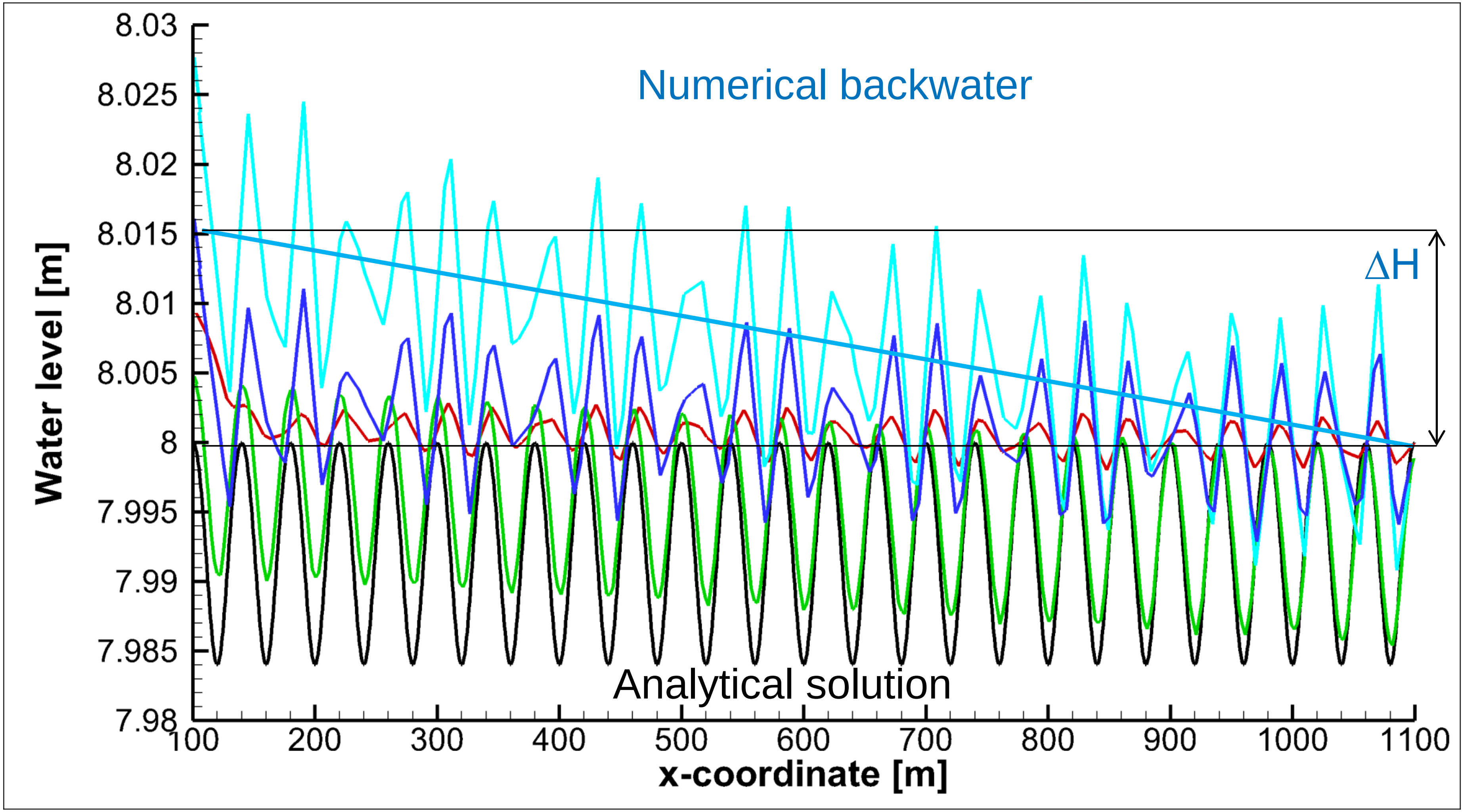
The solution oscillates (with the sinusoidal topography),

but no backwater is generated (which is correct) !



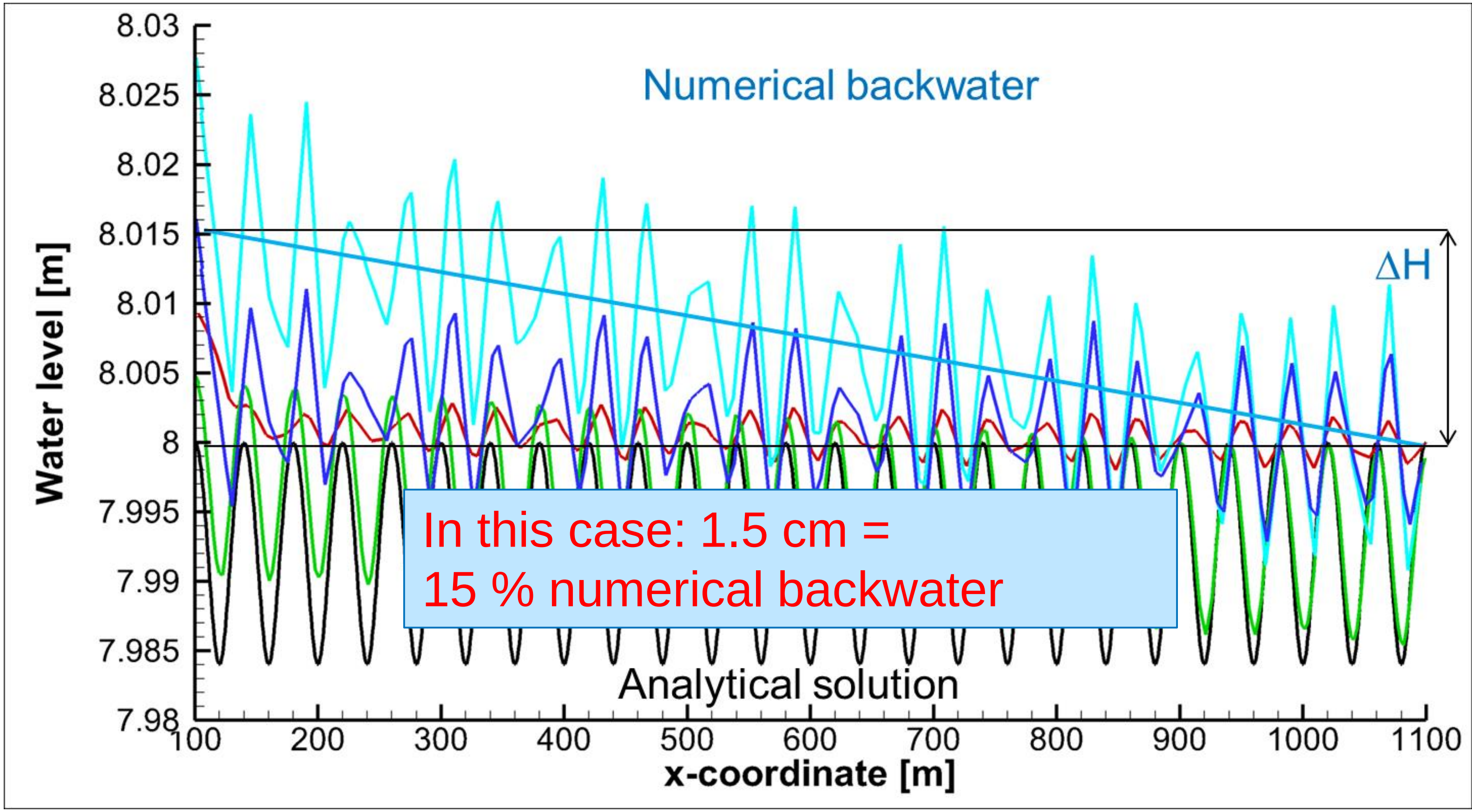
Can our models reproduce this?

