

Assessing Soil Health and Ecosystem Services in Rotterdam

Development of an integrated modelling workflow

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The 'Rotterdam' hydrological system

Adaptation measures:

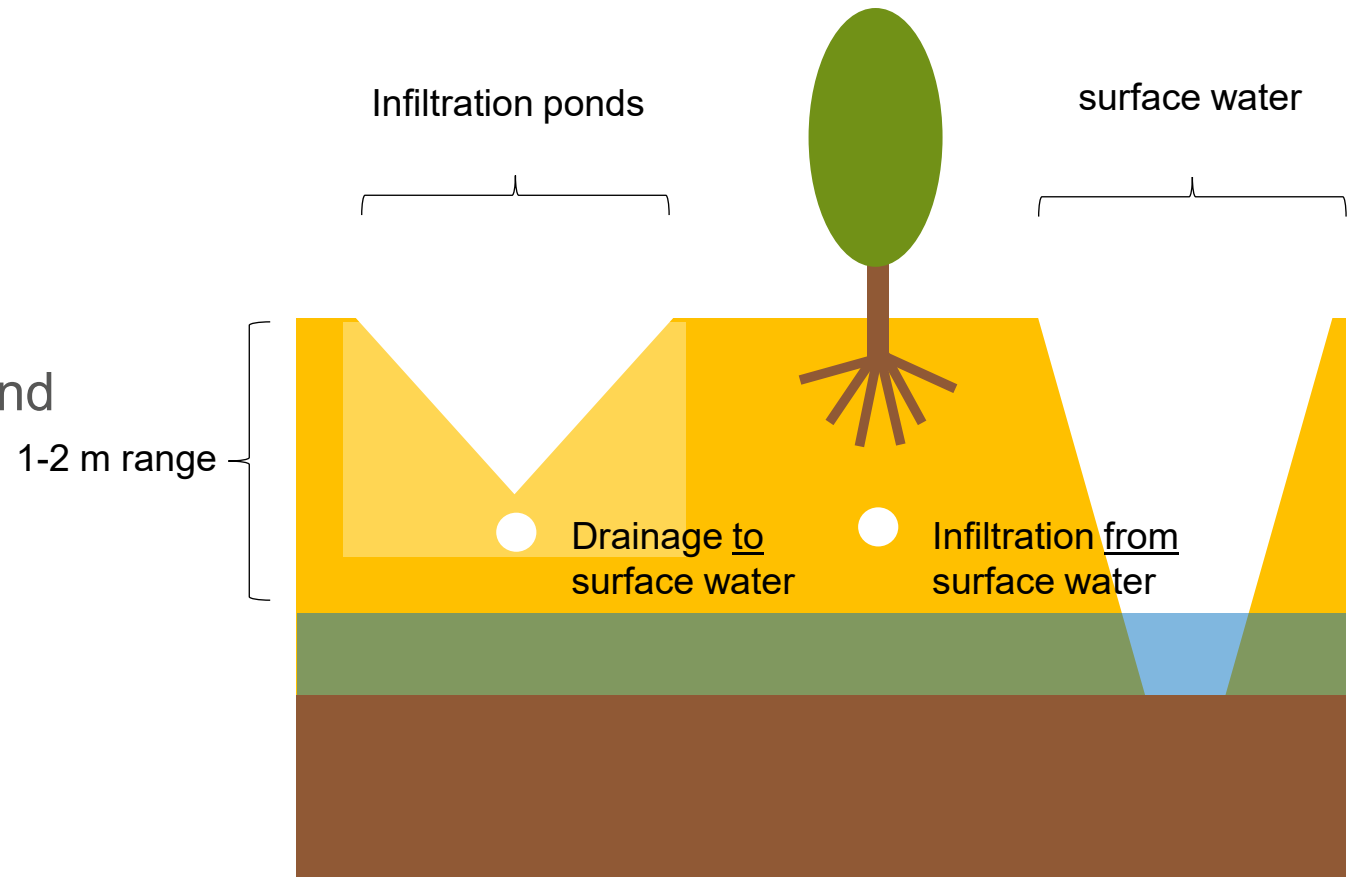
1. *Increase infiltration to:*

- reduce (peak) drainage via sewage system
- retain ground water for dry periods and increased greening

2. *Infiltration of surface water in dry periods*

3. *Greening of public space to:*

- Increase living quality
- Increase heat resistance





The 'Rotterdam' existing model setup

Reservoir model for dynamic ponding at surface level

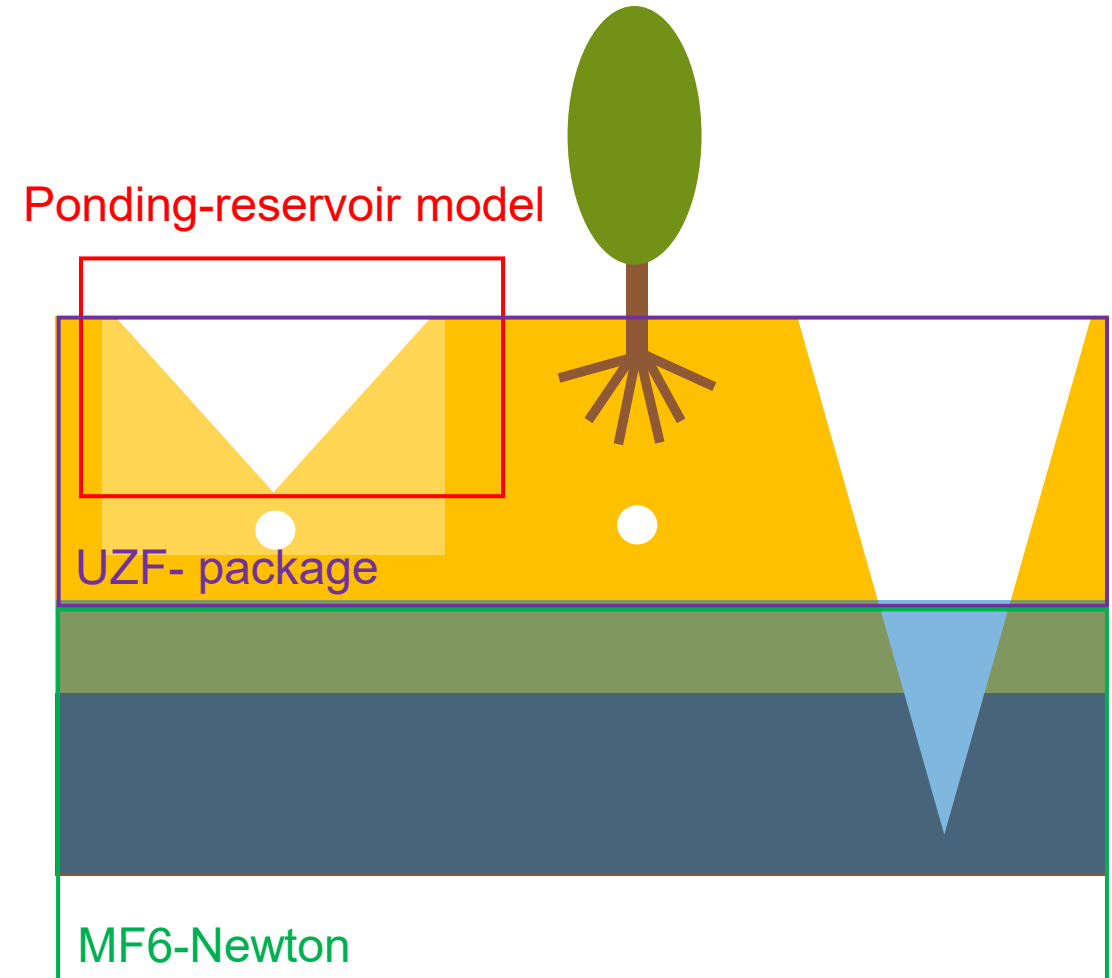
- Keeps waterbalance and waterlevel per timestep
- Keeps track of infiltration and drainage nodes

