Updating the Coupling Algorithm in 'HYDRUS Package for MODFLOW'

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Guided by

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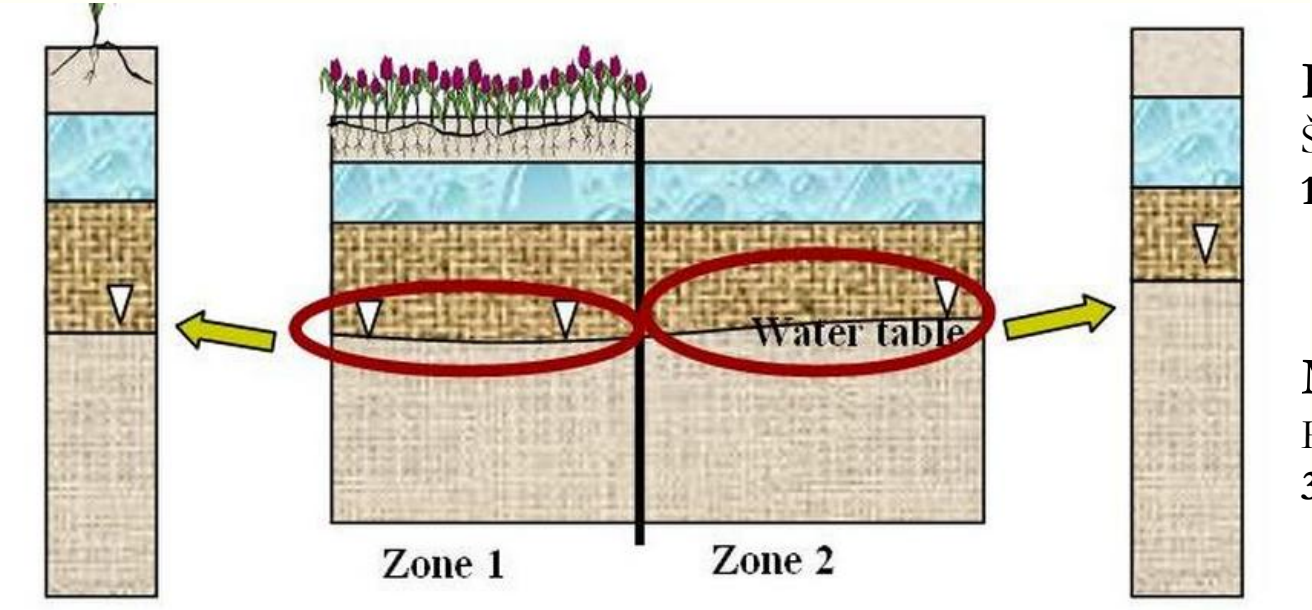
Introduction:
HYDRUS Package for MODFLOW (HPM)

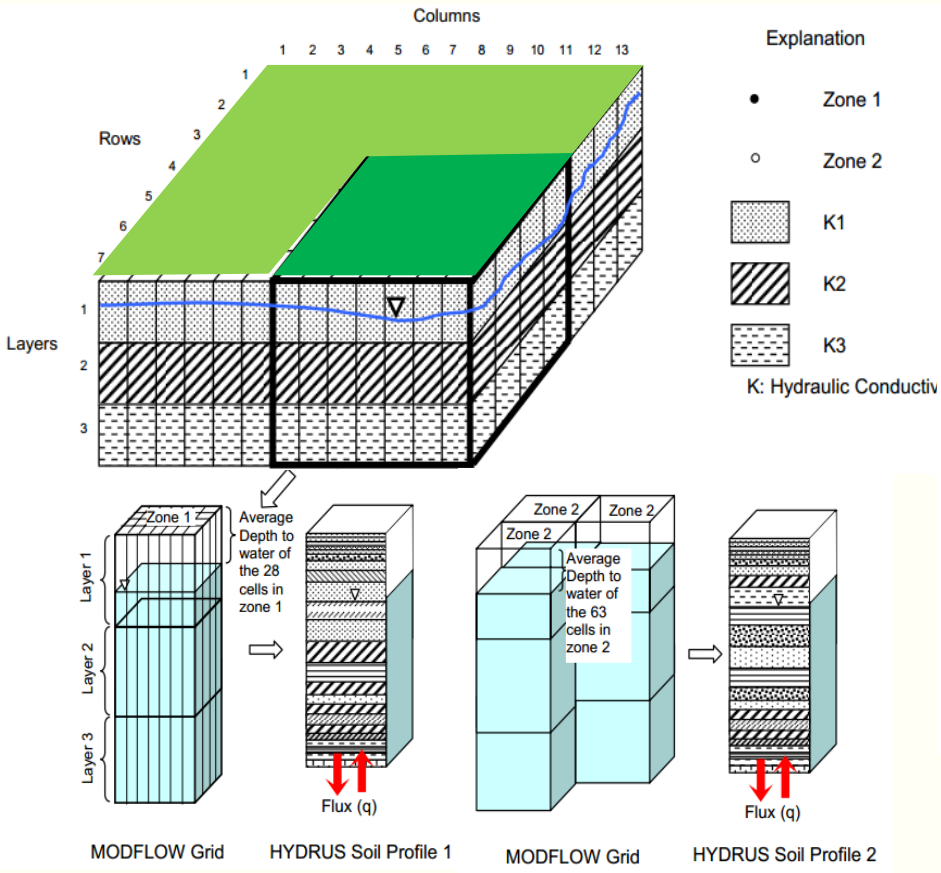
- Seo et al. (2007) and Twarakavi et al. (2008)