Results



Numerical backwater
ΔH
Analytical solution
Water level [m]
x-coordinate [m]
8.03
8.025
8.02
8.015
8.01
8.005
8
7.995
7.99
7.985
7.98
100
200
300
400
500
600
700
800
900
1000
1100

Results

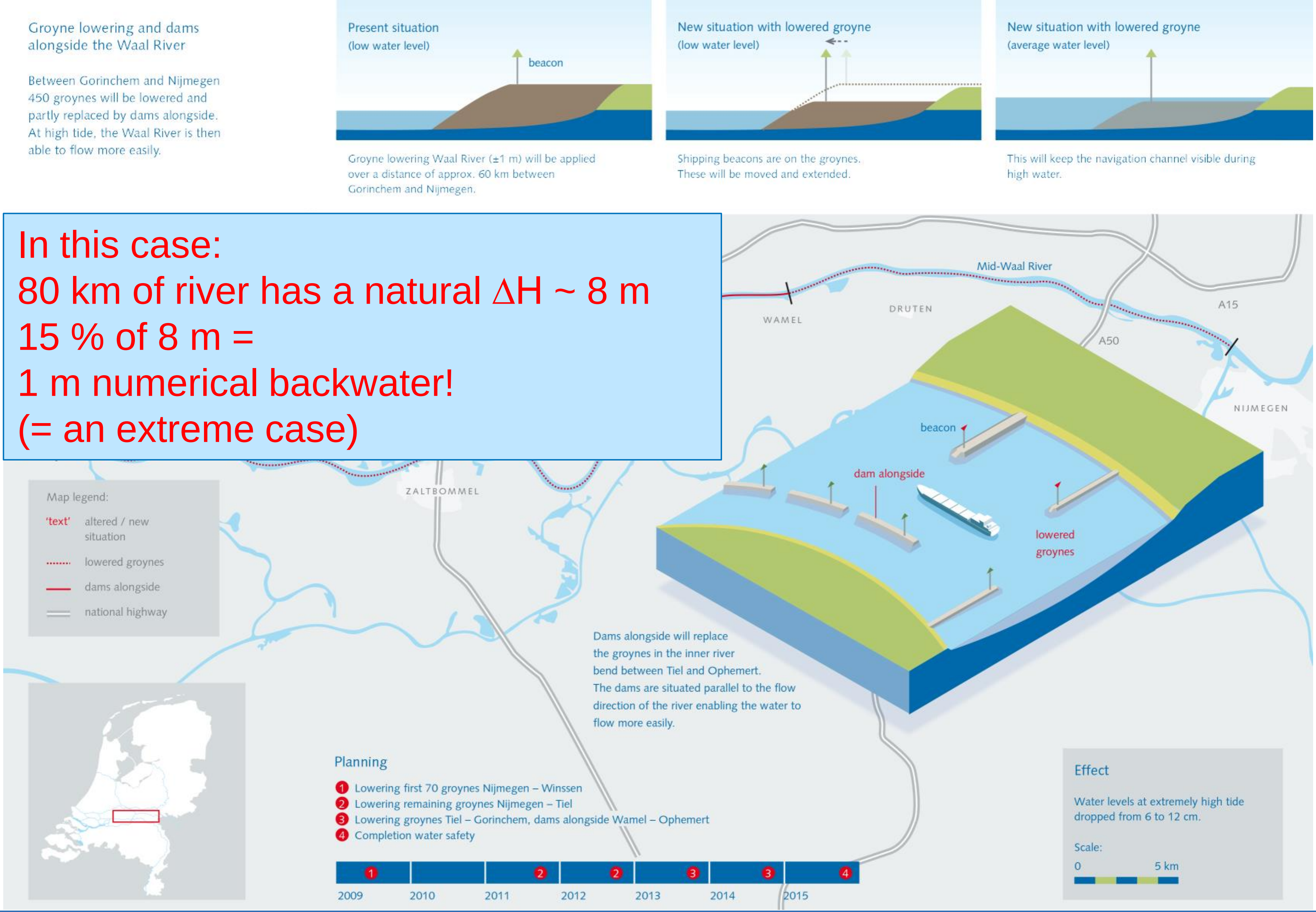


Numerical backwater ΔH for a L = 1000 m channel
with 25 bed forms (A = 0.3 m)

Comparing $\Delta H/L$ with a common channel/river slope i_b = 10-4:

→ Percentual backwater of $\Delta H_{\%} = \Delta H / (L*i_b) * 100$

In this case:
80 km of river has a natural $\Delta H \sim 8$ m
15 % of 8 m =
1 m numerical backwater!
(= an extreme case)



