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Stream-aquifer interaction of a large Alpine river with heat-tracer methods and hydrological modeling

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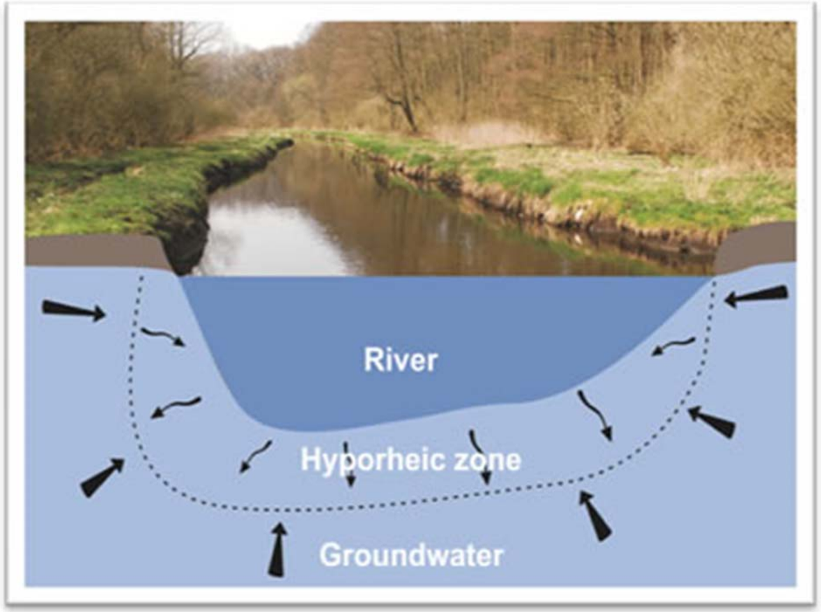
Motivation



An illustration of the hyporheic zone
(© Joerg Lewandowski, IGB)

The transition zone between surface water in streams and groundwater has a key role for:

- maintaining the ecological functions of running waters
- understanding hydrodynamic processes (exfiltration or gaining condition and infiltration or losing condition)
- Predicting water quality issues caused by polluted water transported between groundwater and surface water

Objectives

- Investigating river-groundwater interaction of a large Alpine river, in Italy, through a field campaign
- Implementing a distributed hydrological model that includes groundwater flow and interaction with river
- Predicting infiltration and exfiltration conditions for different flow regimes