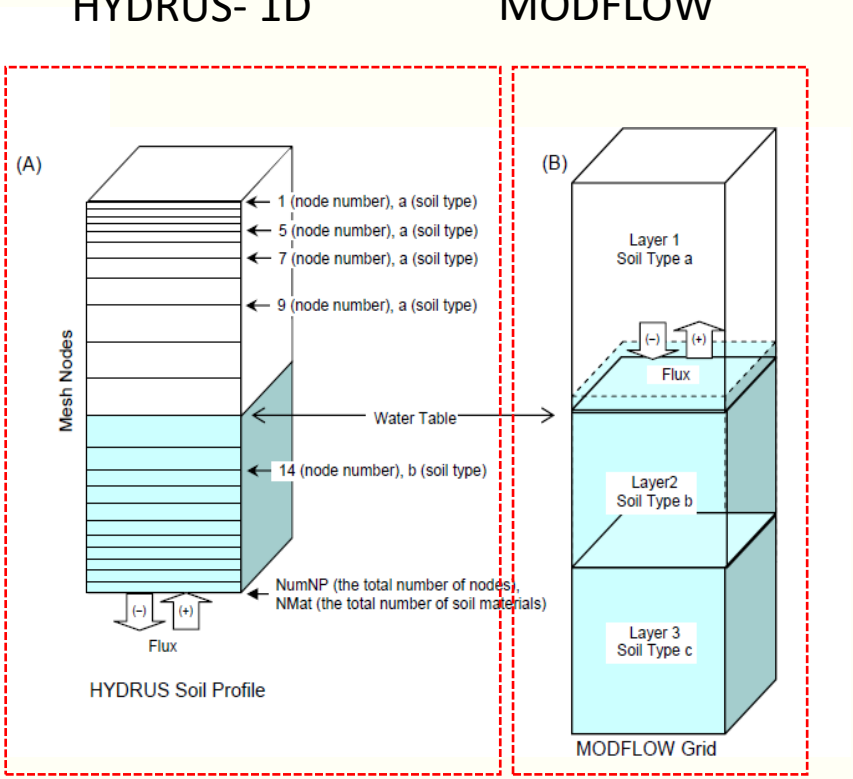


HYDRUS 1D
Šimůnek et al., 2016
1D Richards equation

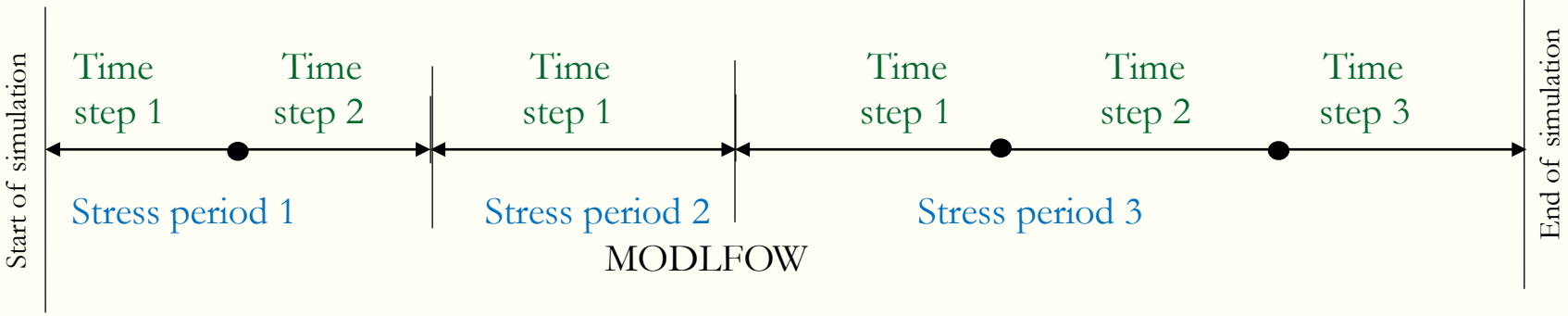
MODFLOW
Harbaugh et al., 2000
3D Groundwater flow

HPM: Spatial discretization



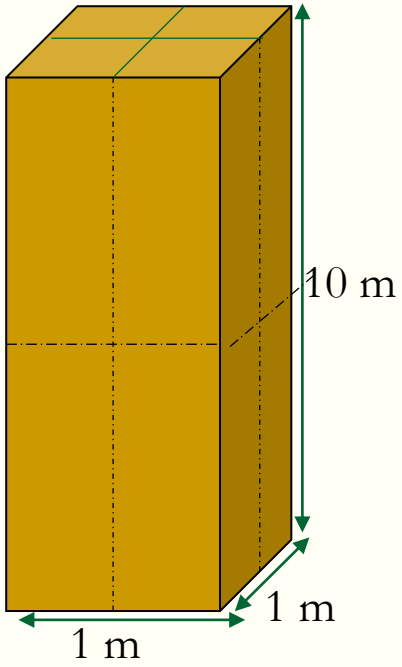


HPM: Temporal discretization

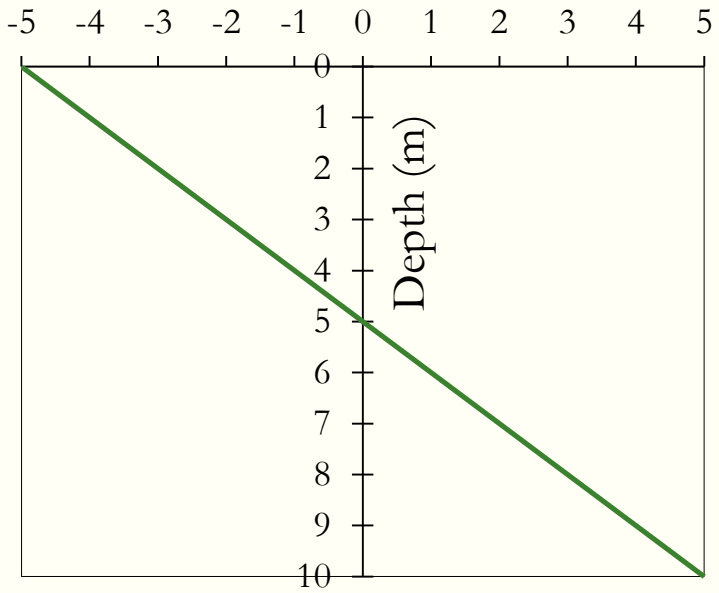


HPM: Limitations

Inflow = 0.001 m/day



Initial pressure head (m)