Results

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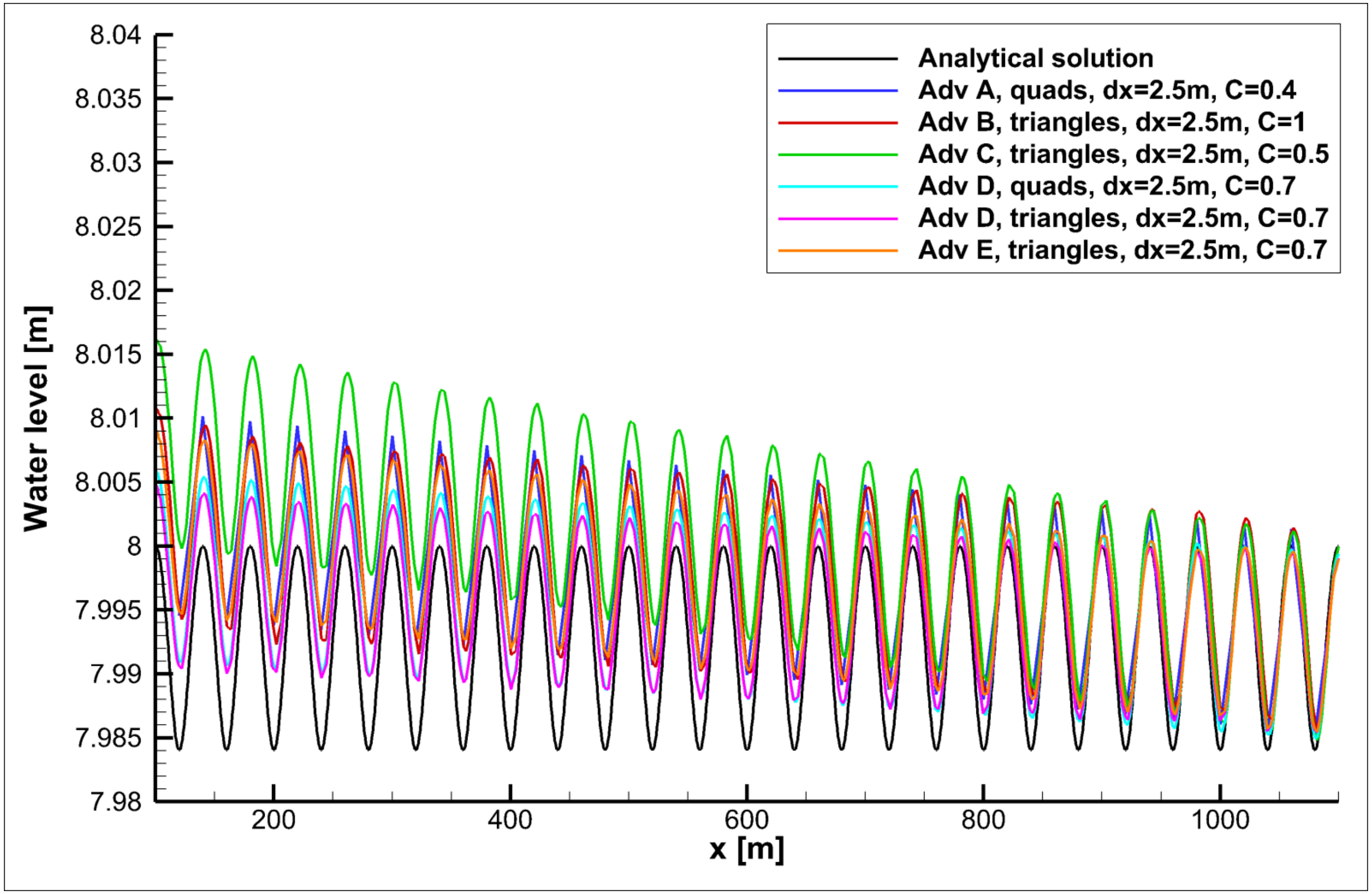
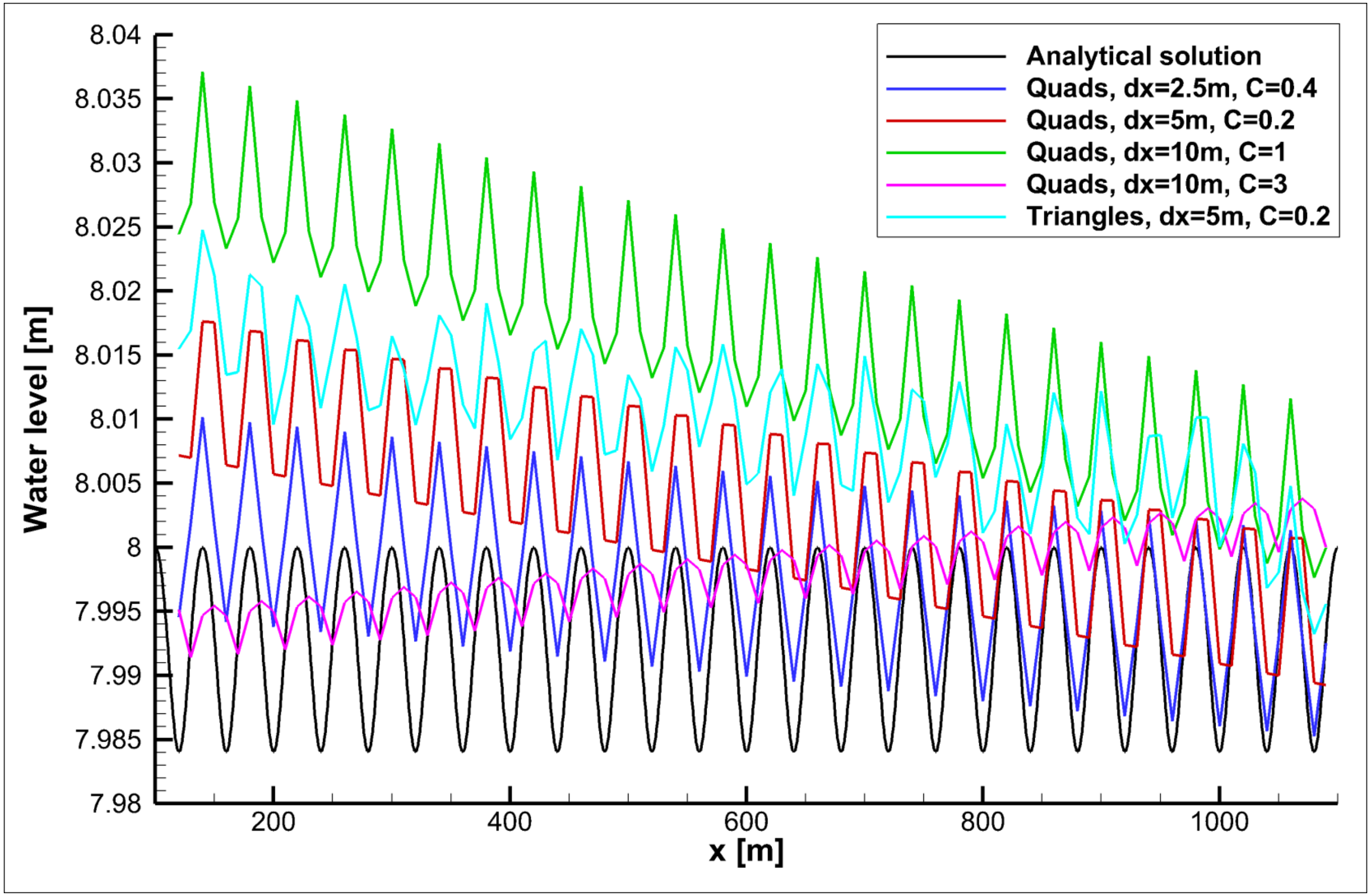
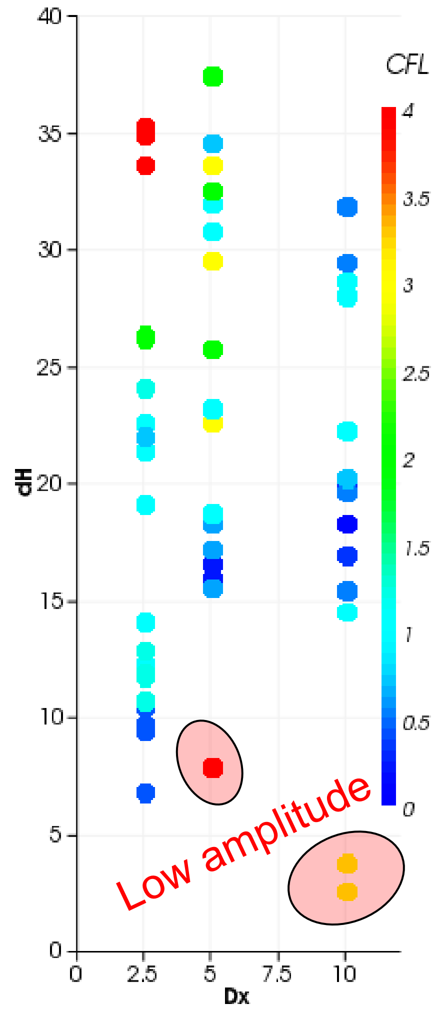
Effect of the advection scheme:



Results

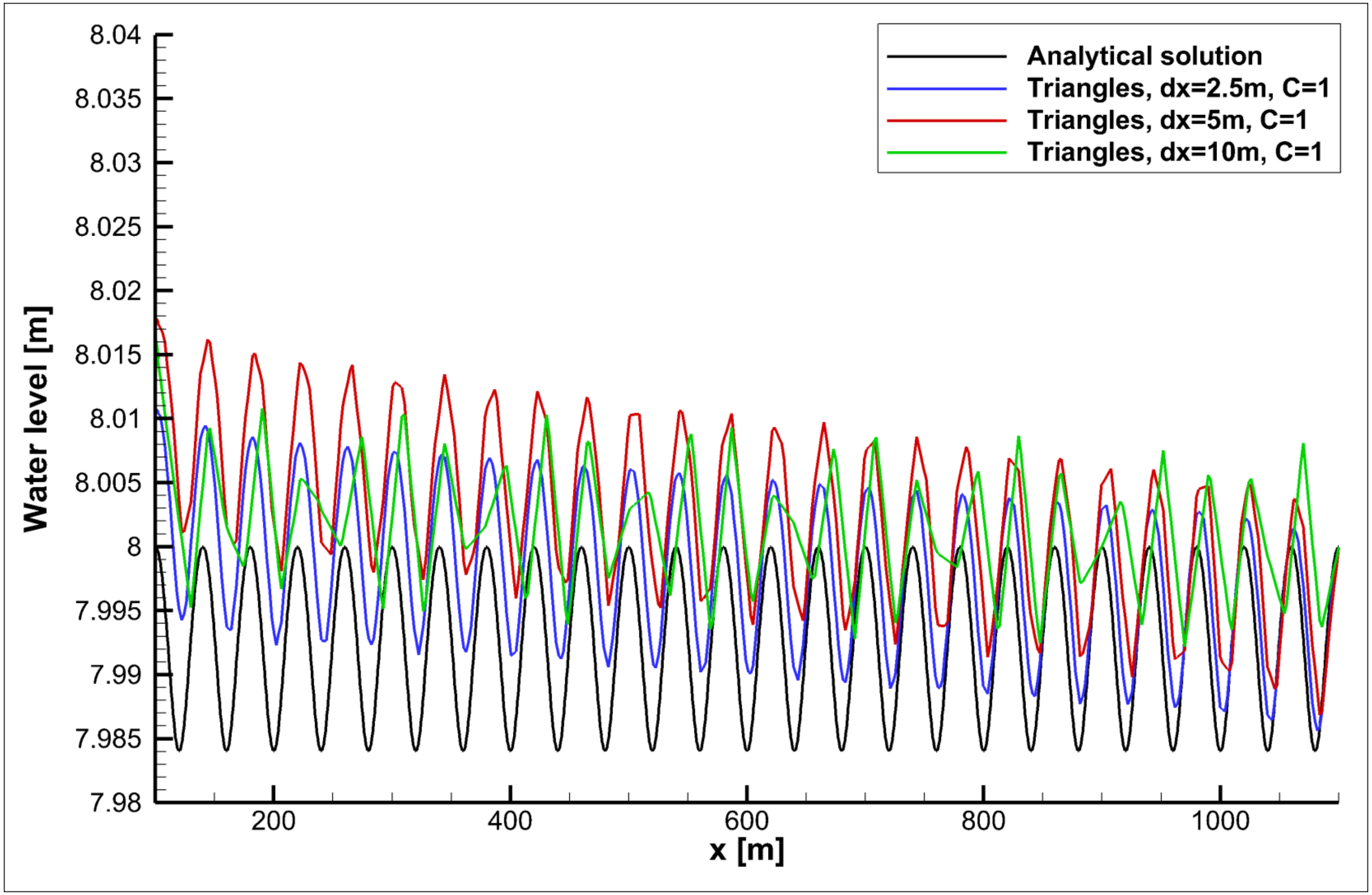
Effect of the grid resolution for advection scheme A (semi-Lagrangian):

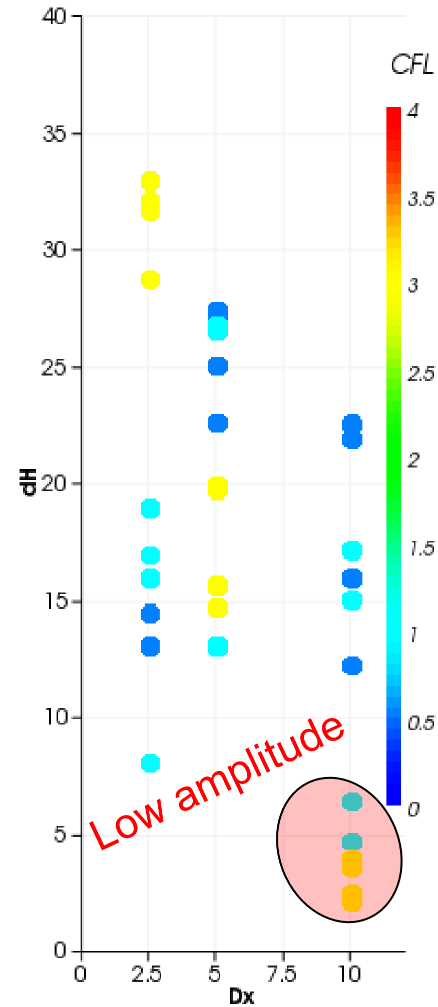




Results

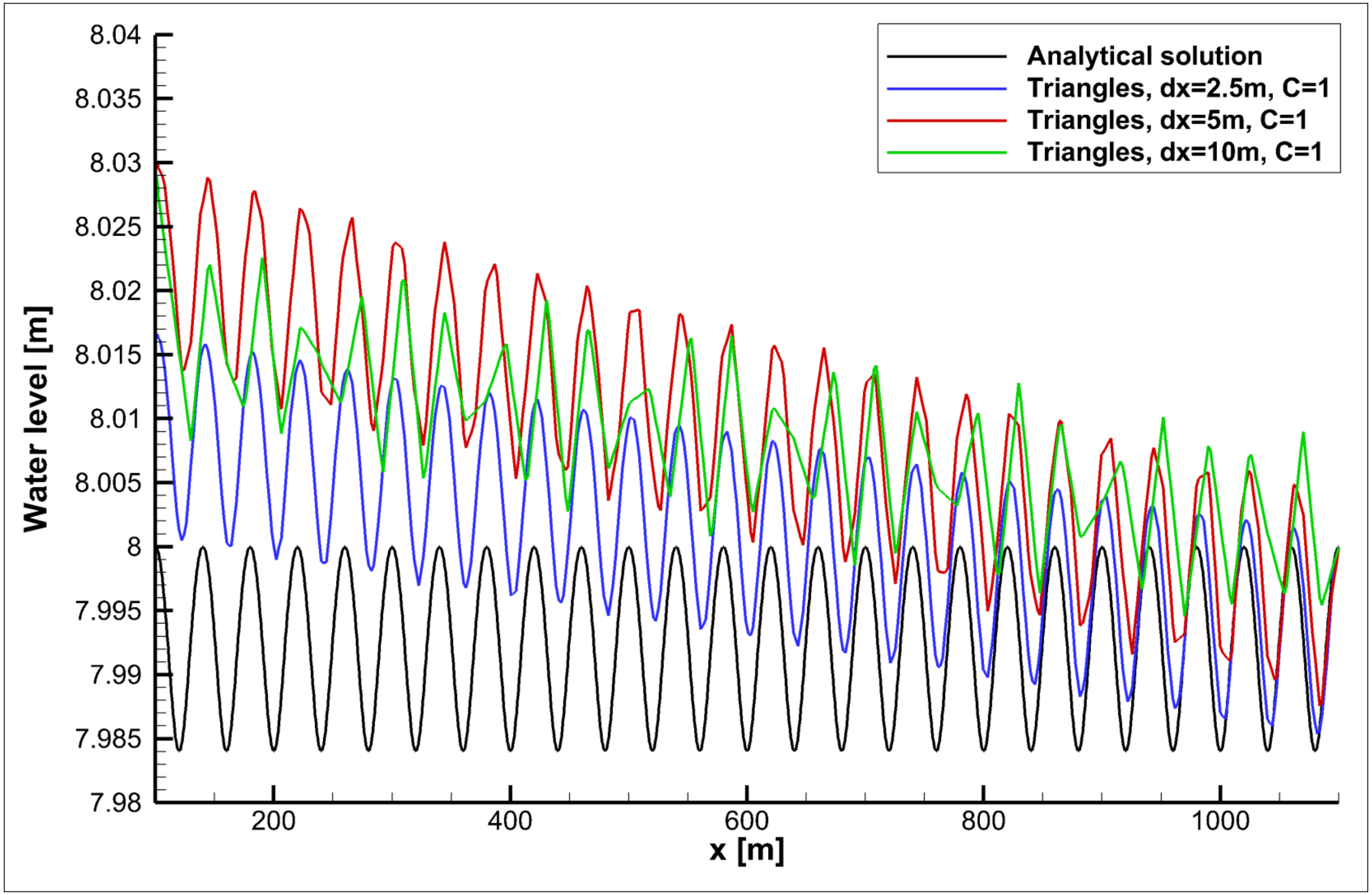
Effect of the grid resolution for advection scheme B (semi-Lagrangian):