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The Toce Alpine river basin

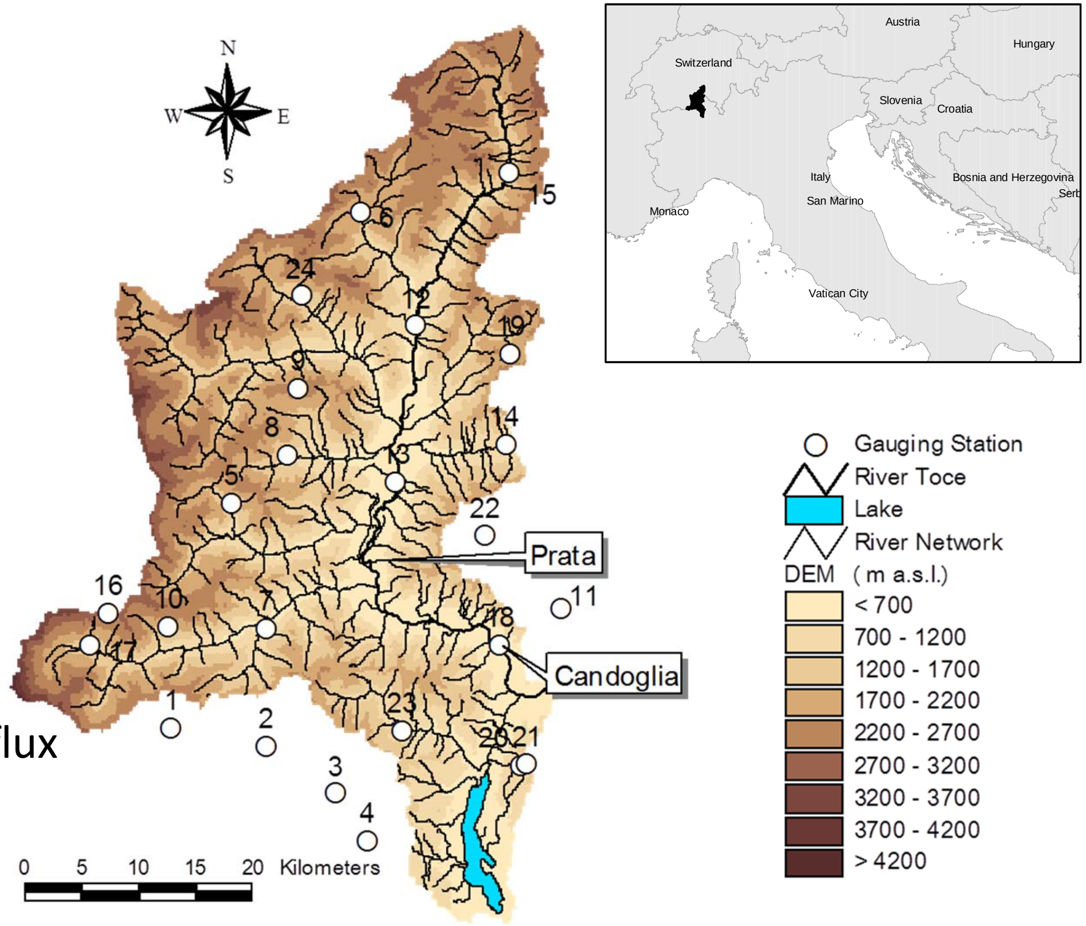
Total area: 1800 km^2

Area at Candoglia: 1500 km^2

Area at Prata: 1100 km^2

Discharge gauging station in Candoglia

Field campaign for groundwater-river flux assessment in Prata



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The flow duration curve

FEST-WB: *F̲lash – flood E̲vent – based S̲patially – distributed rainfall – runoff T̲ransformation – including W̲ater B̲alance*