Start of simulation

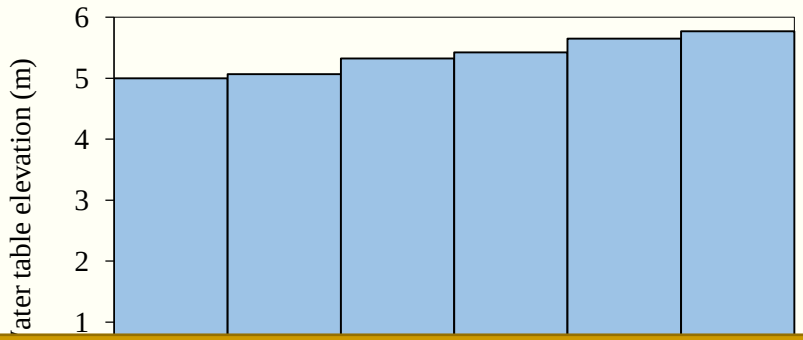
No flow boundaries: Sides and bottom

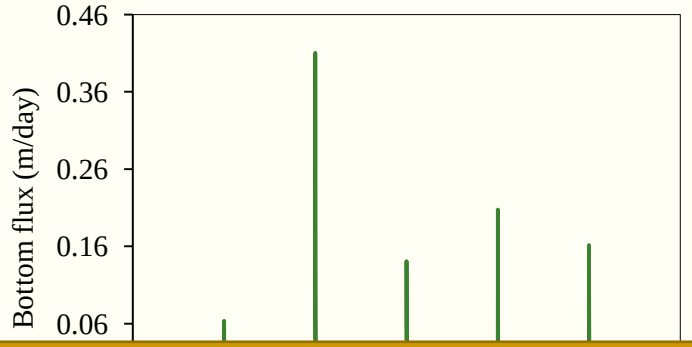
End of simulation

600 days

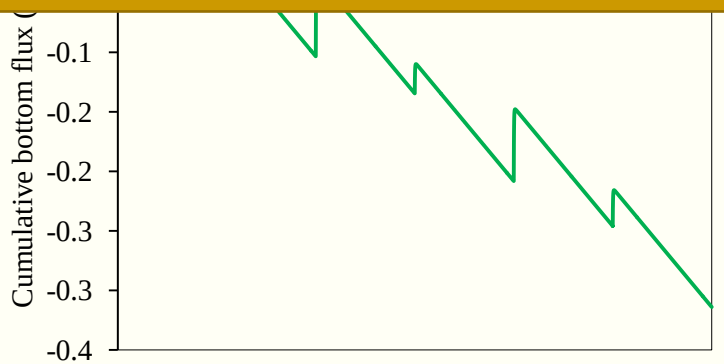
No. of time steps: 6, Duration of each time step: 100 day

HPM: Limitations





Eliminate the sudden variation in the bottom flux from HYDRUS-1D



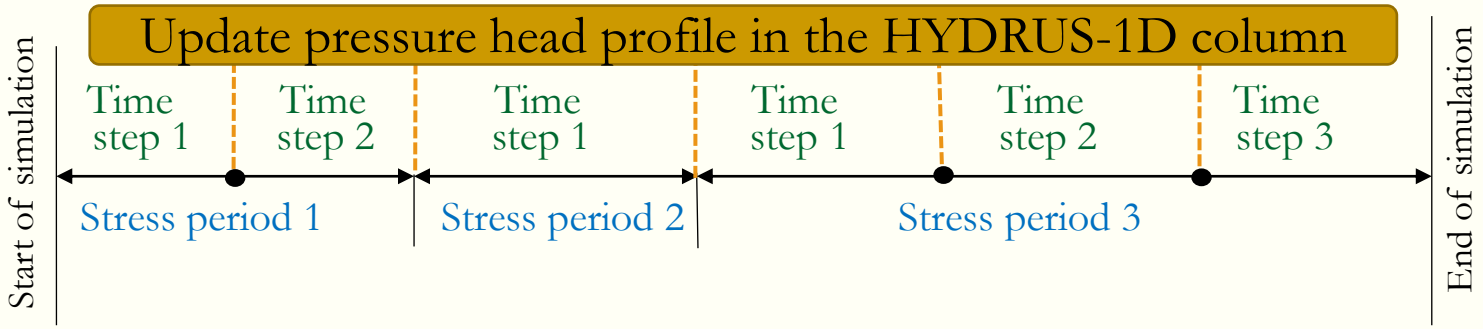
Cumulative bottom flux in the HYDRUS-1D profile.

Objectives

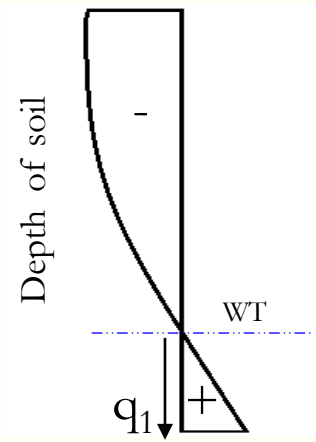
- To update the coupling algorithm between HYDRUS-1D and MODFLOW to eliminate sudden fluxes when the groundwater table depth changes.

- To verify the coupling algorithm using HYDRUS-2D/3D and analytical solution

Updating the coupling algorithm between HYDRUS-1D and MODFLOW

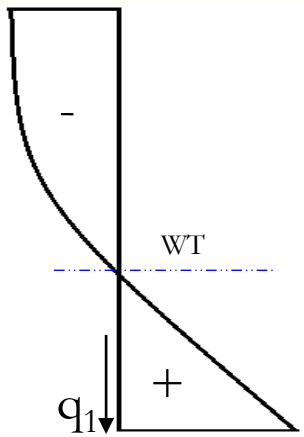


Pressure head profile at the end of T_1



h_1

Steady state pressure head profile



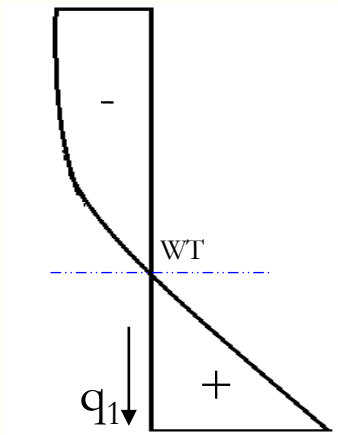
h_2= WT from MODFLOW

Steady-state nodal fluxes compared with the nodal fluxes at T_1

If (relative difference between these two fluxes > 0.1% of the flux);

- Pressure head values below this node = pressure heads obtained by the steady-state profile
- Pressure head values above this node = pressure heads at T_1

Pressure head at the end of T_1 adjusted before moving to T_2



h_2

Coupling algorithm

- Steady state pressure head profile obtained using Darcy-Buckingham law

$$q = -\frac{K(h_i) + K(h_{i+1})}{2}\left(\frac{h_{i+1} - h_i}{z_{i+1} - z_i} + 1\right)$$