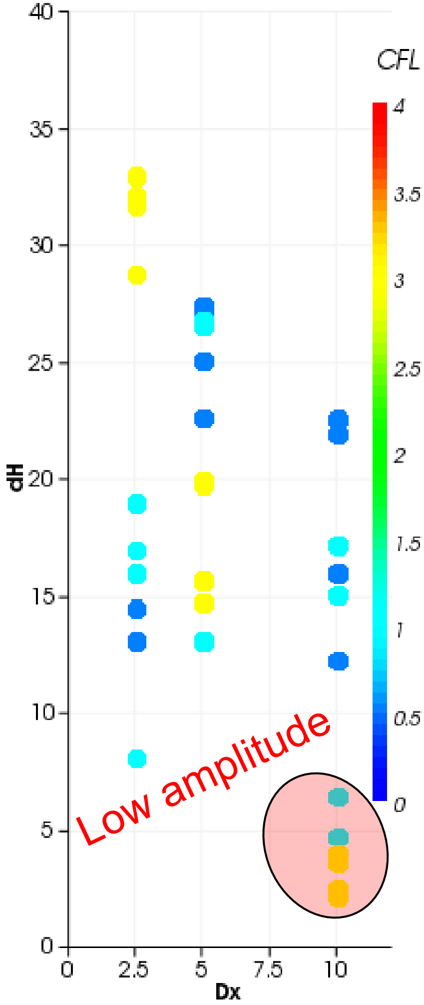




Results

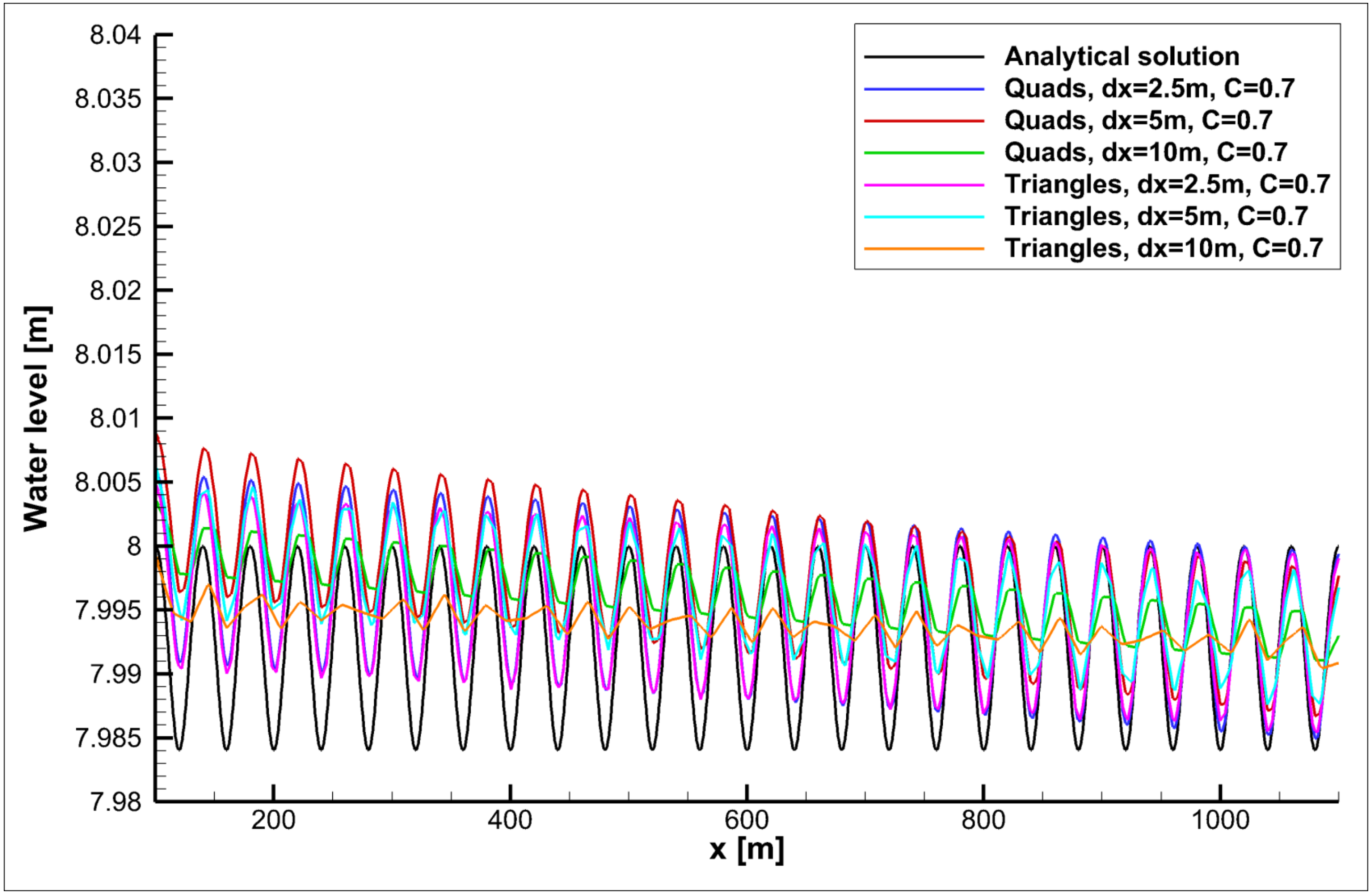
Effect of the grid resolution for advection scheme C (multi-directional upwind):

