POLITECNICO MILANO 1863

Assessing groundwater contribution to streamflow of a large Alpine river with heat-tracer methods and hydrological modeling

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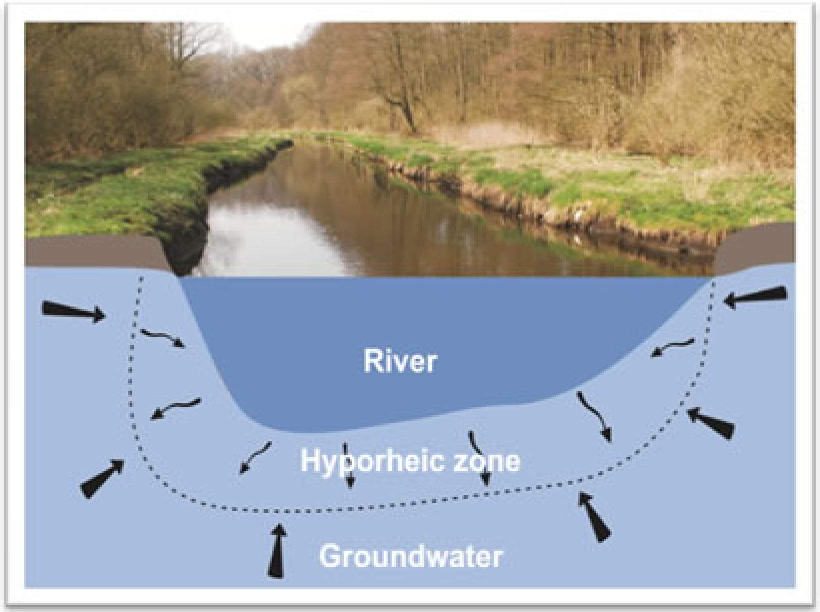
ACCADEMIA NAZIONALE DEI LINCEI

Roma, March 22nd 2018

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

Ravazzani, G., Curti, D., Gattinoni, P., Della Valentina, S., Fiorucci, A., Rosso, R., 2015. Assessing groundwater contribution to streamflow of a large Alpine river with heat-tracer methods and hydrological modeling. ***River Research and Applications***, 32(5), 871-884, doi: 10.1002/rra.2921