Unsaturated zone flow model (UZF) for unsaturated zone processes

- 1D gravitational driven Richard's flow
- Effect of crop development via Evapotranspiration package

MODFLOW 6 (Newton) for saturated zone

- 3D Darcy based flow

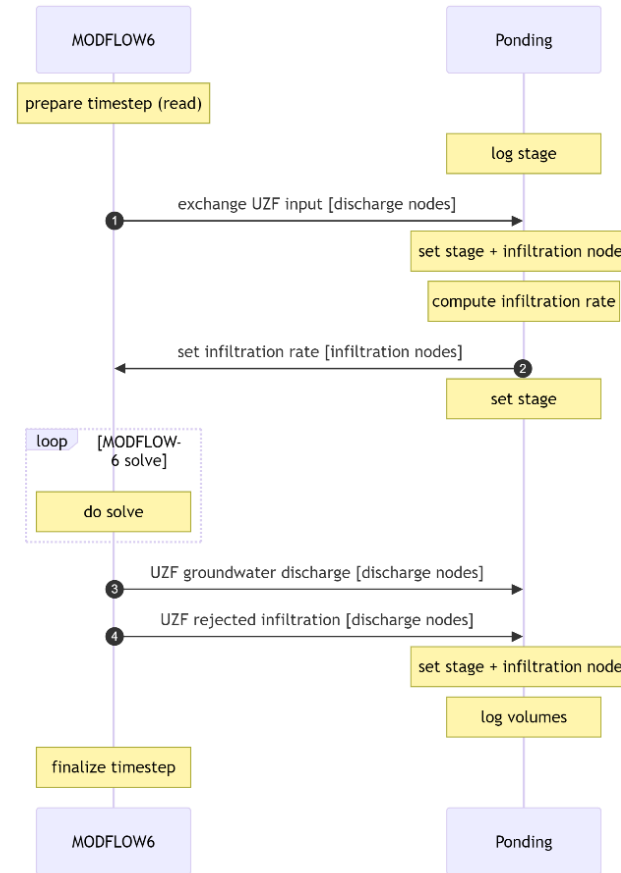




The 'Rotterdam' existing model setup

Coupling

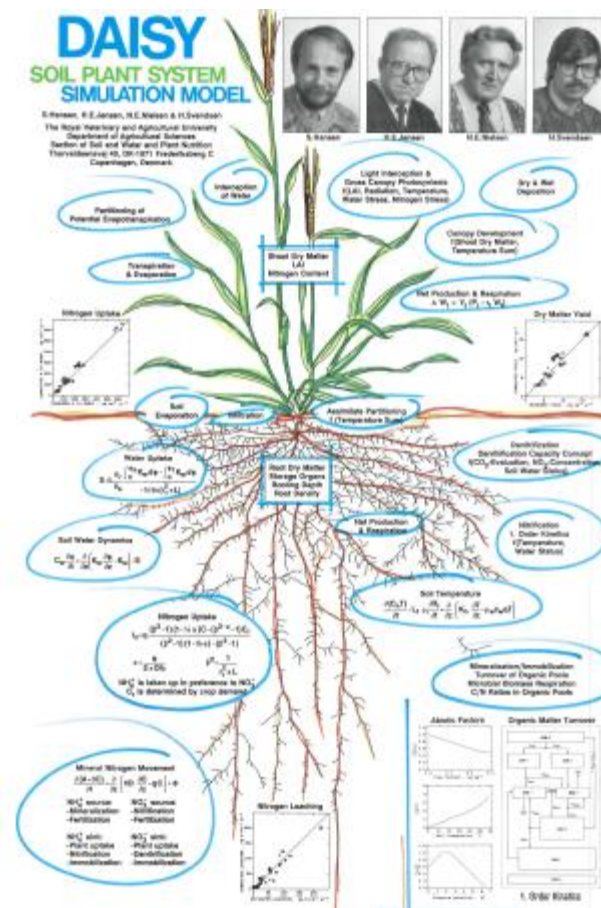
- Explicit; time-step based coupling
- Online coupling via MODFLOW 6 BMI/XMI
- Python-based coupling driver





- ✓ Soil contamination
(concentration of heavy metals
and organic contaminants)
- ✓ Soil water holding capacity
- ❑ Soil biodiversity
- ❑ Soil organic carbon stock