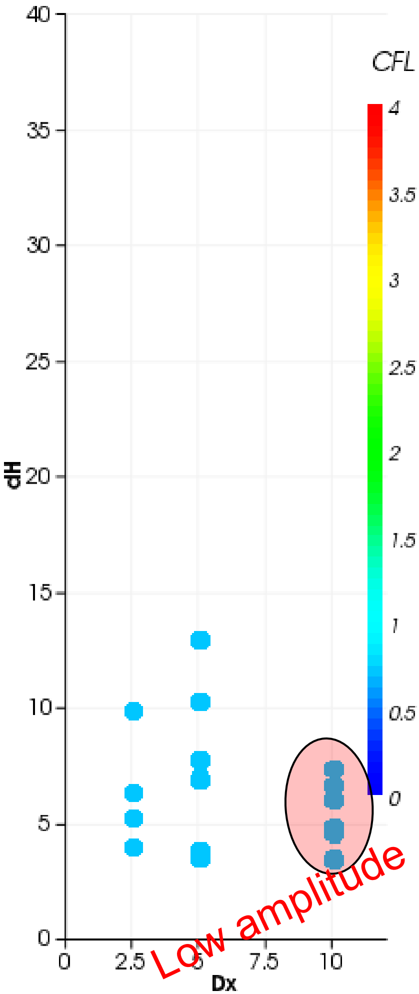




Results

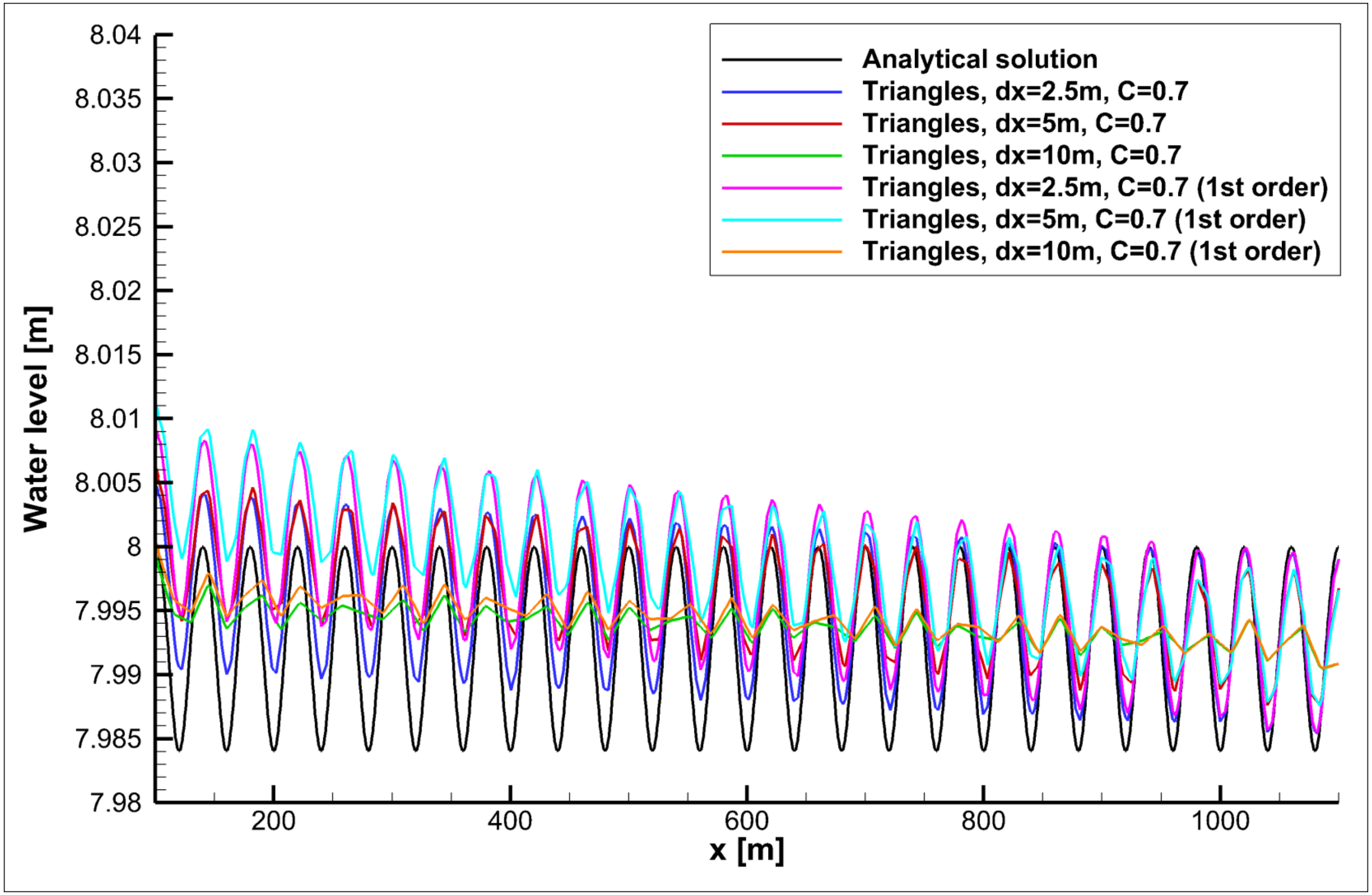
Effect of the grid resolution for advection scheme D ("momentum-conservative, 2nd order accurate"):

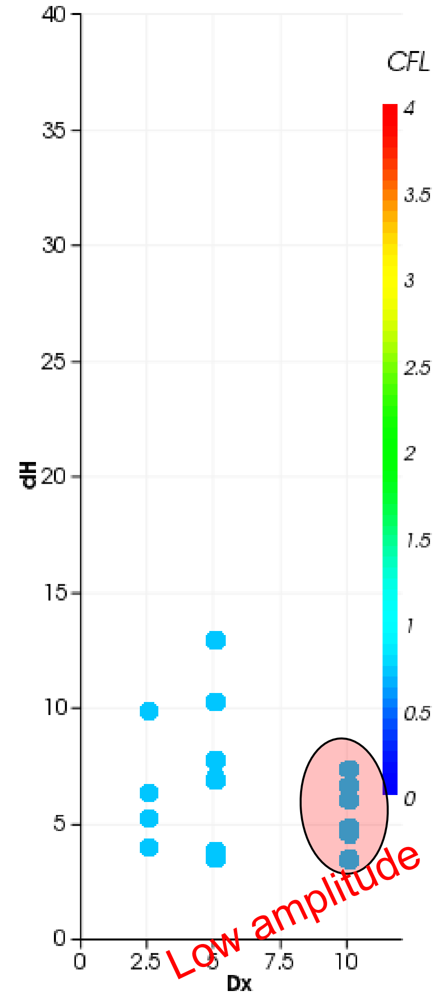




Results

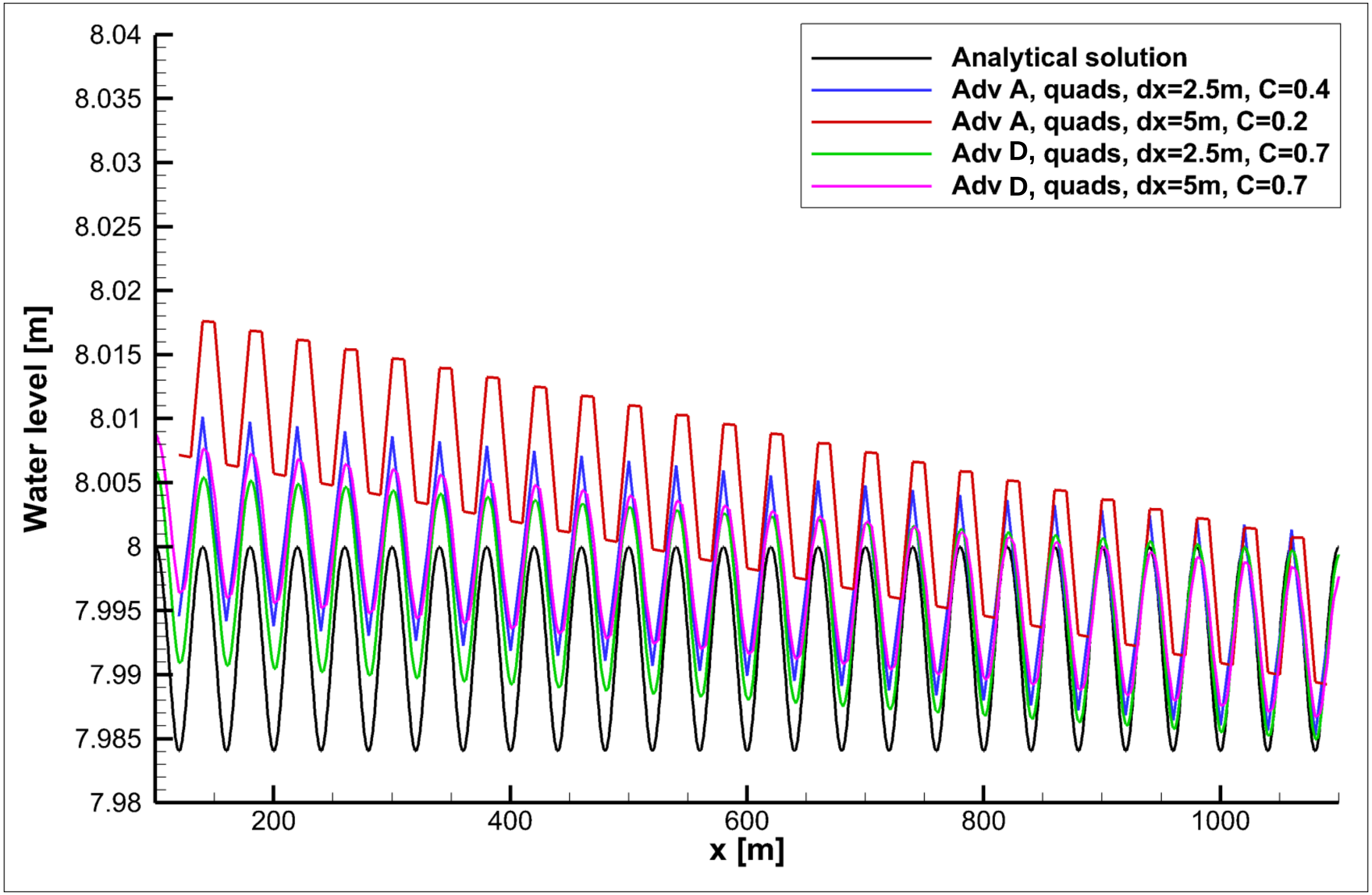
Effect of the grid resolution for advection schemes D and E
(“momentum-conservative, 2nd and 1st order accurate”):