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The Toce Alpine river basin

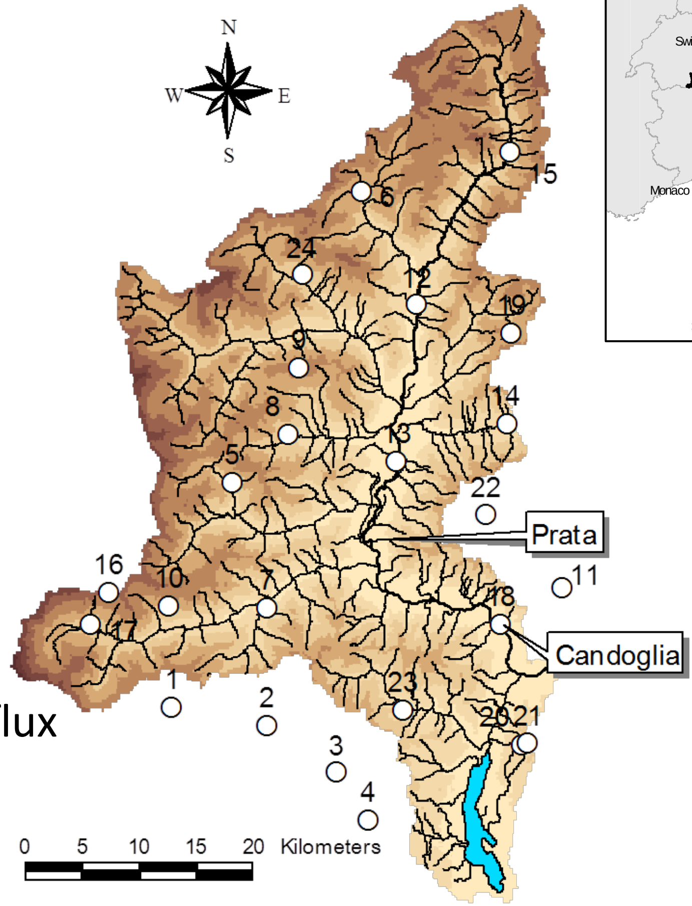
Total area: 1800 km^2

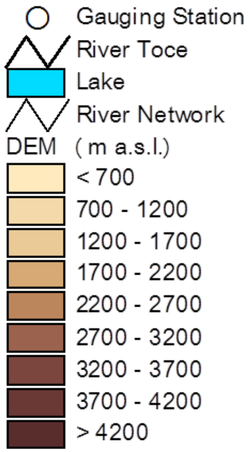
Area at Candoglia: 1500 km^2

Area at Prata: 1100 km^2

Discharge gauging station in Candoglia

Field campaign for groundwater-river flux assessment in Prata





The flow duration curve

FEST-WB: *Flash – flood Event – based Spatially – distributed rainfall – runoff Transformation – including Water Balance*

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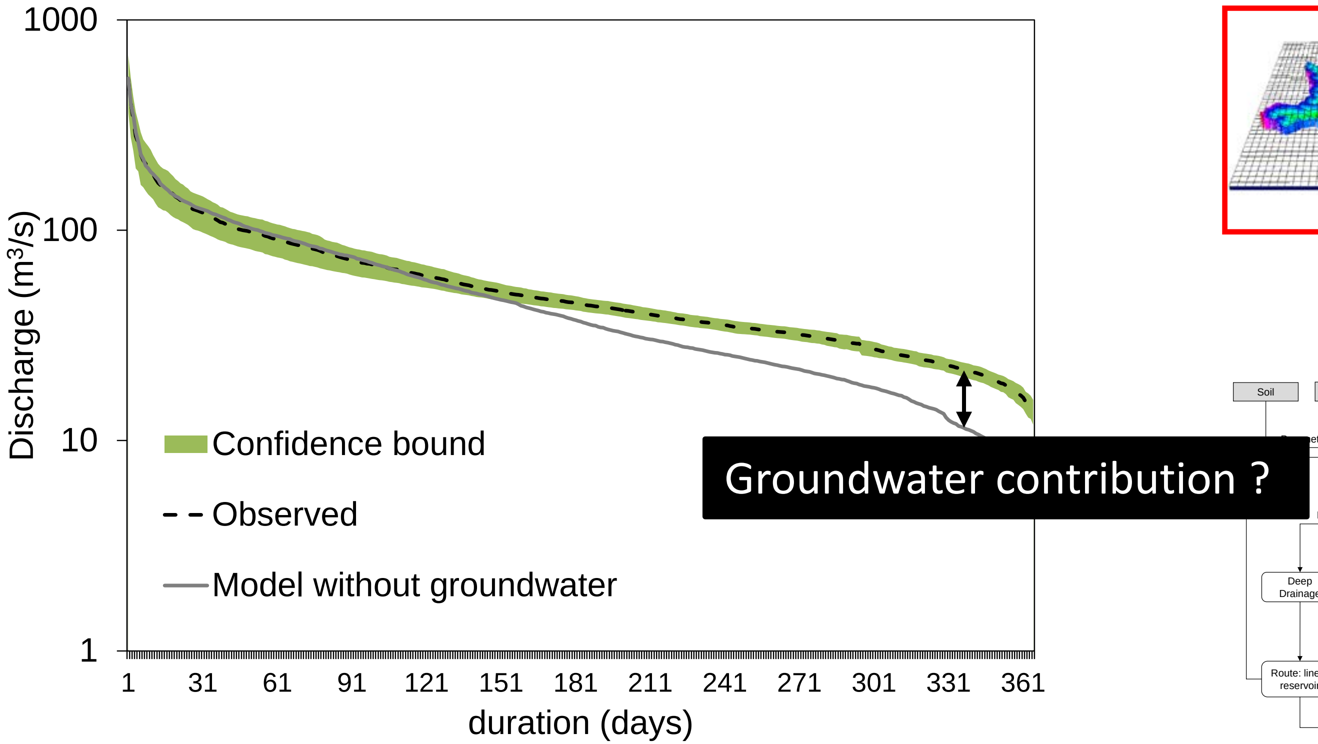