→ Additional soil-health indicators provided by Daisy





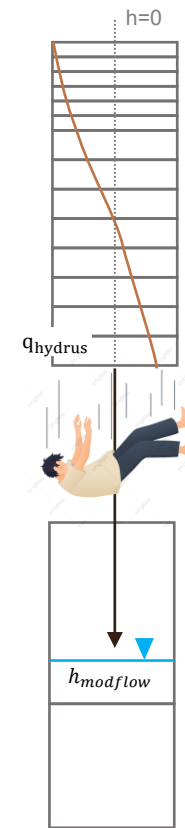
Coupling to Daisy

More complex than existing
(lumped!) HYDRUS-1D
MODFLOW2005 coupling
(Pawlowicz et al, 2024)

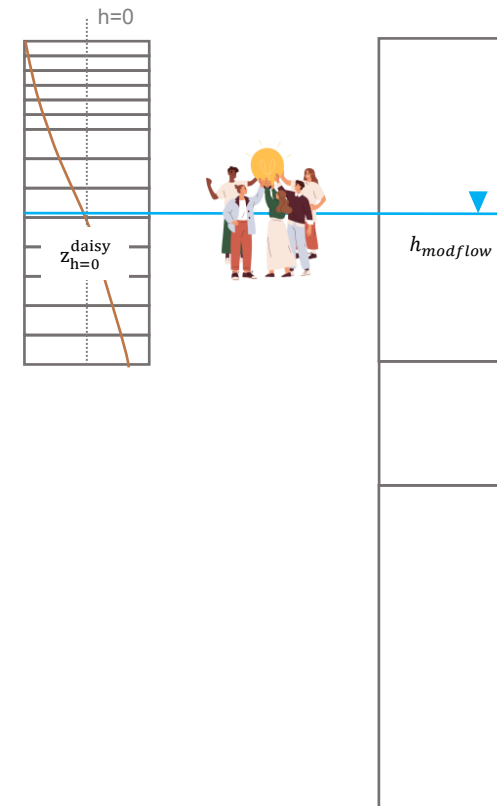
Due to shallow unsaturated
zone; continues overlap of
model domain!

→ MF6 head $\approx$ Daisy $Z_{h=0}$

Hydrus 1D /
MODFLOW 2005



Daisy /
MODFLOW 6





Coupling concepts

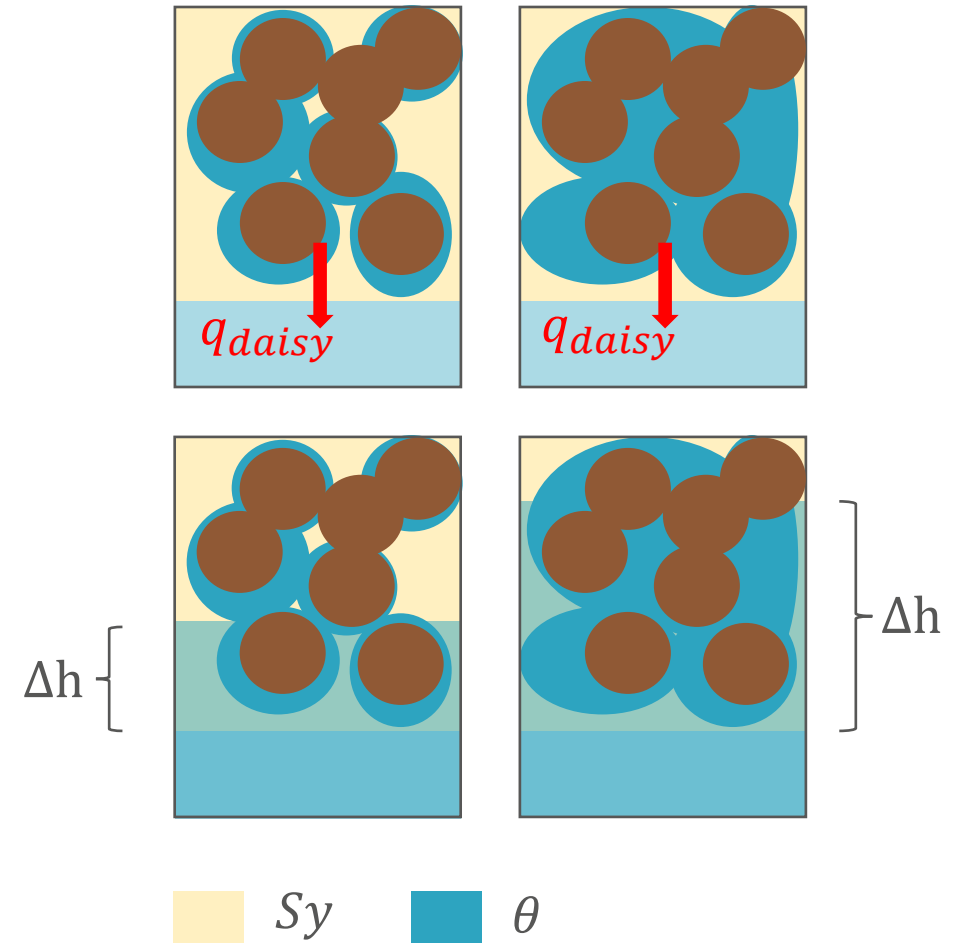
- Coupling at groundwater-level
- Groundwater-level movement reflects both interface fluxes and changes in the moisture profile.

MODFLOW solves for:

$$Sy (h^n - h^{n-1}) = q_{daisy}^n \Delta t$$

$q_{daisy} = q$ over h_0 face to saturated zone

$$\Delta H_{modflow} = \frac{q_{daisy}}{\Delta \theta / \Delta Z_{h0}} \approx \Delta Z_{daisy}^{h_0}$$