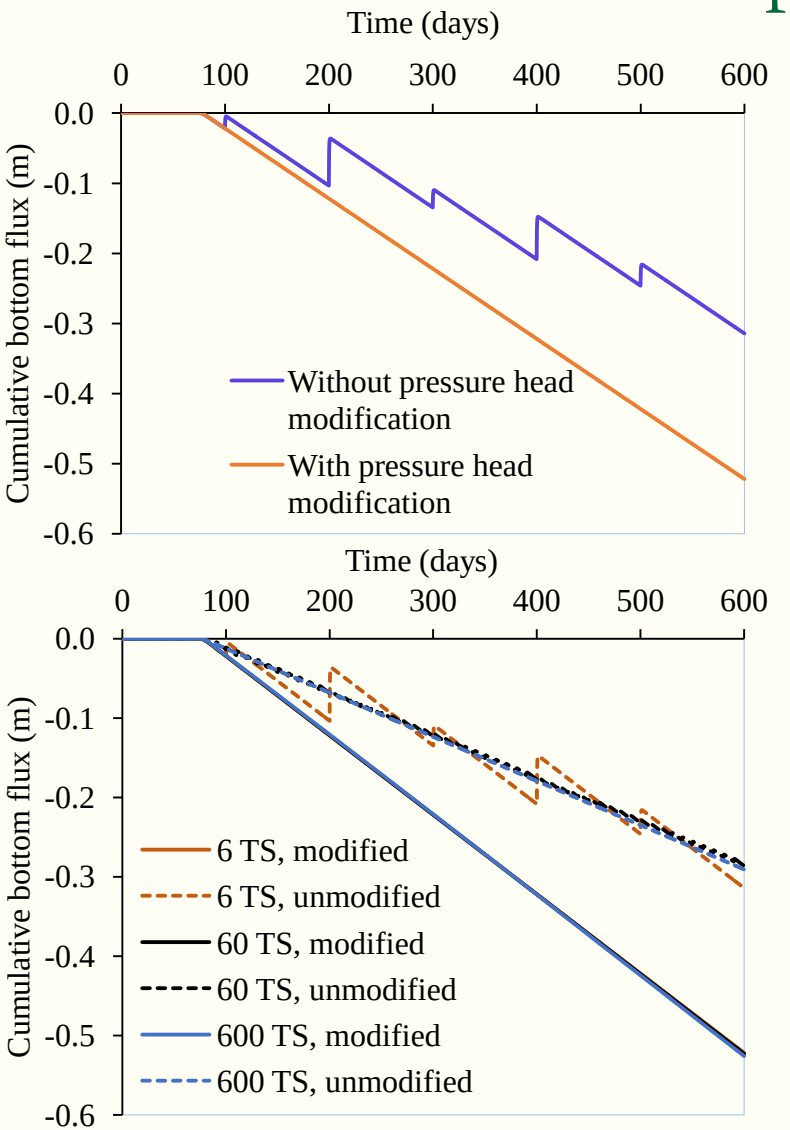
- The above equation has to be solved for h_{i+1}, while the value h_i is known and q is equal to the bottom flux.

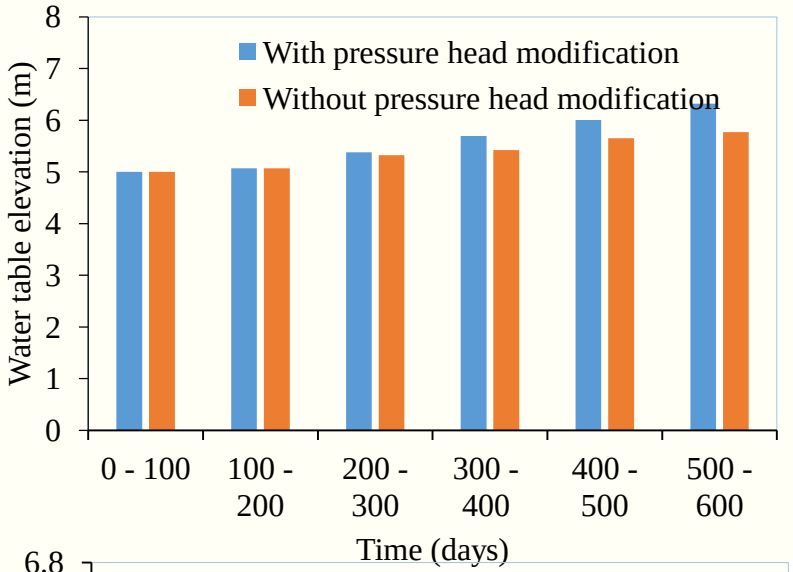
- Soil Hydraulic models
  - Van Genuchten model
  - Modified van Genuchten (Vogel and Cislerova)
  - Brooks and Corey
  - Van Genuchten with air entry value of 2 cm
  - Log-normal (Kosugi)

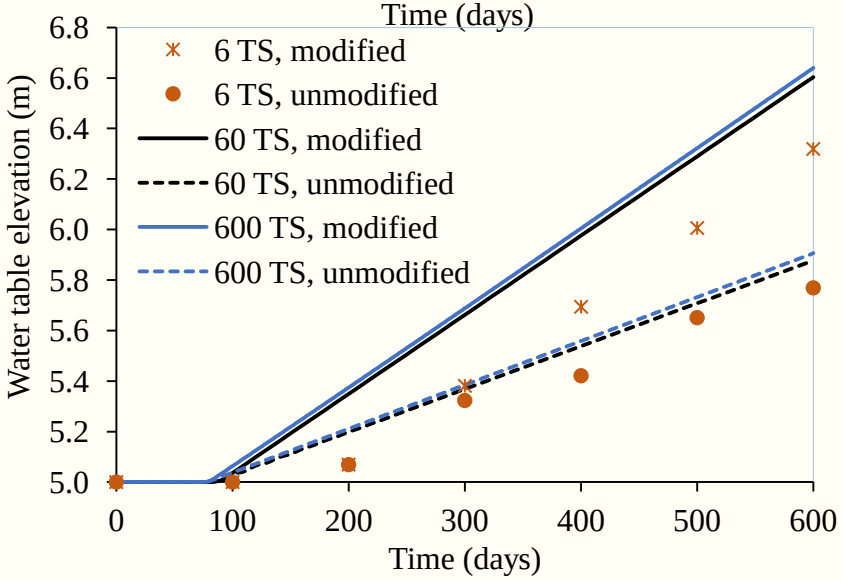
Verification of the updated coupling algorithm