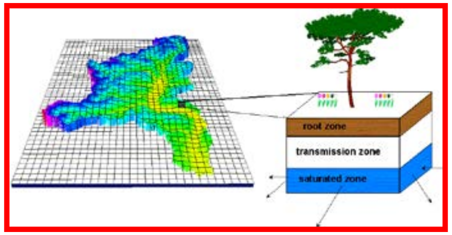

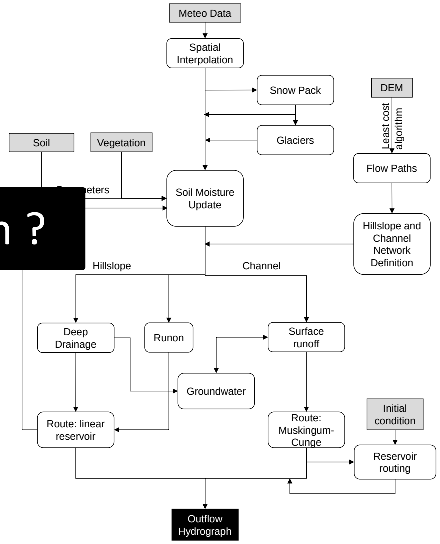

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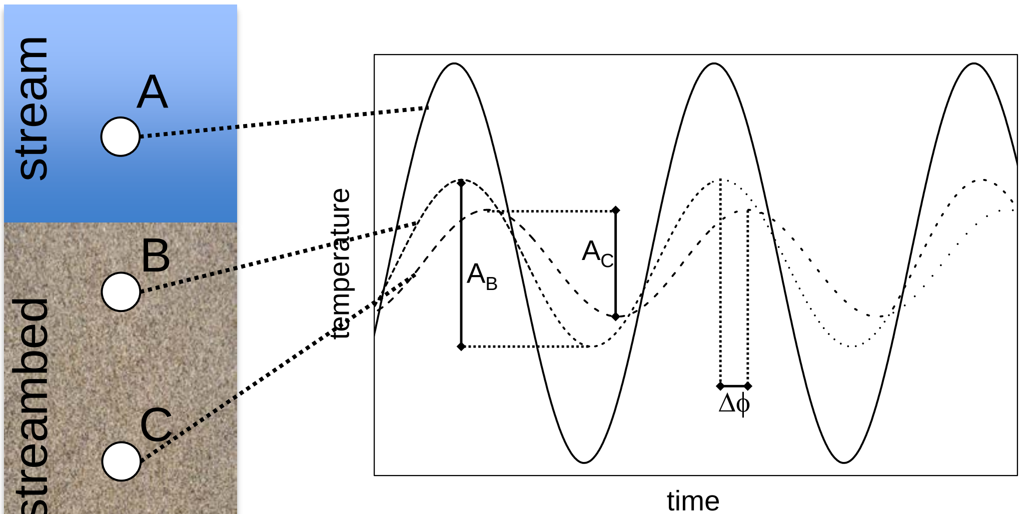
Heat-tracer methods
Transient heat transport solution