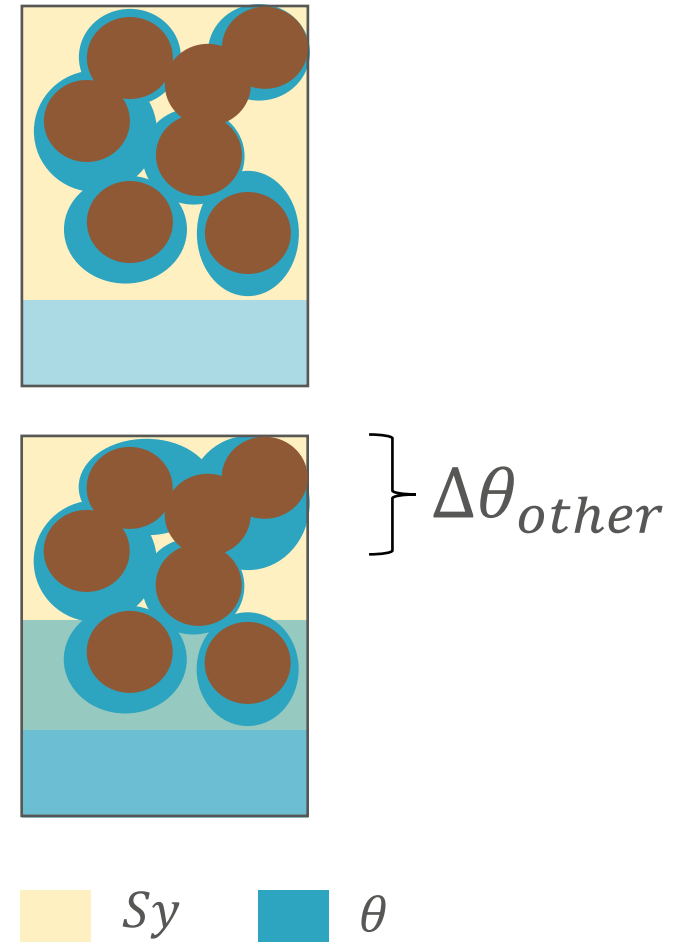
Coupling concepts

Apparent S_y ; from a soil texture constant to a function of moisture profile

$$S_y := \Delta\theta / \Delta Z_{h0}$$

$$\Delta\theta = \Delta\theta_{gwl} + \Delta\theta_{other}$$

→ Difficult to isolate the groundwater-level response





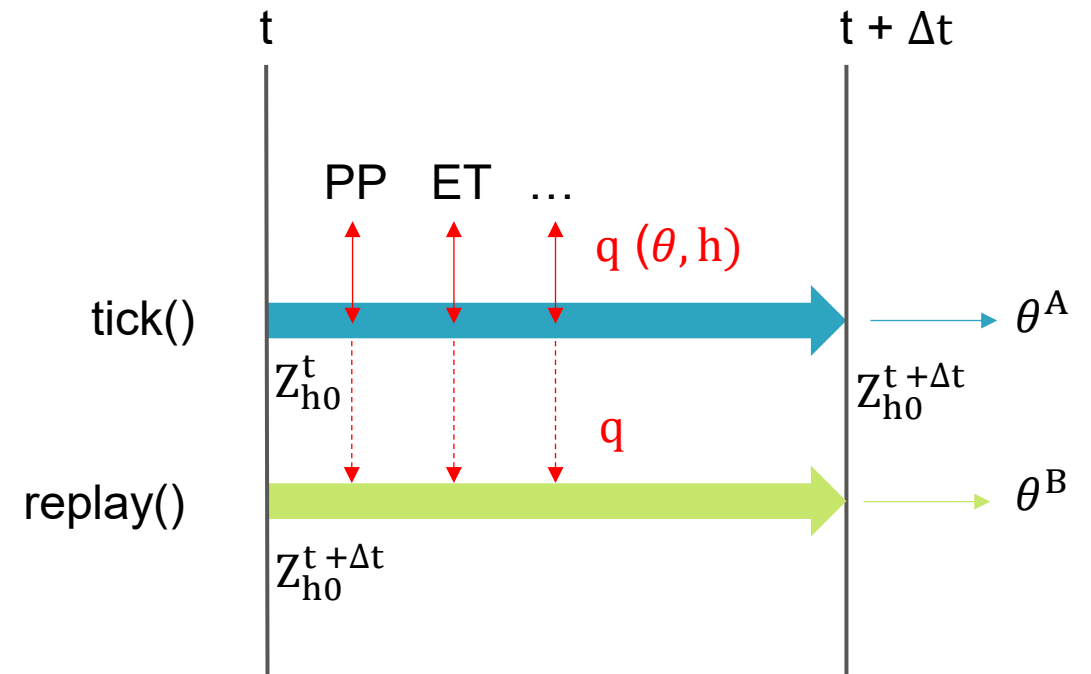
Coupling concepts

Perturbation of gwl at bottom boundary, while redoing the Richards tick() for t.

$$S_y^{\text{perturb}}(t) = \frac{\sum_i [\theta_i^B(t) - \theta_i^A(t)] \cdot \Delta z_i}{\Delta h(t)}$$

$$\Delta h(t) = z_{h=0}^{\text{Daisy}}(t) - z_{h=0}^{\text{Daisy}}(t - \Delta t)$$

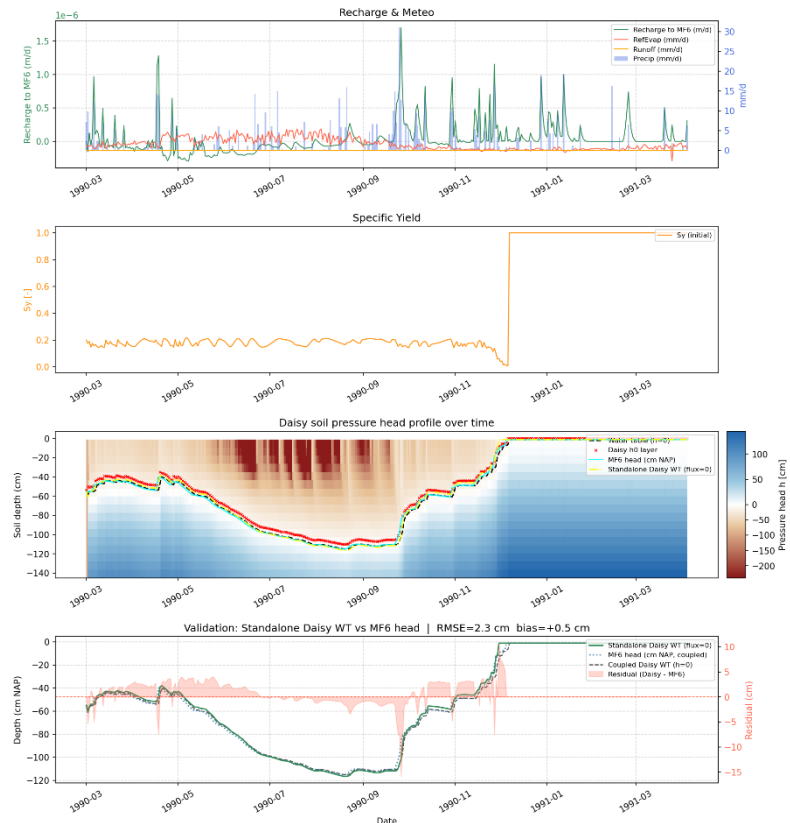
Both tick() use real PP flux, ET sinks (S_{sum}) and same post-ice θ snapshot $\rightarrow \theta_i^B - \theta_i^A$ represents the 'pure' response to bottom boundary perturbation