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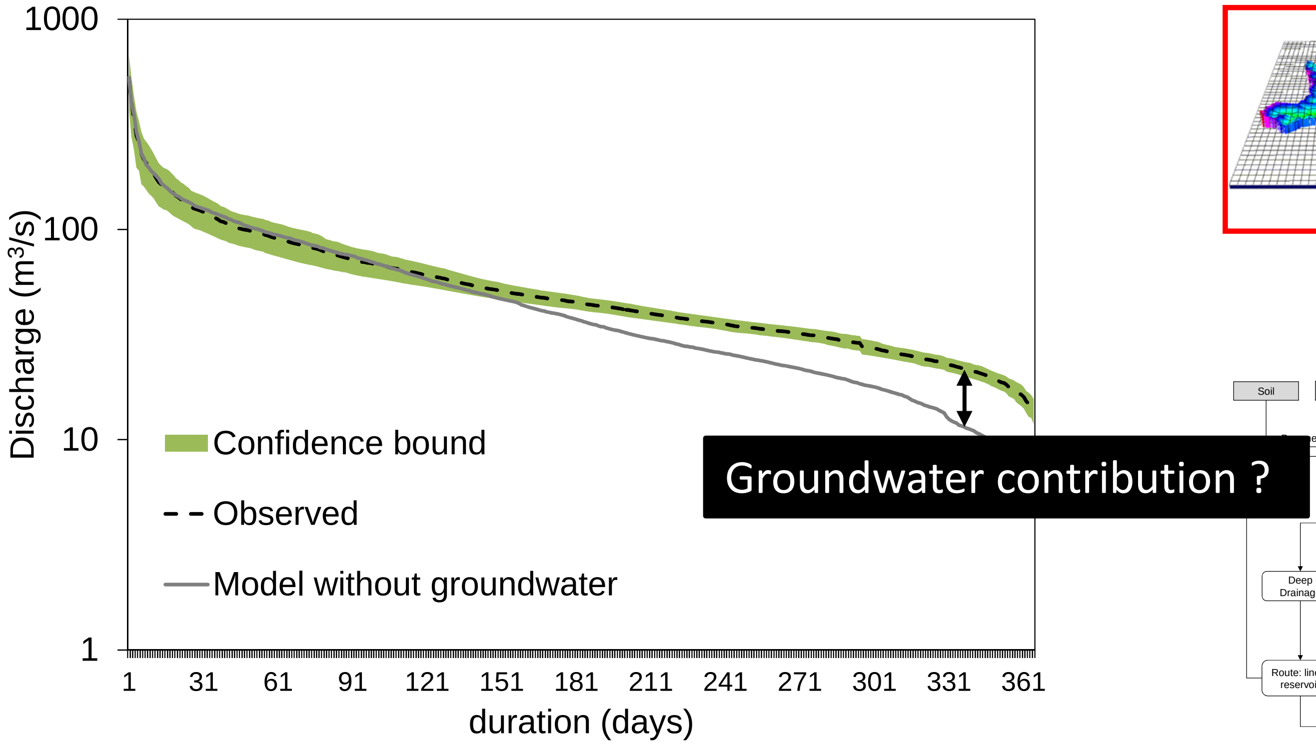