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

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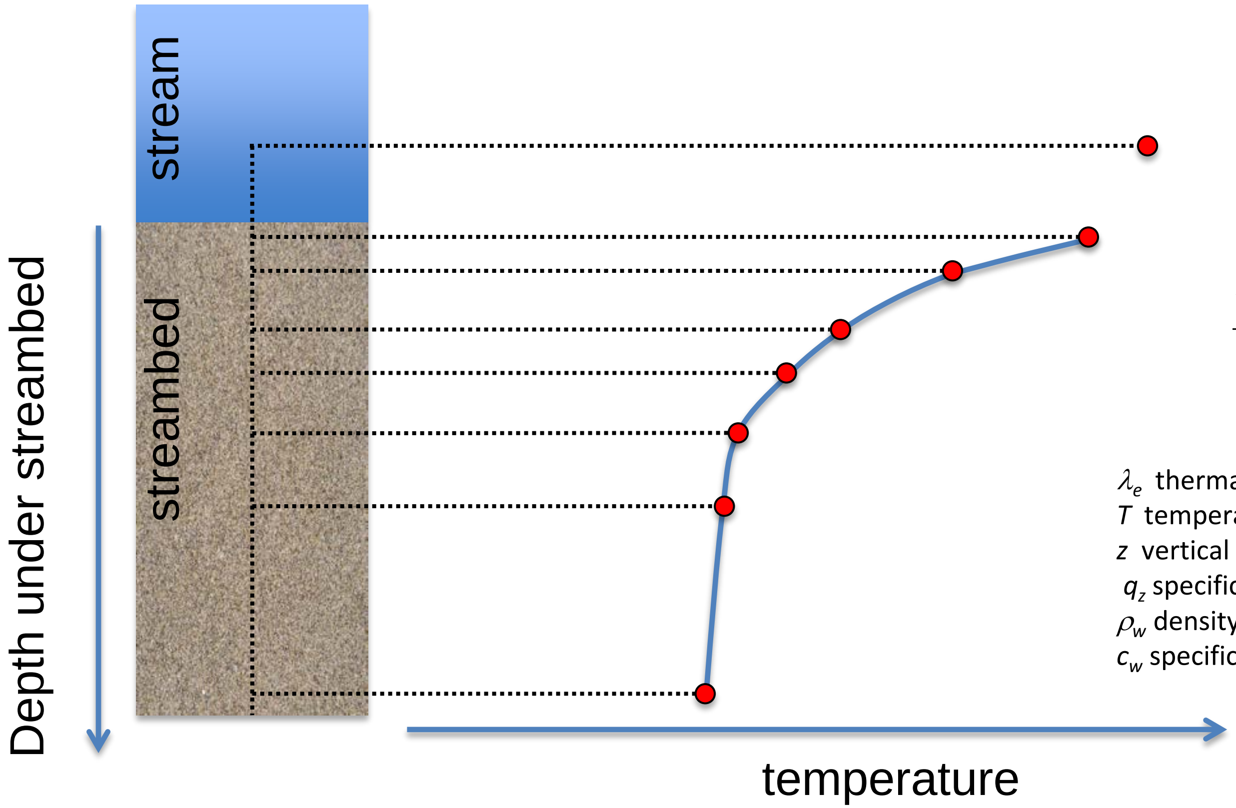
Heat-tracer methods

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 [$ML^2T^{-2}K^{-1}$]