- Constant boundary condition
- Varying boundary conditions
- Different soil types
- Comparison with HYDRUS 2D/3D
- Comparison with Analytical solution

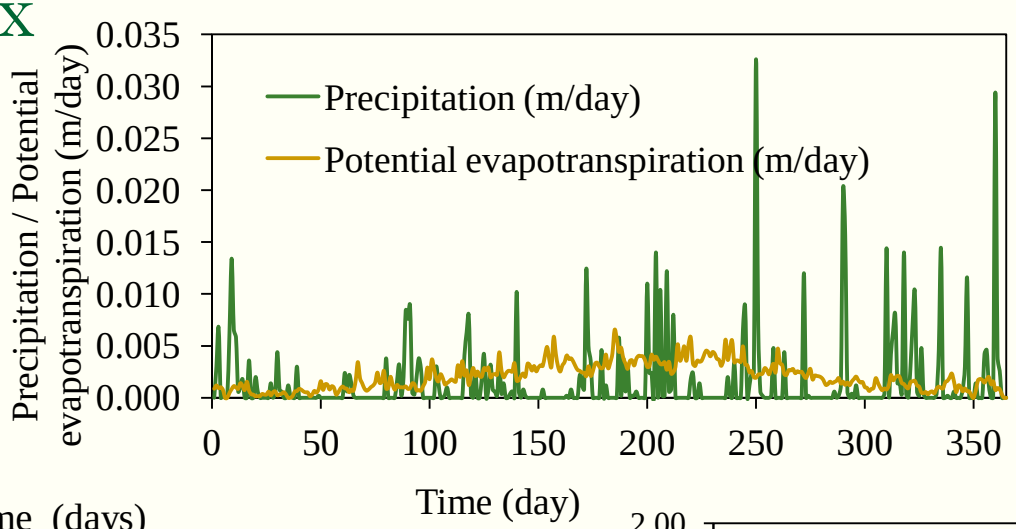
Verification of the coupling algorithm: Constant surface flux