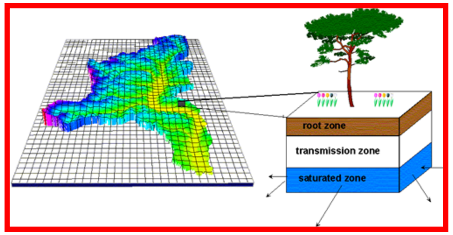
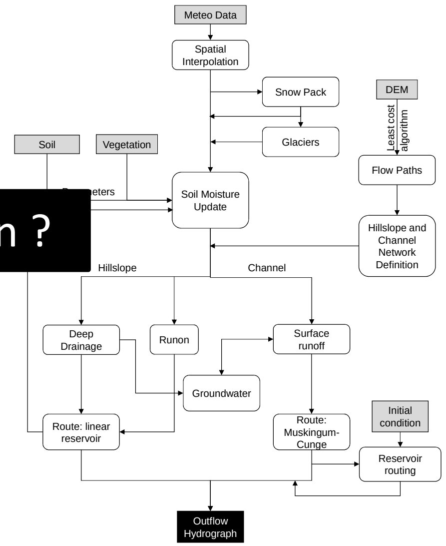
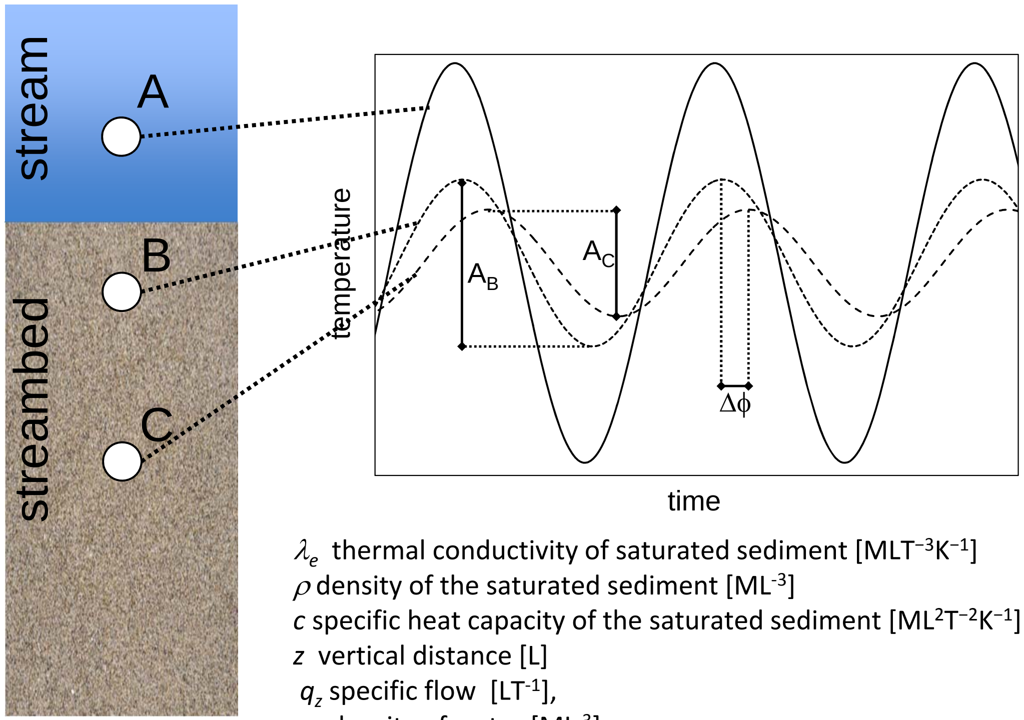