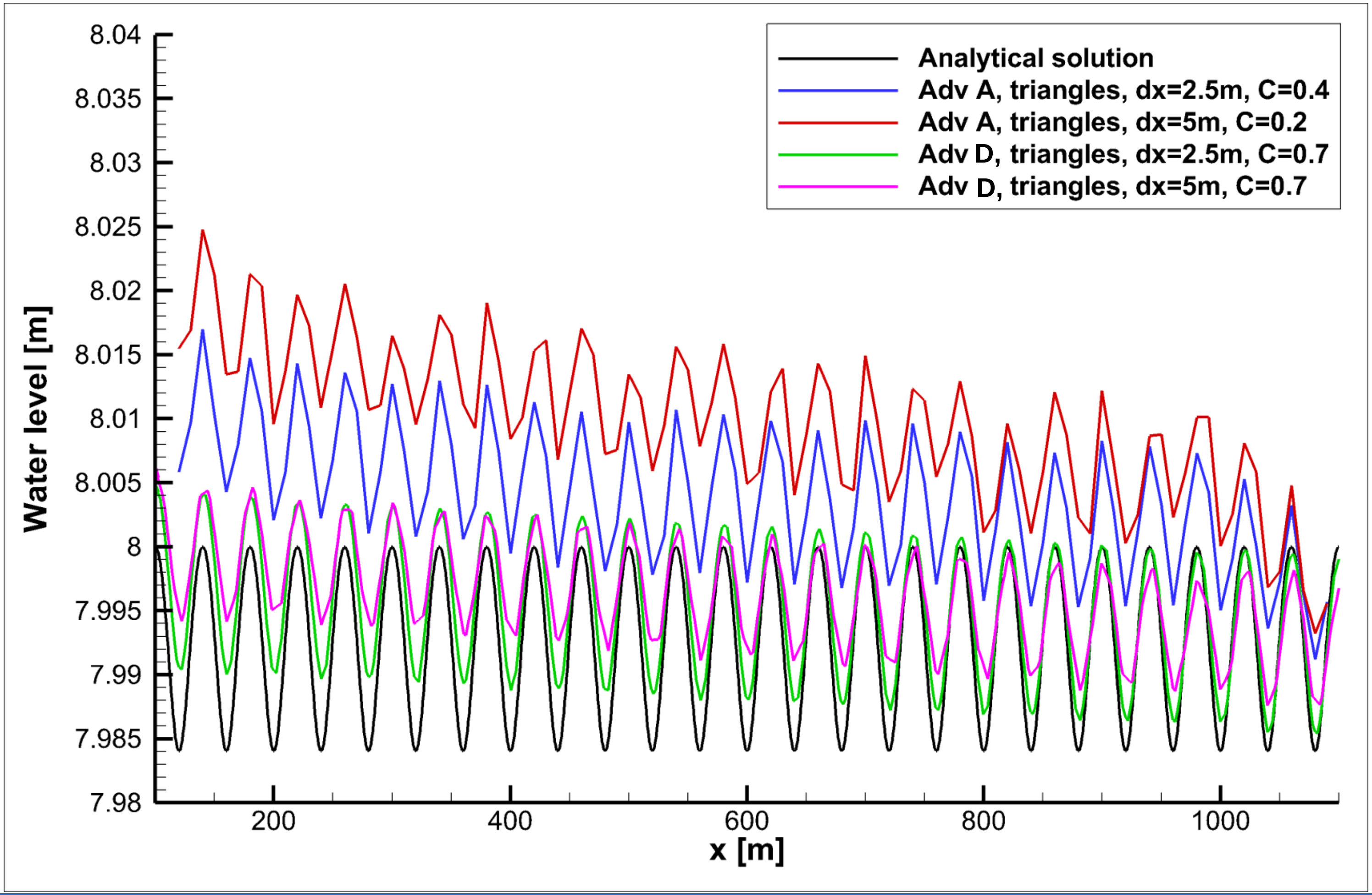
Results

Effect of the grid structure (advection schemes A and D):



Results

Effect of the grid structure (advection schemes A and D):