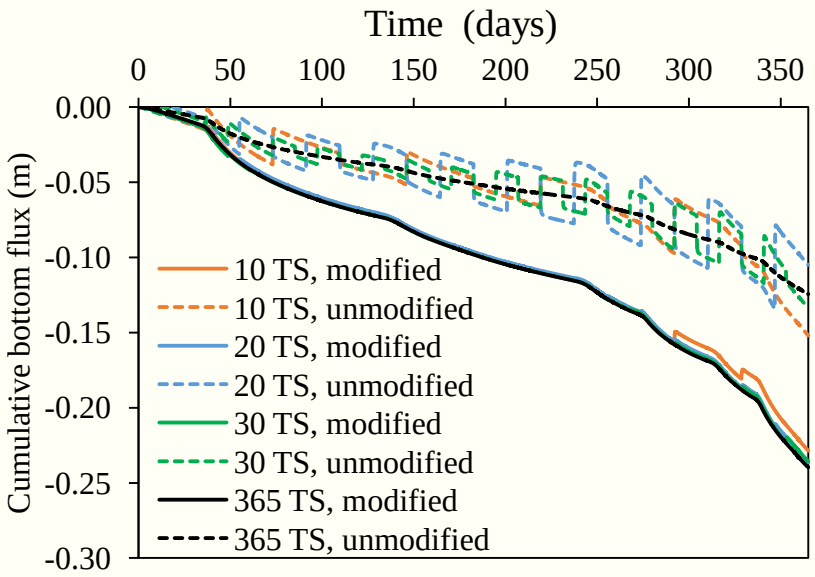


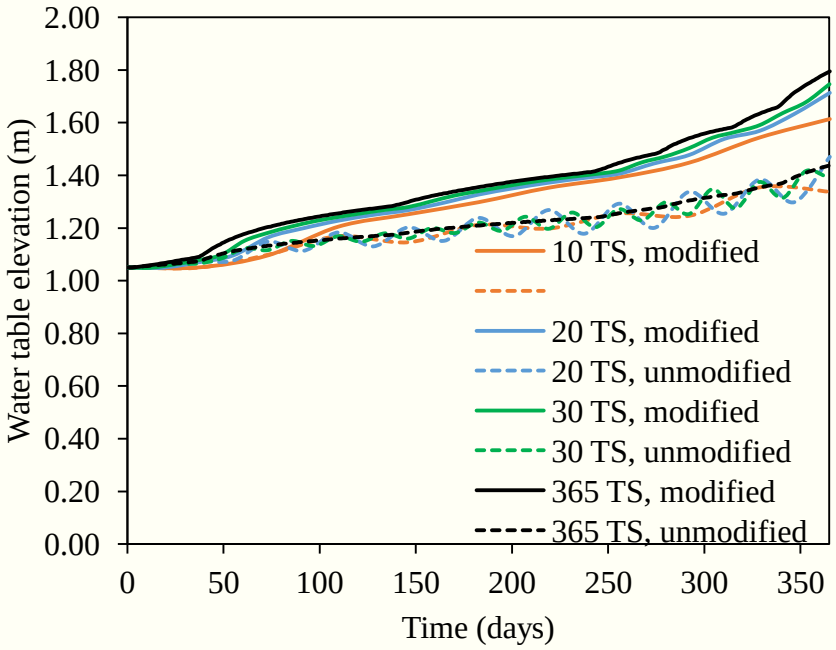




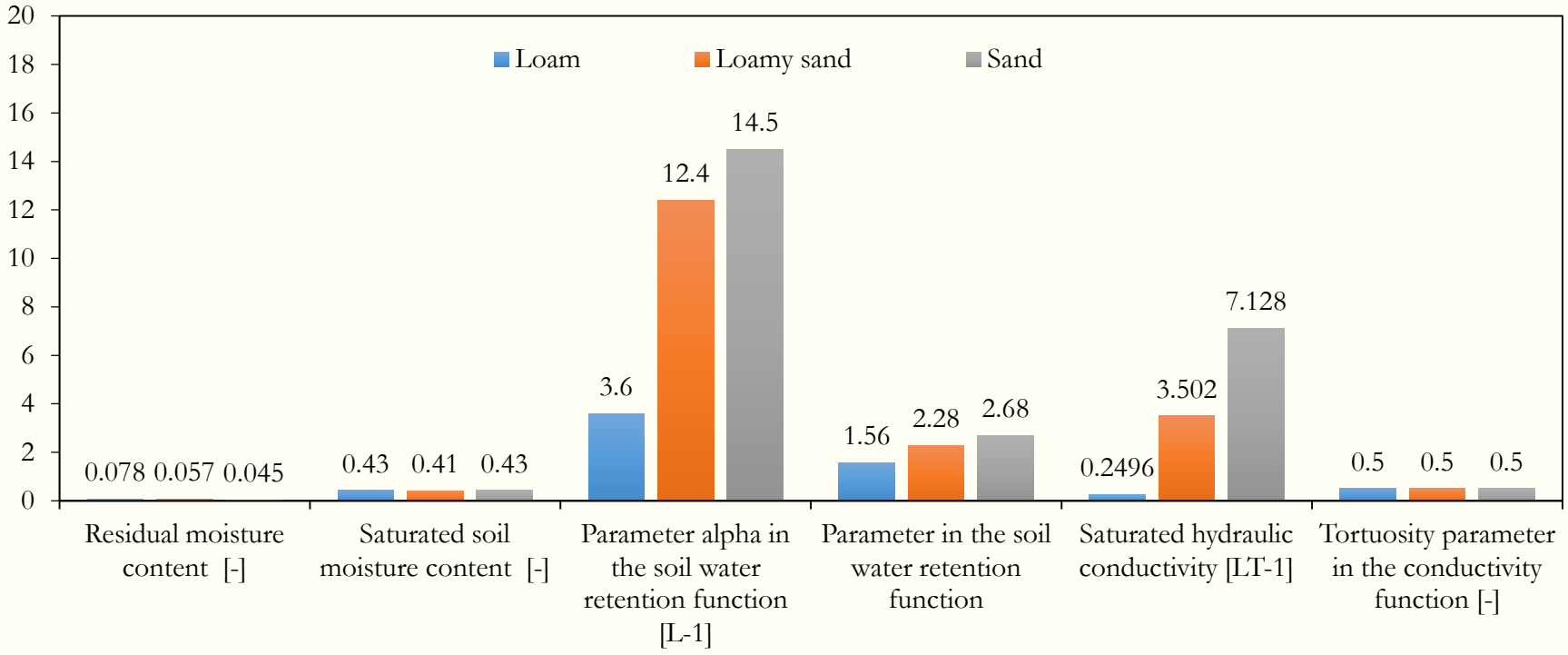
Verification of the coupling algorithm: Variable surface flux

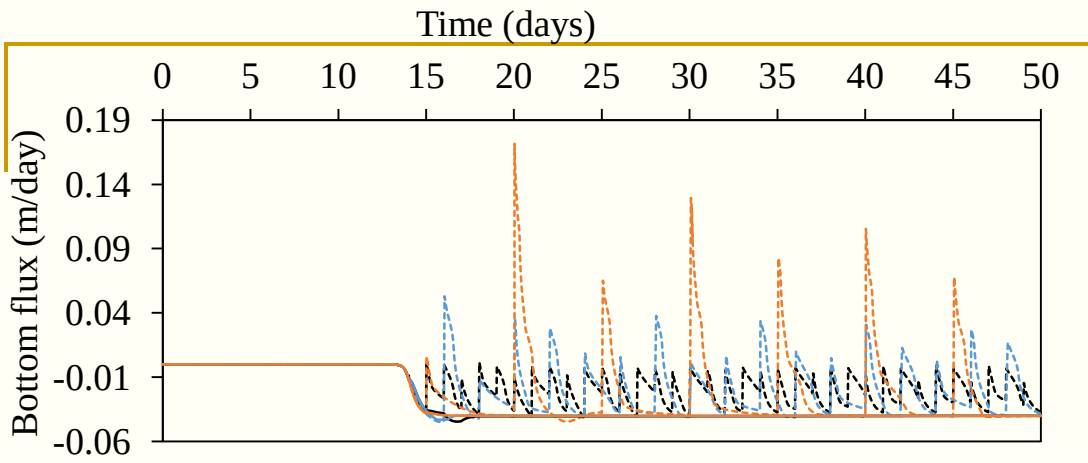






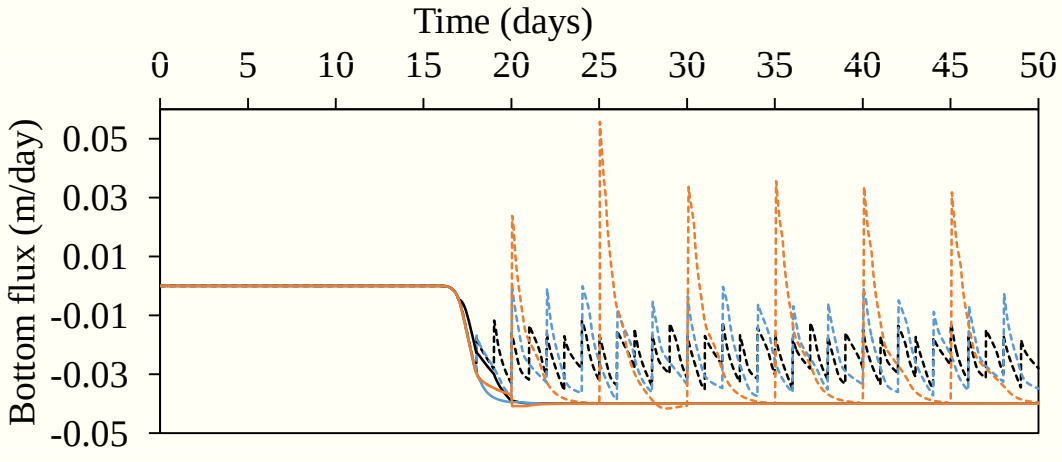
Verification of the coupling algorithm: Different soil types