Damping and phase attenuation of temperature with depth



Keery et al. (2007)

$$\left(\frac{H^3 D}{4z}\right)q_z^3 - \left(\frac{5H^2D^2}{4z^2}\right)q_z^2 + \left(\frac{2HD^3}{z^3}\right)q_z + \left(\frac{\pi c \rho}{\lambda_e \tau}\right)^2 - \frac{D^4}{z^4} = 0$$

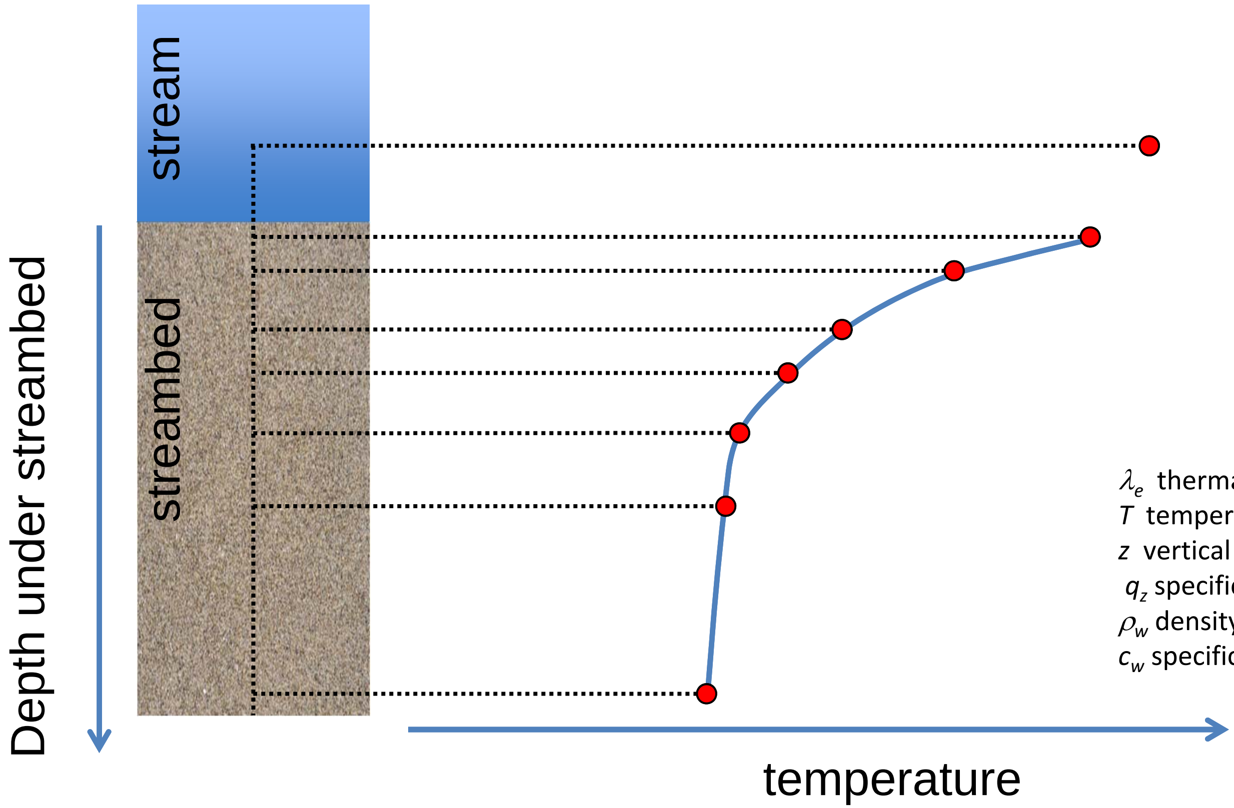
$$D = \ln\left(\frac{A_{z,t+\Delta t}}{A_{0,t}}\right) \qquad H = \frac{c_w \rho_w}{\lambda_e}$$