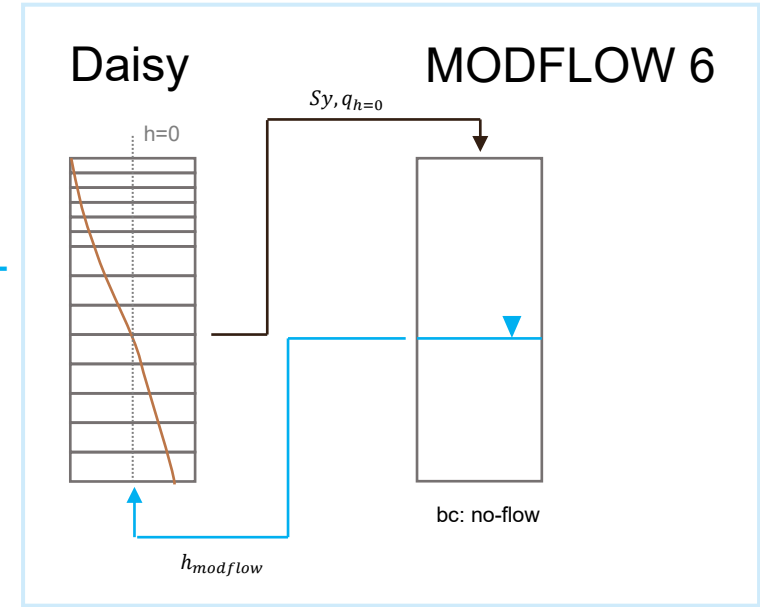


Coupling validation

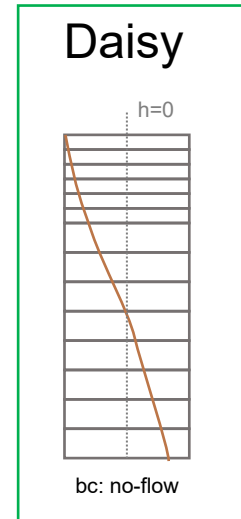
Single column experiment



coupled



stand alone



$$z_{h=0}^{daisy} \approx H_{modflow}$$

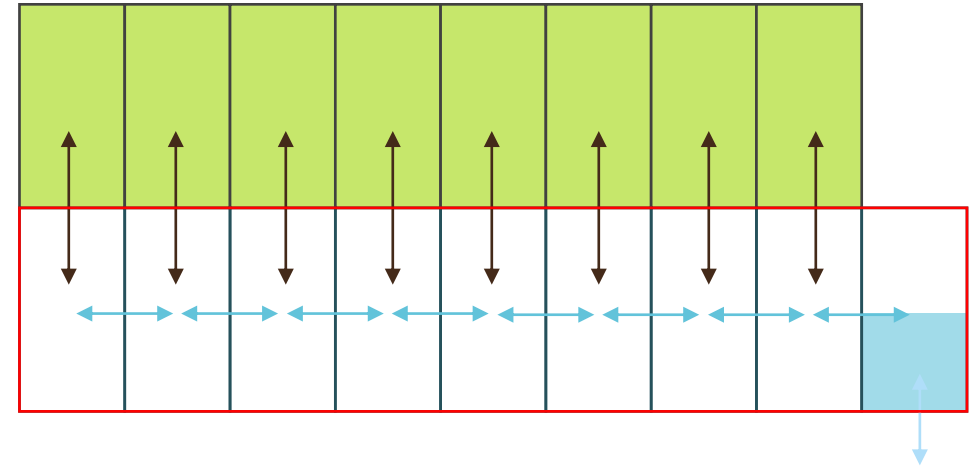


Multiple column instances

Daisy wrapped via BMI/API

→ Compiled as a Python extension (.pyd)