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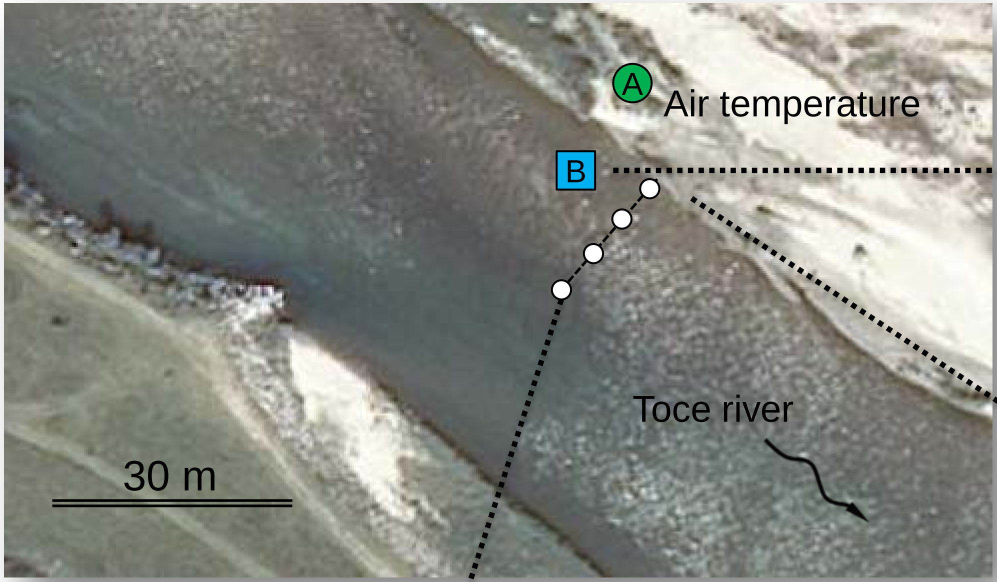
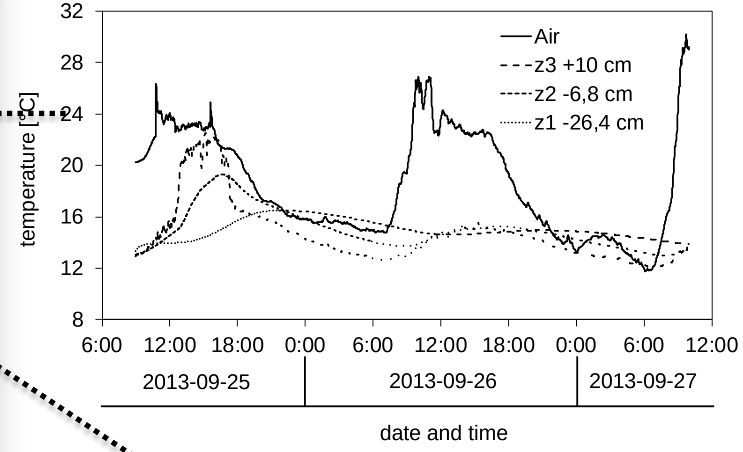
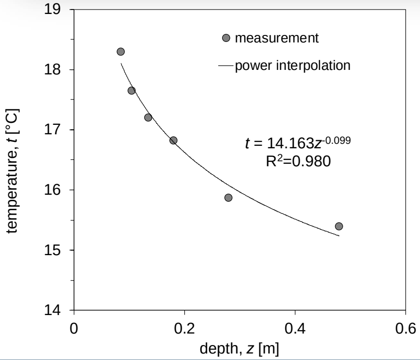
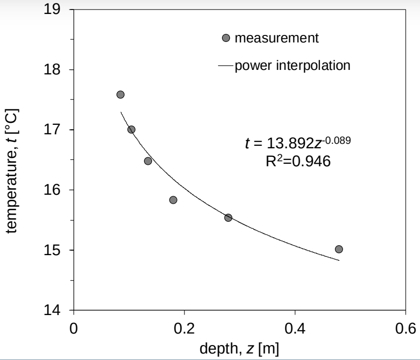
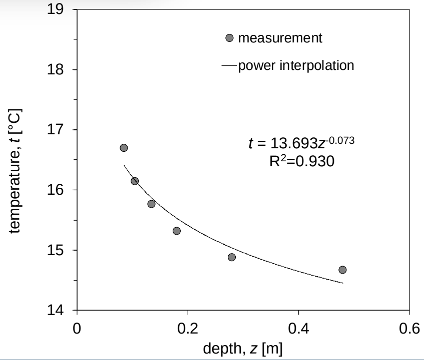
Field campaign