λ_e thermal conductivity of saturated sediment [$MLT^{-3}K^{-1}$]
ρ density of the saturated sediment [ML^{-3}]
c specific heat capacity of the saturated sediment [$ML^2T^{-2}K^{-1}$]
z vertical distance [L]
q_z specific flow [LT^{-1}],
ρ_w density of water [ML^{-3}]
c_w specific heat capacity of the water [$ML^2T^{-2}K^{-1}$]

$A_{z,t+\Delta t}$ temperature amplitude at depth z and time $t + \Delta t$
$A_{0,t}$ temperature amplitude at the river bed surface at time t
Δt time lag between temperature amplitudes

Heat-tracer methods
Steady-state heat transport solutions

Temperature profile along a vertical

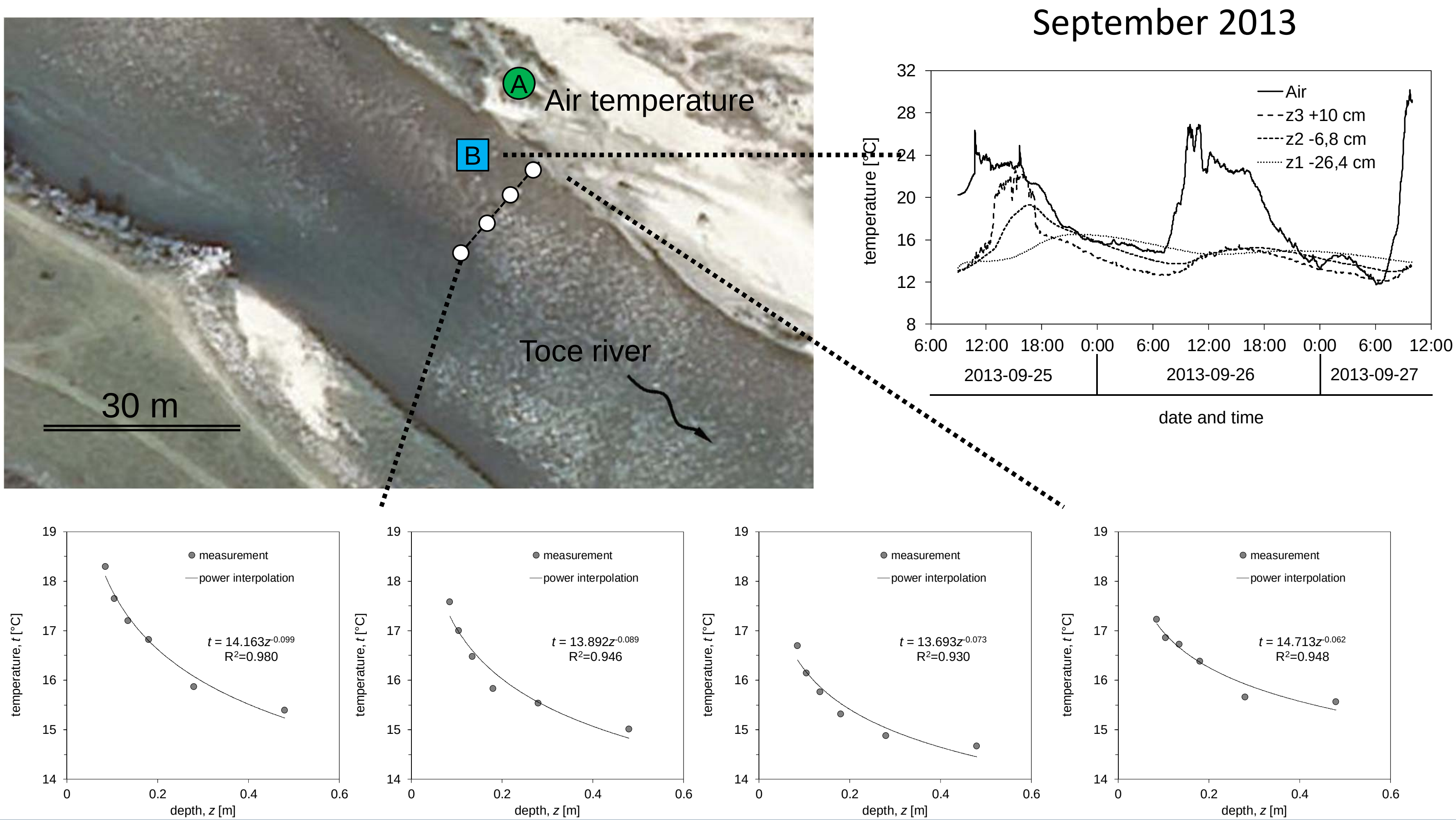


Bredehoeft and Papadopulos (1965)
Schmidt et al., (2006)

$$\frac{T(z)-T_0}{T_L - T_0} = \frac{\exp\left(\frac{q_z \rho_w c_w}{\lambda_e} z\right) - 1}{\exp\left(\frac{q_z \rho_w c_w}{\lambda_e} L\right) - 1}$$

λ_e thermal conductivity of saturated sediment $[MLT^{-3}K^{-1}]$
T temperature [K]
z vertical distance [L]
q_z specific flow $[LT^{-1}]$,
ρ_w density of water $[ML^{-3}]$
c_w specific heat capacity of the water $[ML^2T^{-2}K^{-1}]$