→ Supports multiple concurrent Daisy instances



-  MODFLOW 6 model
-  MODFLOW 6 GHB node
-  Daisy column instance

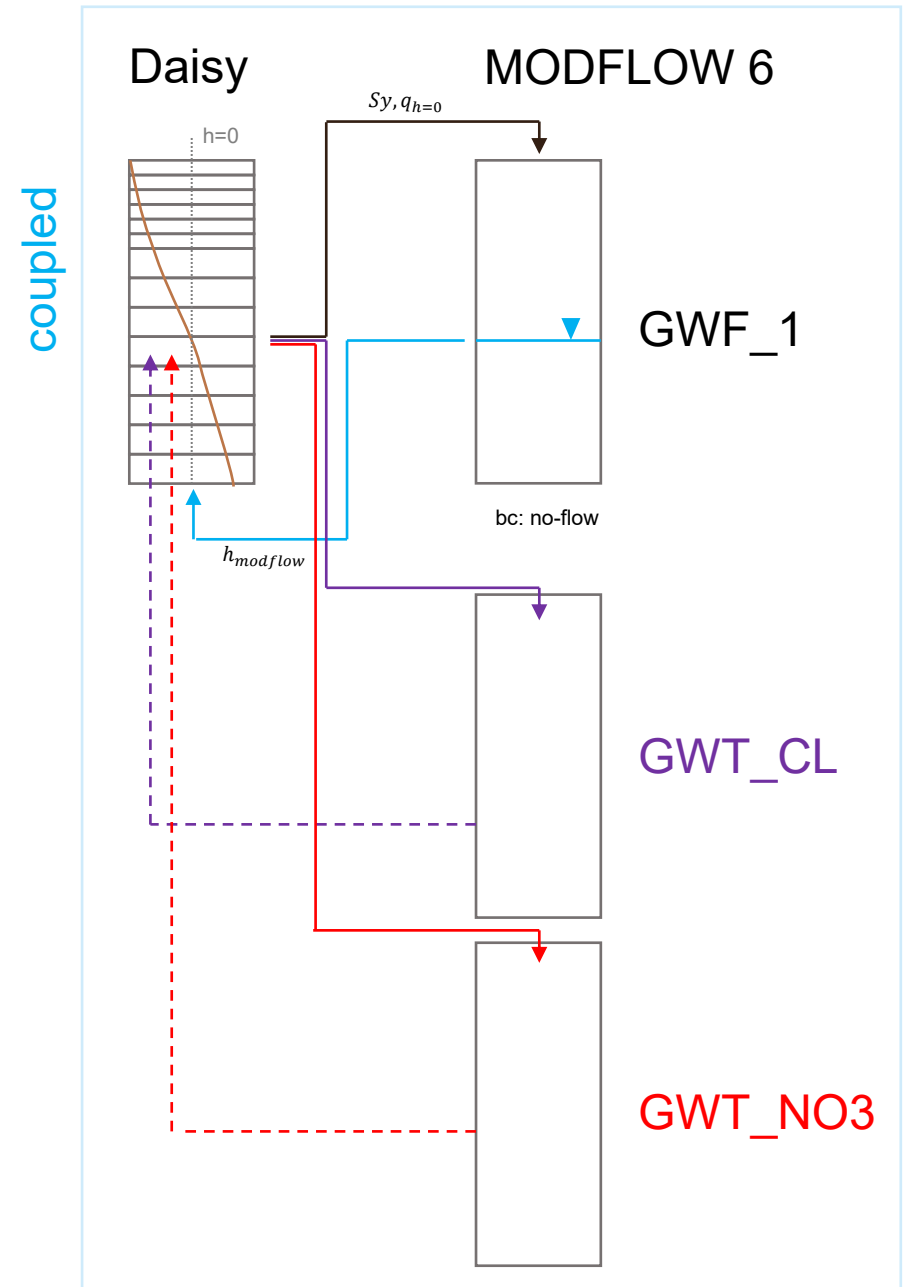


Coupled solute transport

Daisy solute transport coupled to MODFLOW 6 GWT models

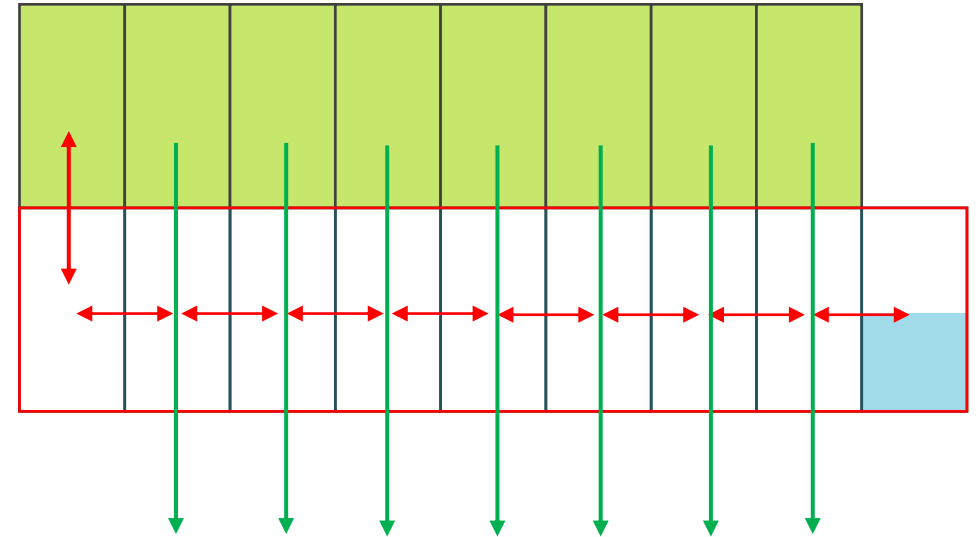
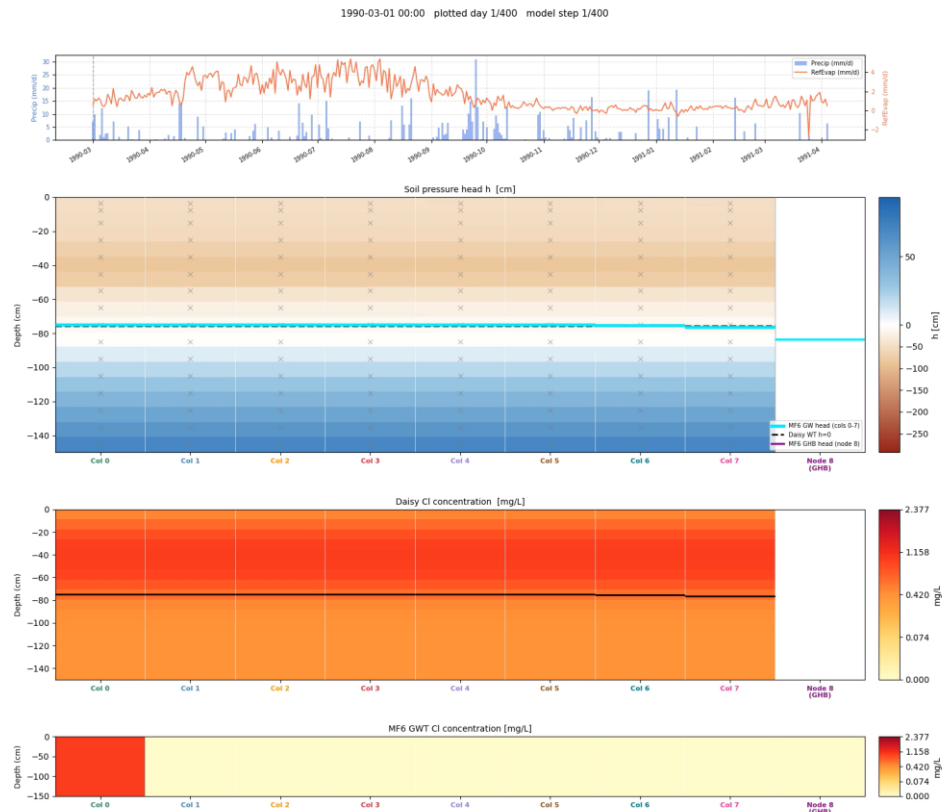
- Daisy → GWT: Concentration at $z_{h=0}$
- GWT → Daisy: Concentration at all layers $h > 0$