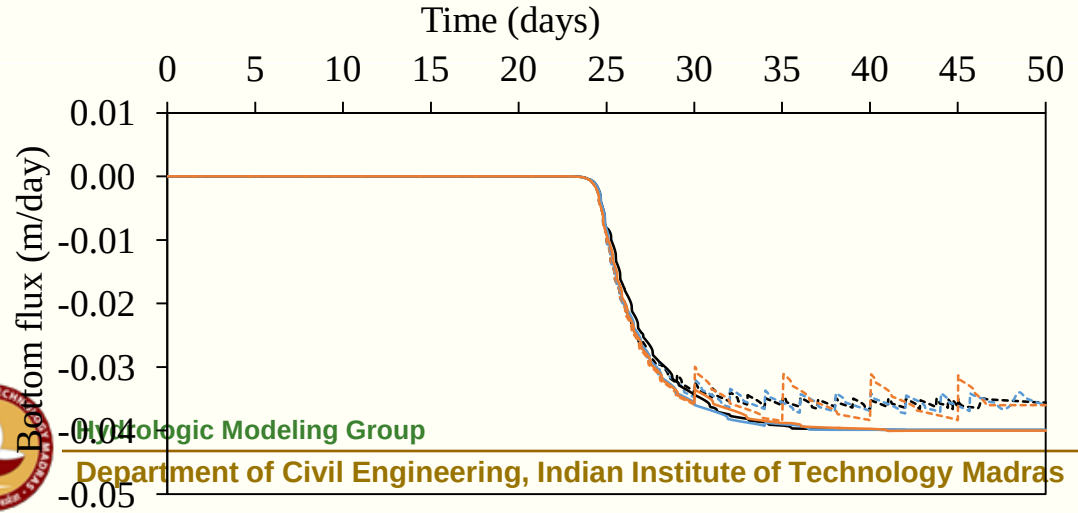
50 TS, unmodified
25 TS, unmodified
10 TS, unmodified
50 TS, modified
25 TS, modified
10 TS, modified

Sand
(K=7.128 m/day)



50 TS_unmodified
25 TS_unmodified
10 TS_unmodified
50 TS_modified
25 TS_modified
10 TS_modified

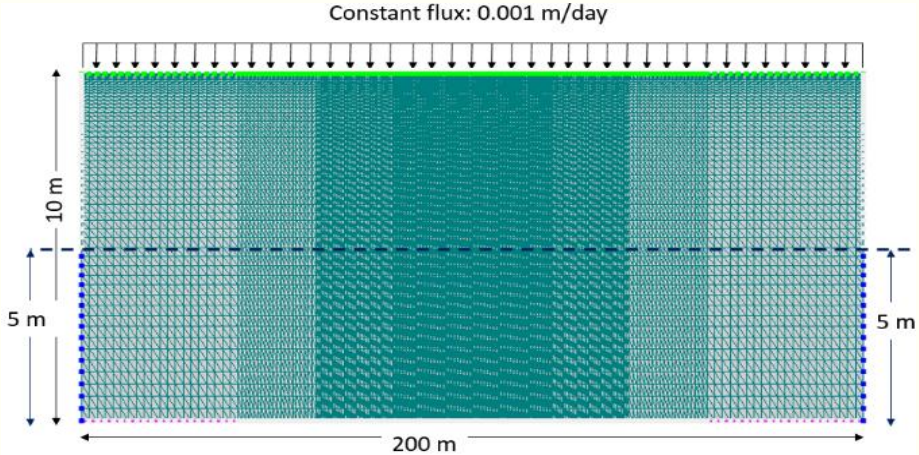
Loamy sand
(K= 3.502 m/day)

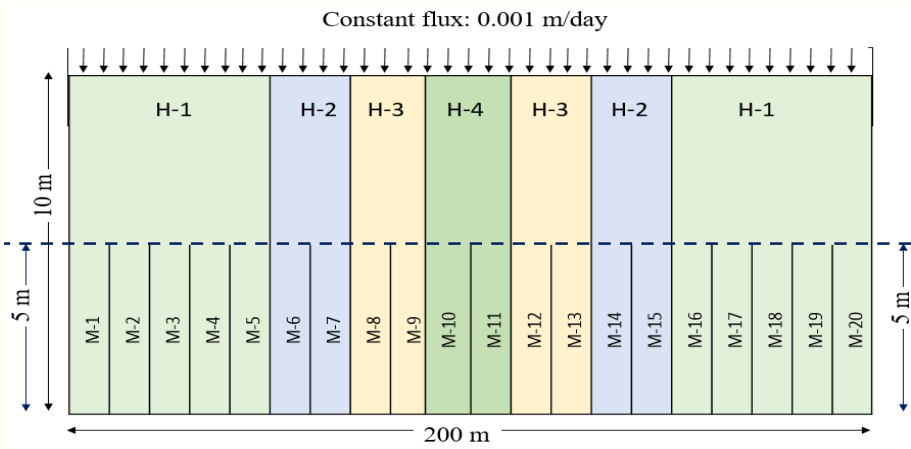


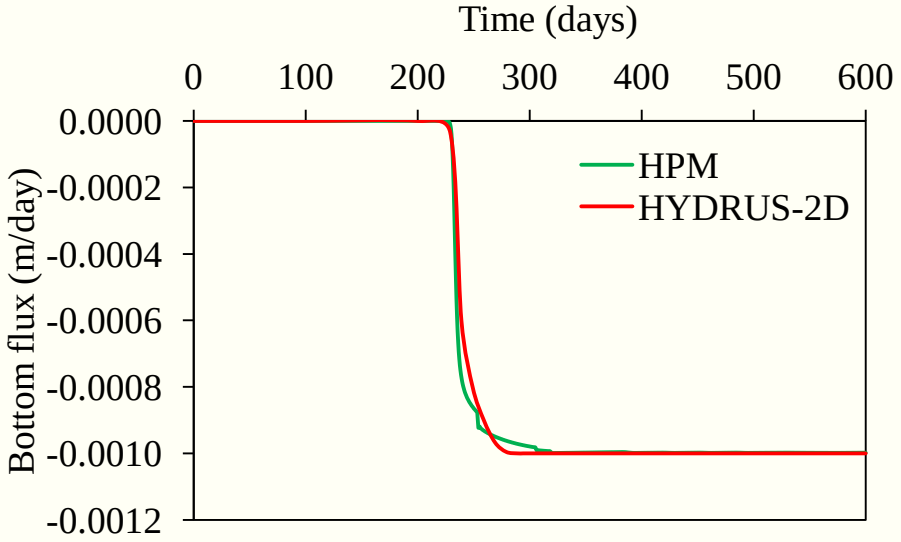
50 TS, unmodified
25 TS, unmodified
10 TS, unmodified
50 TS, modified
25 TS, modified
10 TS, modified