Field campaign



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Field campaign

Transient heat transport solution

q_z *[m/d] = -0.31*

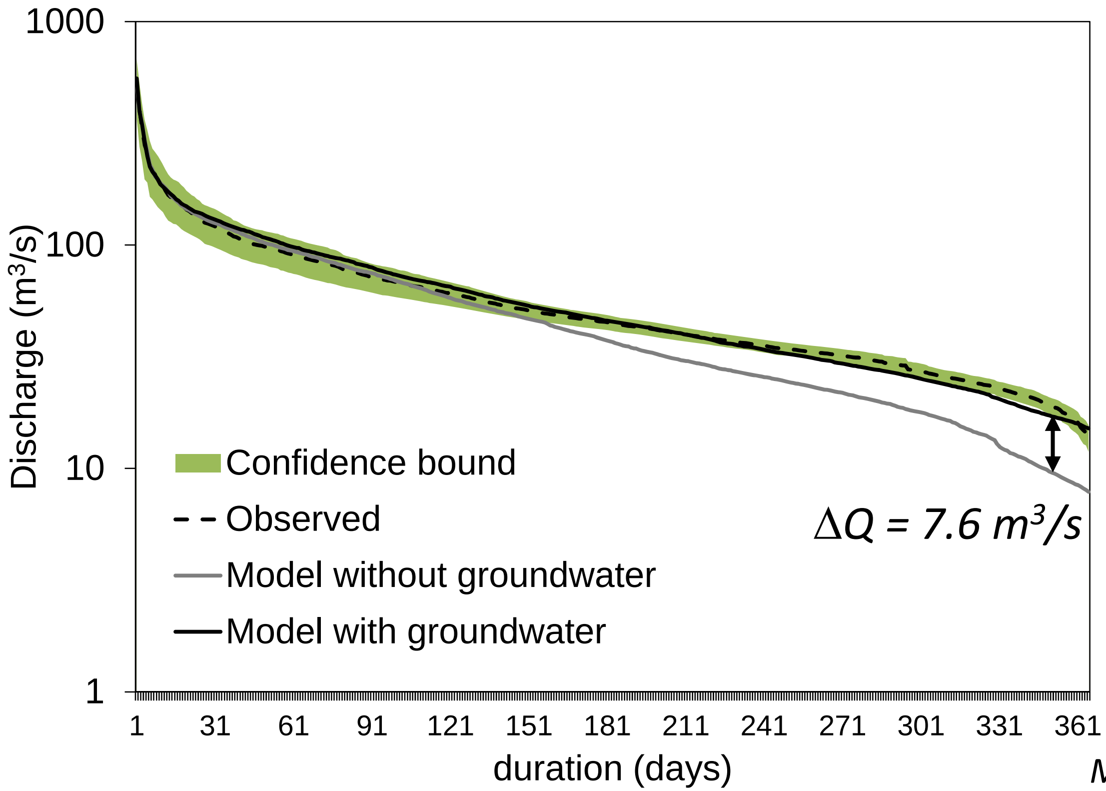
Q [m^3*/s] = 7.17*

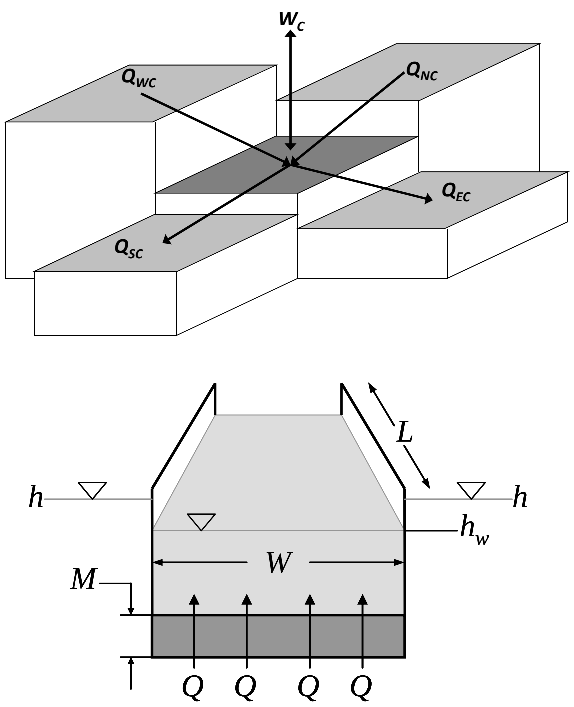
Steady-state heat transport solutions

q_z *[m/d] = -0.33*

Q [m^3*/s] = 7.64*

The flow duration curve with groundwater interaction





MACCA-GW, Ravazzani et al. / Environmental Modelling & Software 26 (2011) 634e643