→ GWT-model per solute





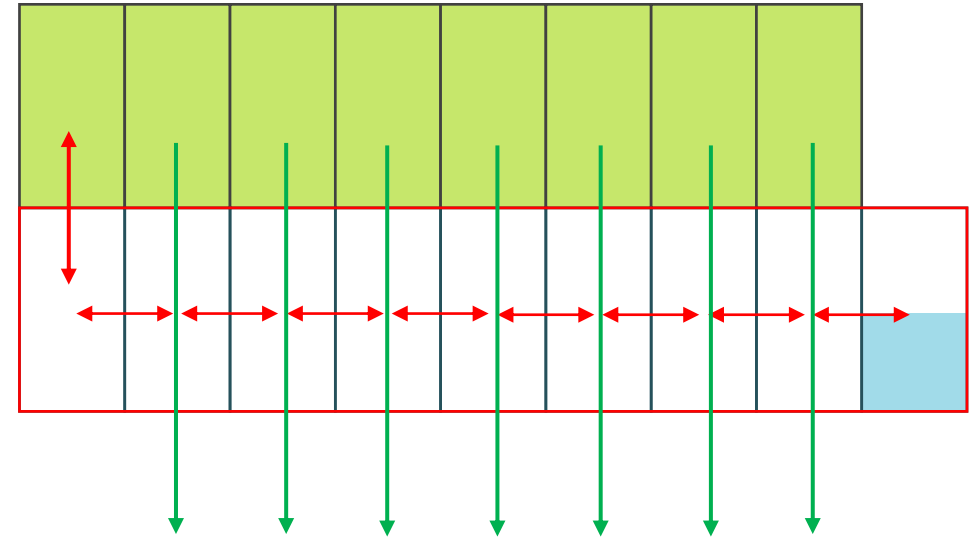
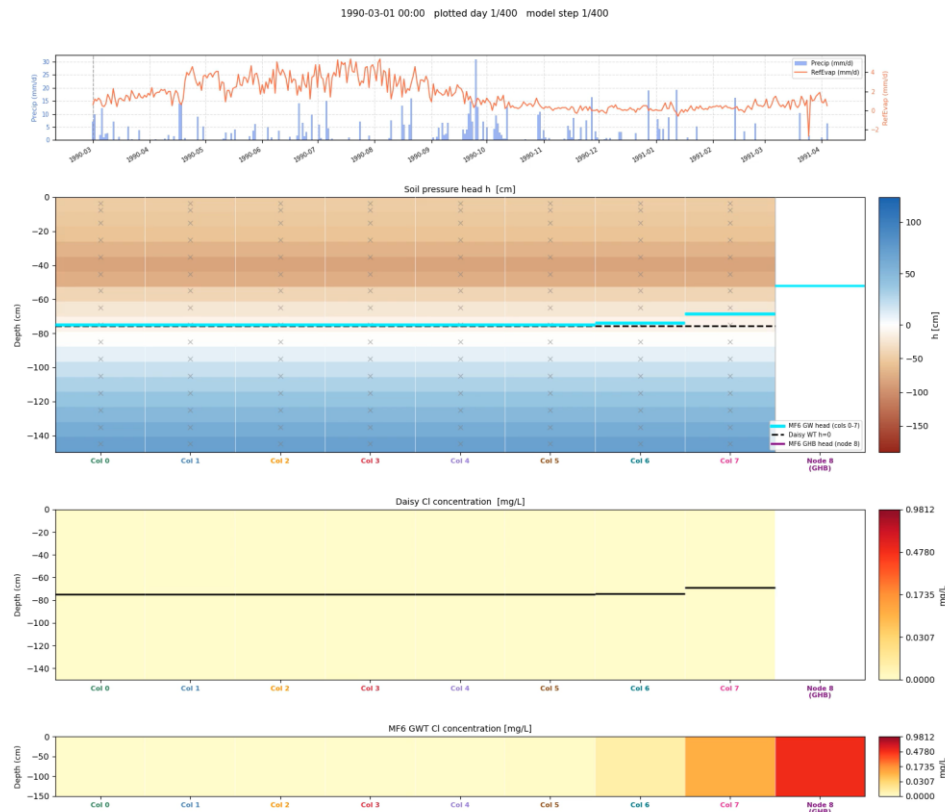
Coupled chloride transport



- All columns coupled for flow
- Initial Cl = 1 mg/L in all columns
- Only column 0 coupled for transport
- Column 0 experiences lateral Cl export



Coupled chloride transport



- Initial Cl = 0 mg/L in all columns
- Initial Cl = 1 mg/L in ditch
- Lateral saturated transport towards column 0
- Column 0 receives Cl through capillary uptake



Coupling insights

Apparent S_y is timestep dependent

Smaller perturbations remain within the saturated fringe and yield smaller apparent S_y values.