Results

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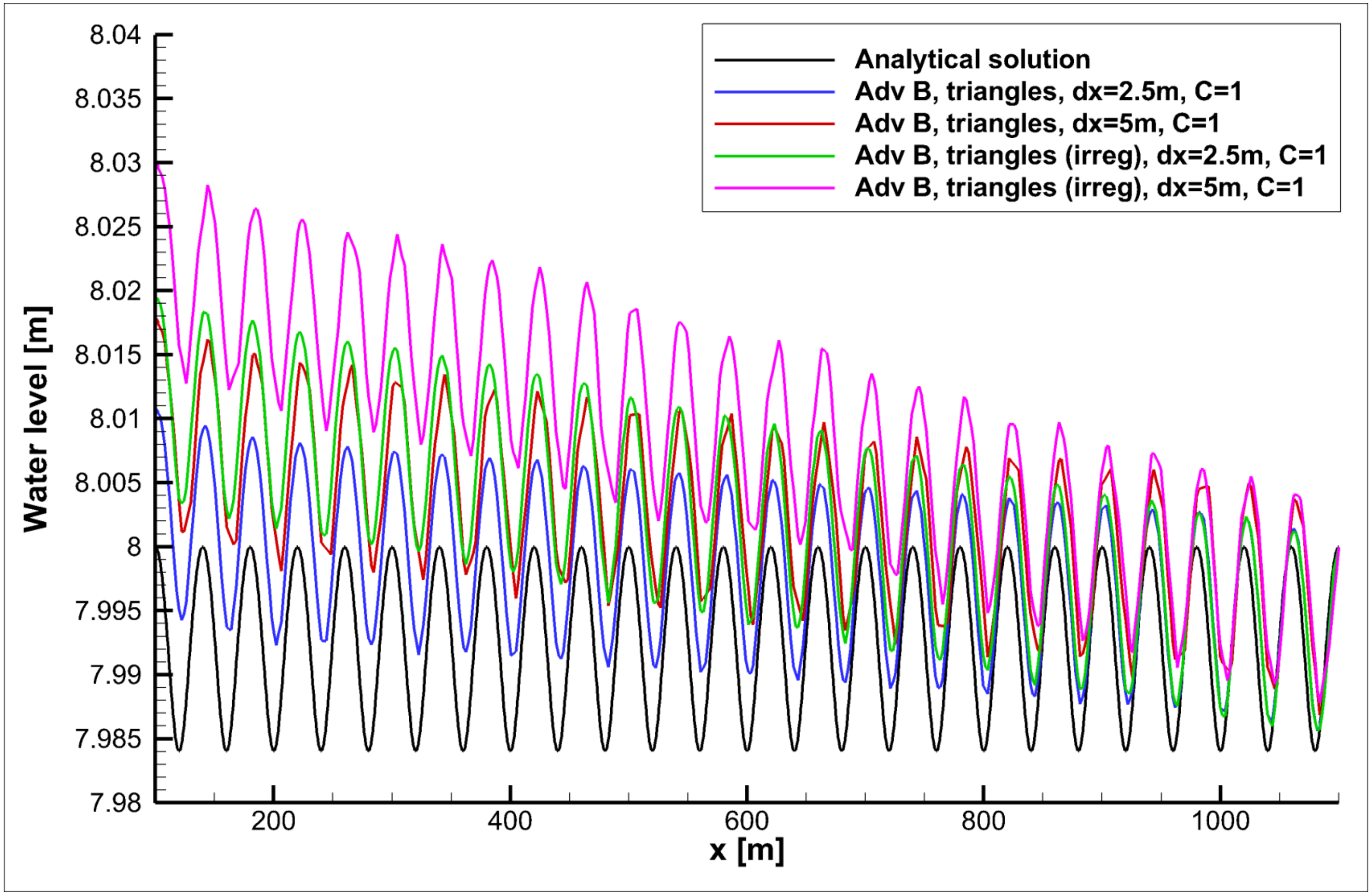
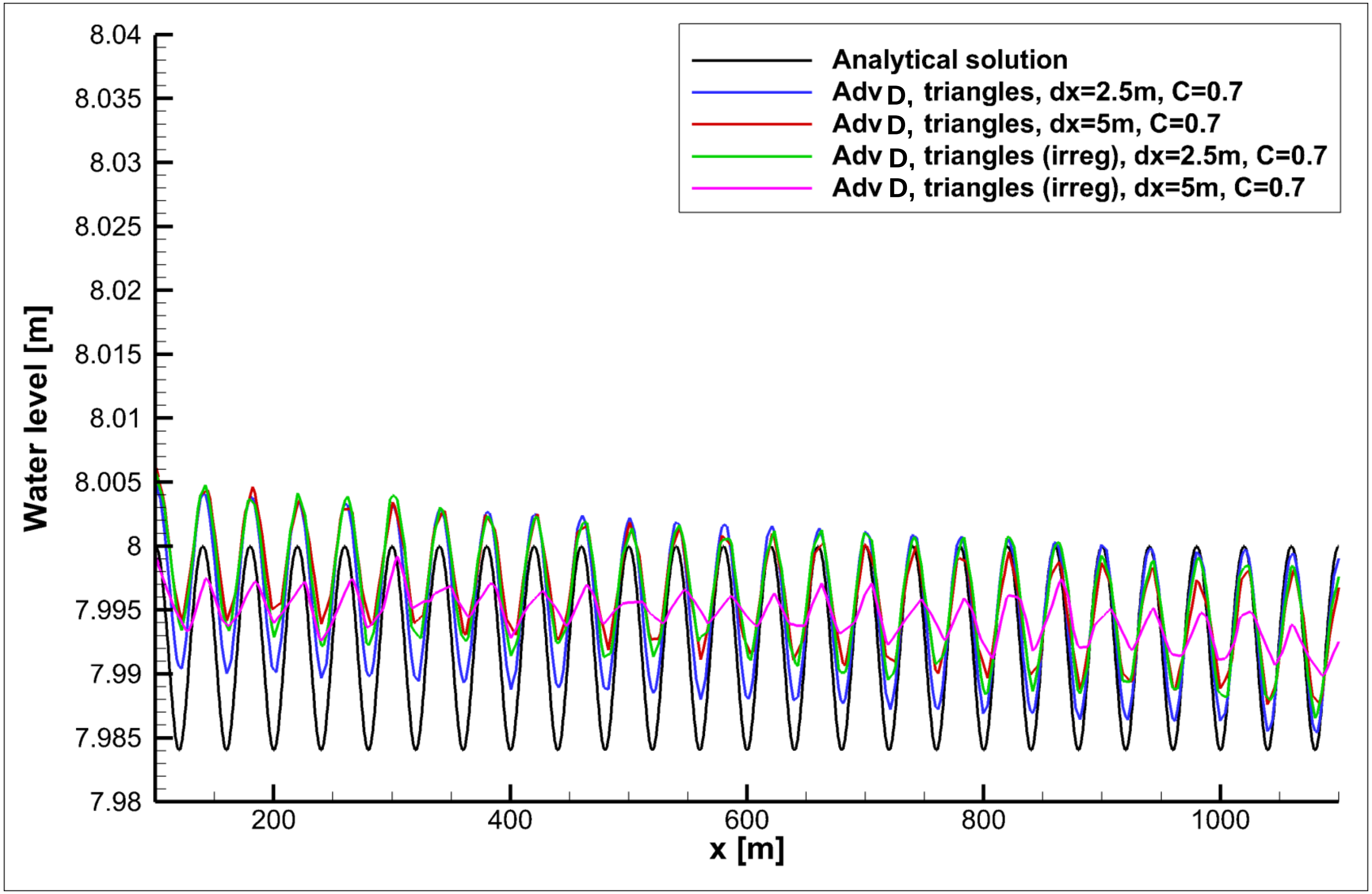
Effect of the grid regularity (advection scheme B):



Results

Effect of the grid regularity (advection scheme D):



Results

Tests using subgrid method:

Effect of subgrid was found to be very limited for this test

(no bottom friction, but improved volumes and cross-sections…)

Requires some more investigation

Summary

1) Coarse grid computations may show different dependence on grid structure, advection scheme and time step, than fine grid computations.

2) The type of advection scheme may strongly affect the numerical backwater

2) (Near-)momentum conservative schemes provide less numerical backwater

4) Quadrilateral grids show slightly less numerical backwater than triangular grids (except for advection scheme A, but the triangular grids results were not stationary)

5) Grid irregularity introduces some numerical backwater but not very significant

Next steps

1) Get the triangular grid computations using advection scheme 1 stationary

2) Analyze the schemes for the origin of the numerical backwater (and the differences)
   e.g. effect of bottom discretization is unknown

2) Test the effect of:
- local grid refinements
- quad / triangle transitions

3) Test for larger Froude number

4) Tests in 3D (σ- and z-layers)

5) Further test the effect of subgrid

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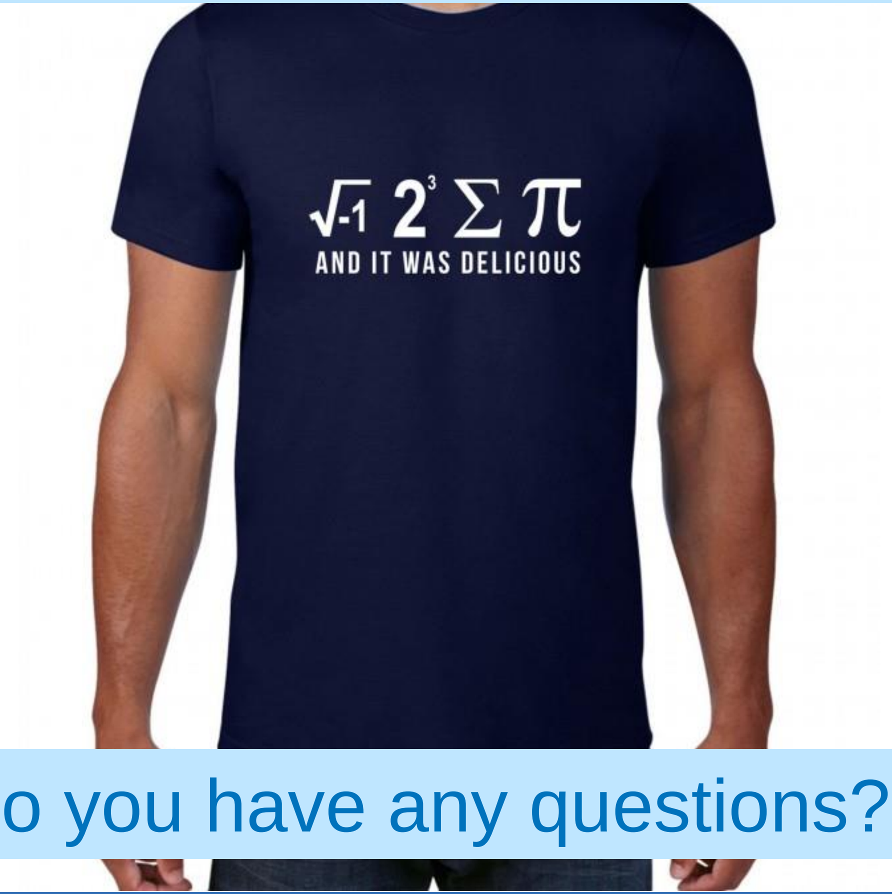
Thank you for your attention!



Do you have any questions?