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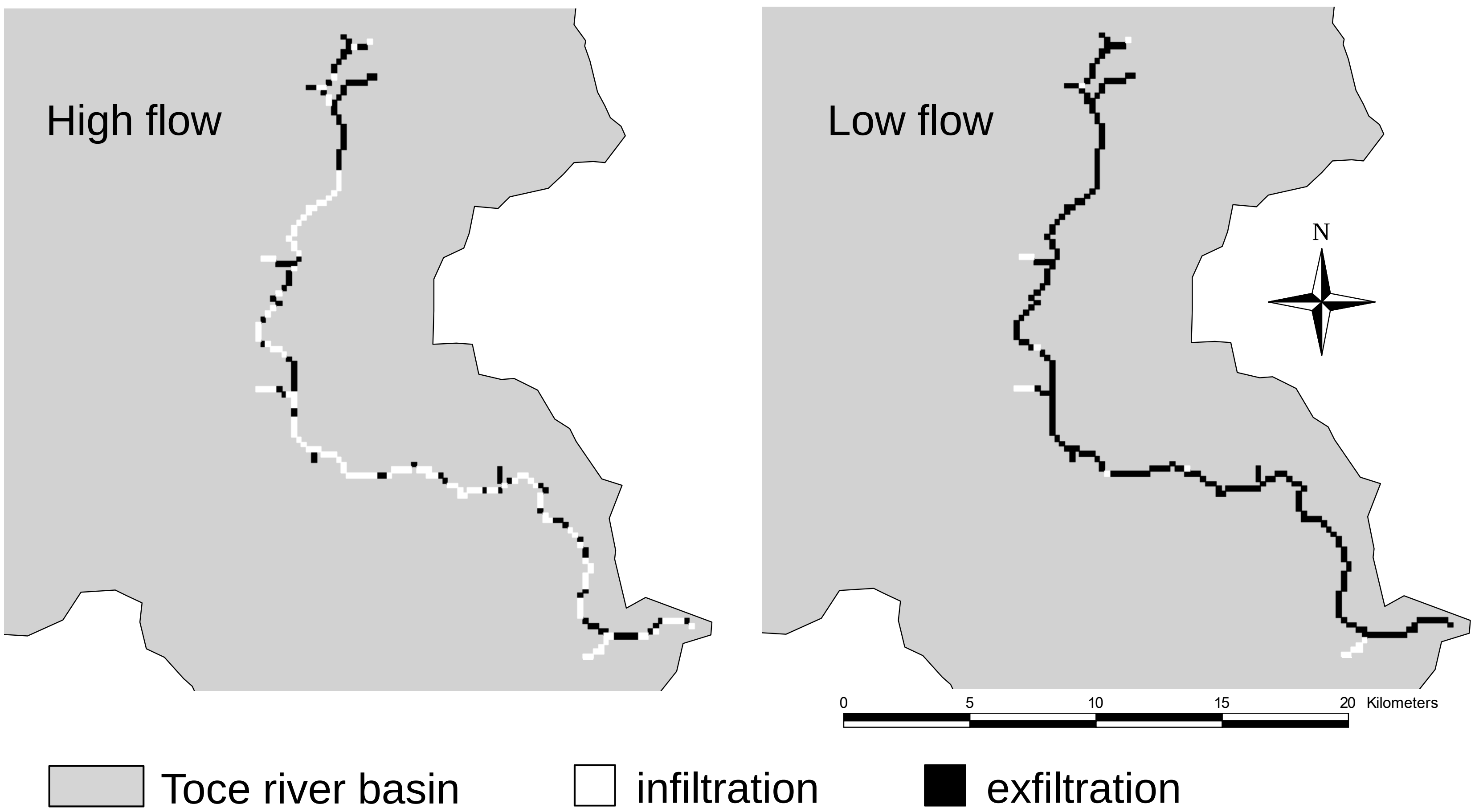
Modelled infiltration and exfiltration condition



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Conclusions

- Through a field campaign we assessed that groundwater contribution to Toce streamflow is significant when river discharge is low
- A groundwater model that interacts with river flow was implemented and, as a result, underestimation of river discharge for low flow regime was eliminated.
- Modelled groundwater contribution to streamflow is in agreement with the field campaign results
- the distributed hydrological model allows to predict infiltration and exfiltration conditions even for high discharge when a field campaign would not be possible

THANK YOU FOR YOUR ATTENTION

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