→ Strong impact on MODFLOW stability

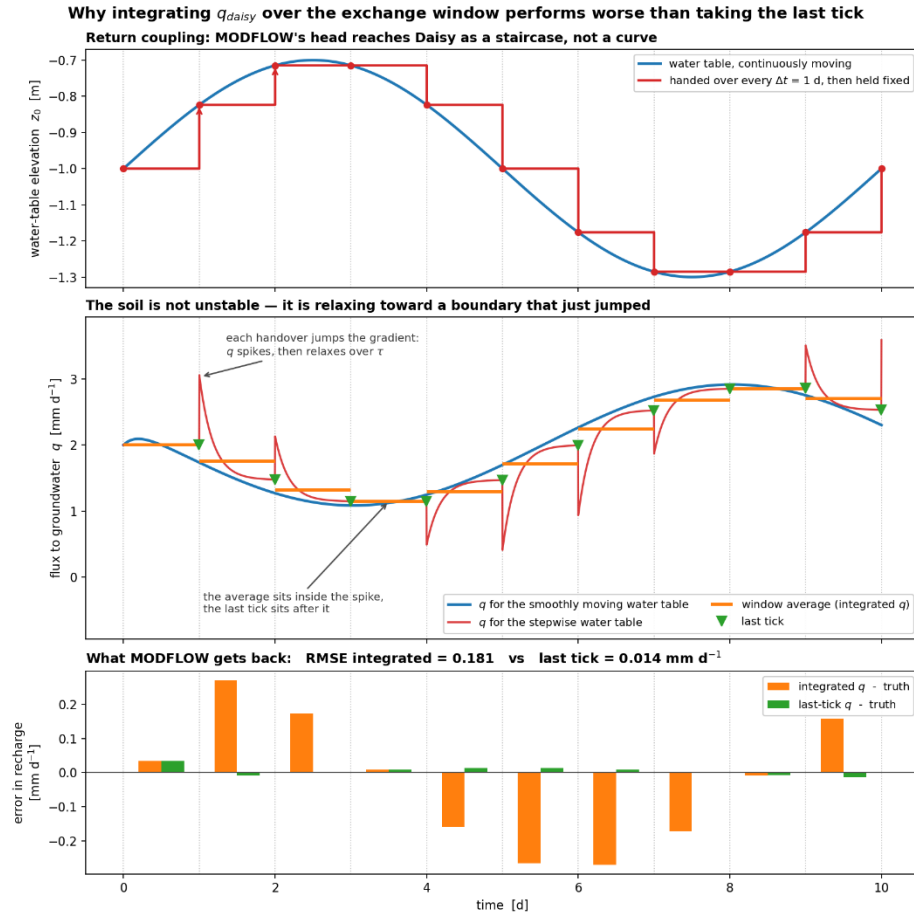
→ Exchange performed at $\Delta t = 1$ day



Coupling insights

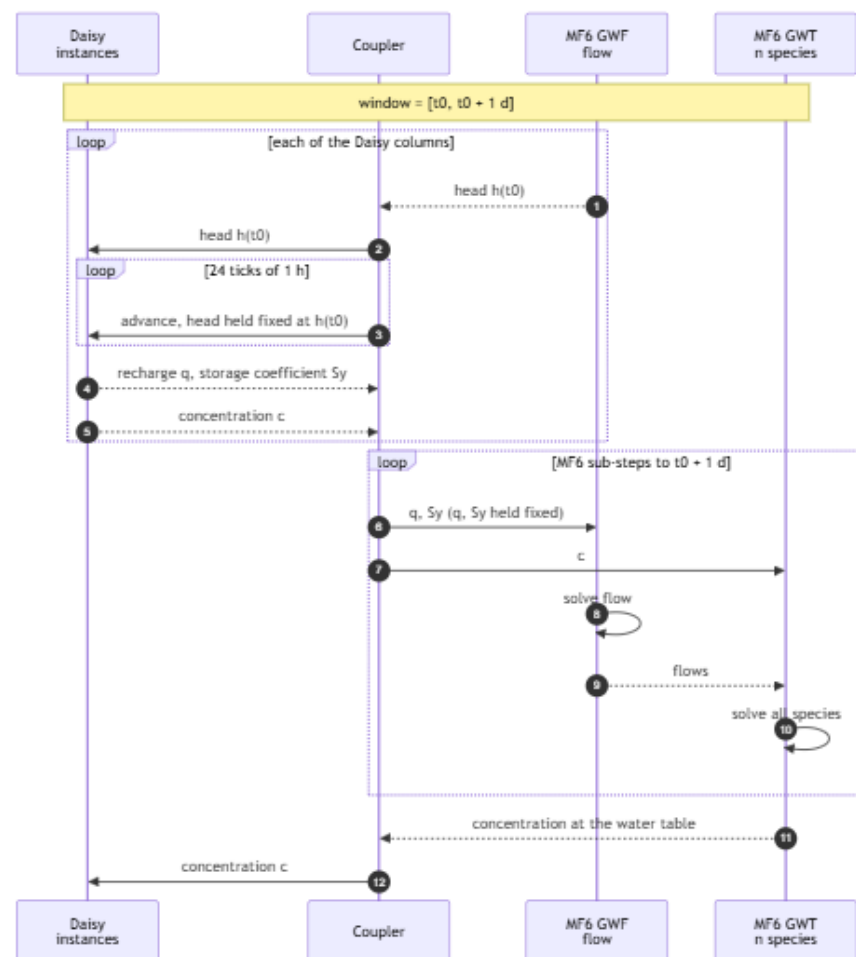
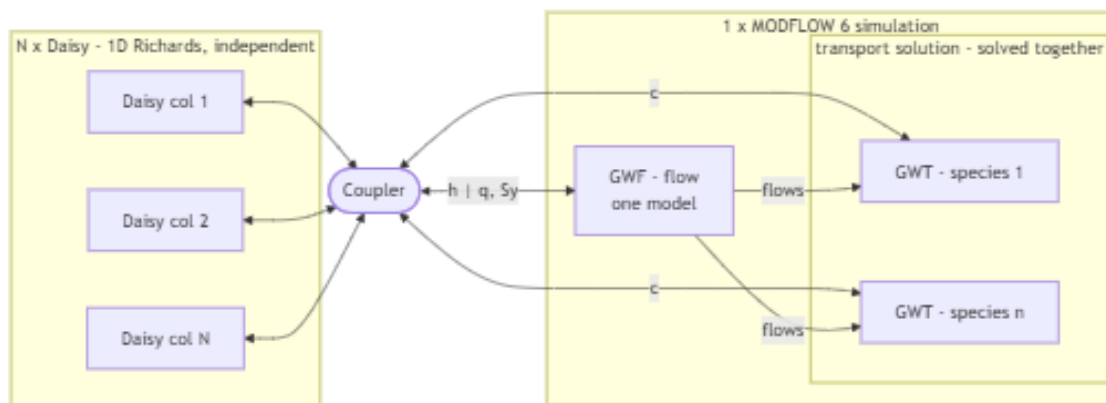
Window-averaged q is biased by exchange-induced transients; the final timestep provides a cleaner recharge signal.

→ Exchange flux taken from final Richards timestep





Final architecture



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