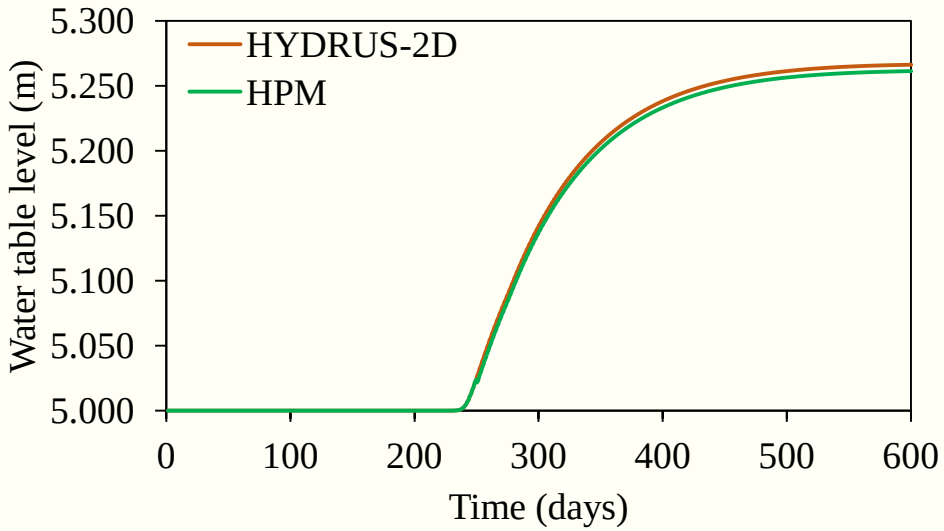
Loam
(K=0.2496 m/day)

Verification of the modified HPM with HYDRUS 2D/3D



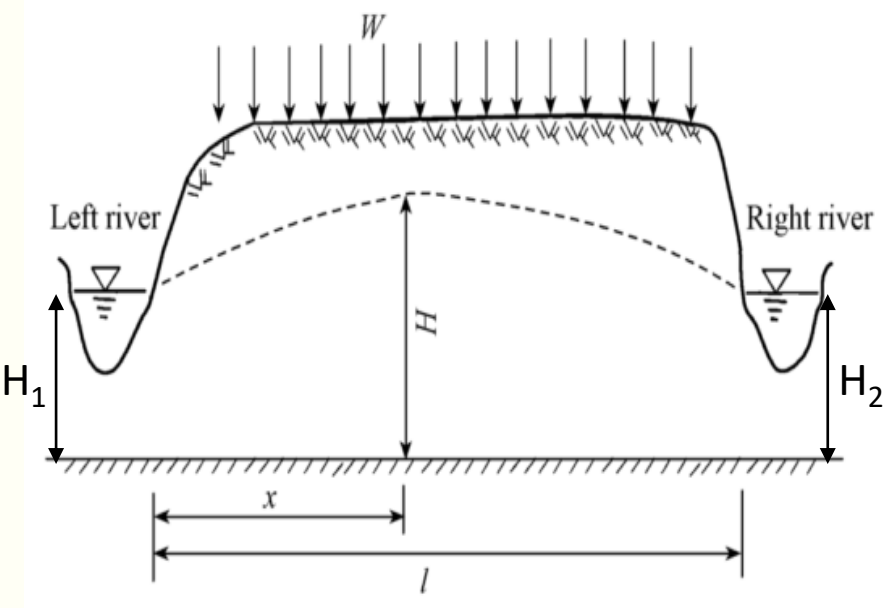


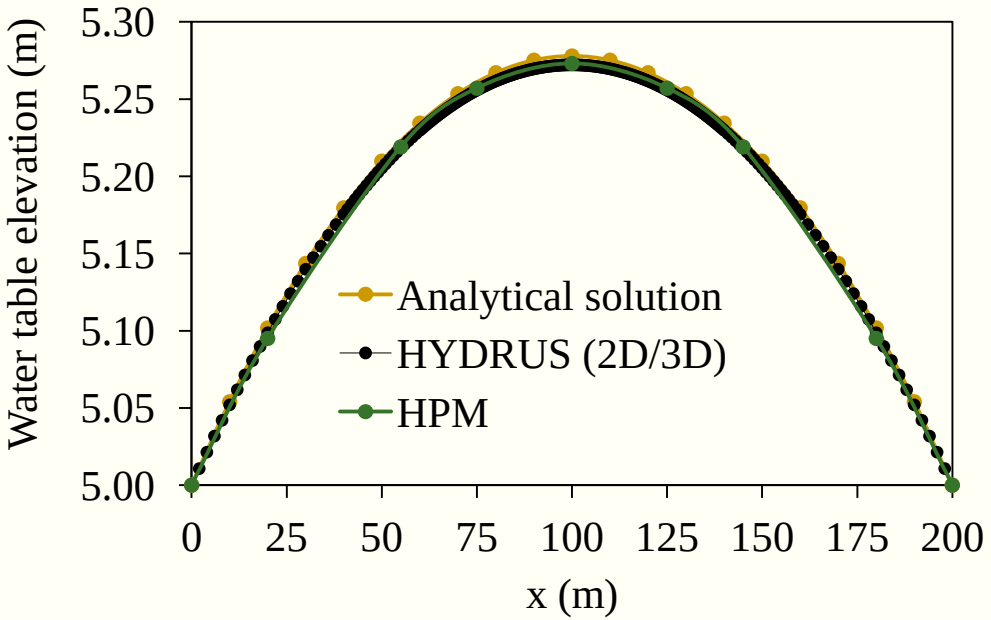




Comparison with analytical solution

$$H(x)^2 = (H_1)^2 + \frac{(H_2)^2 - (H_1)^2}{l} x + \frac{W}{K}(lx - x^2)$$ (Bear, 1972)





Summary and Conclusion

- The coupling algorithm between HYDRUS-1D and MODFLOW is updated in HPM
- The algorithm is verified for its functionality for
  - Different boundary condition
  - Different soil types
- HPM is verified by comparing the HPM results with the results obtained using HYDRUS-2D/3D and analytical solution