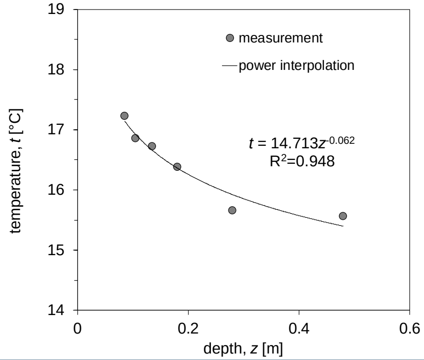












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Field campaign

Transient heat transport solution

q_z [m/d] = -0.31

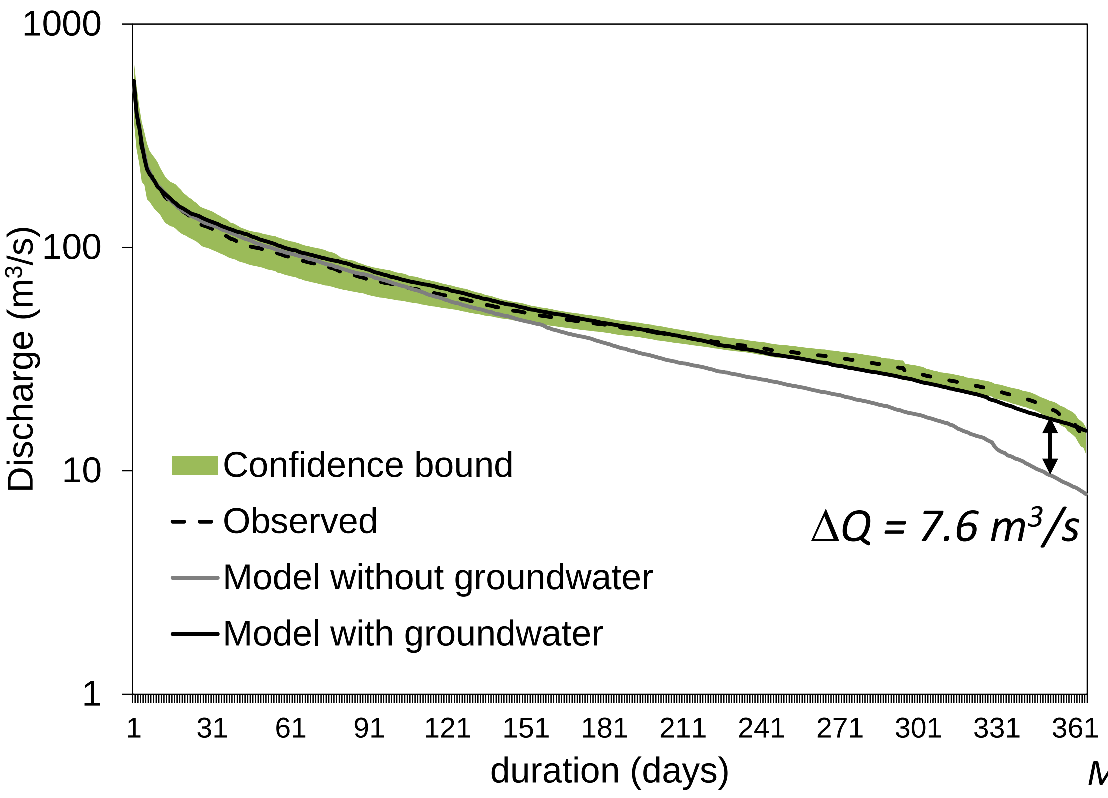
Q [m^3/s] = 7.17

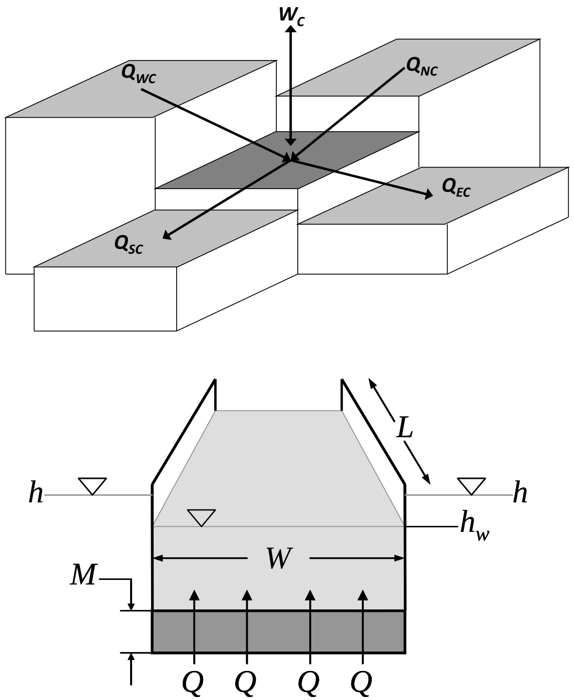
Steady-state heat transport solutions

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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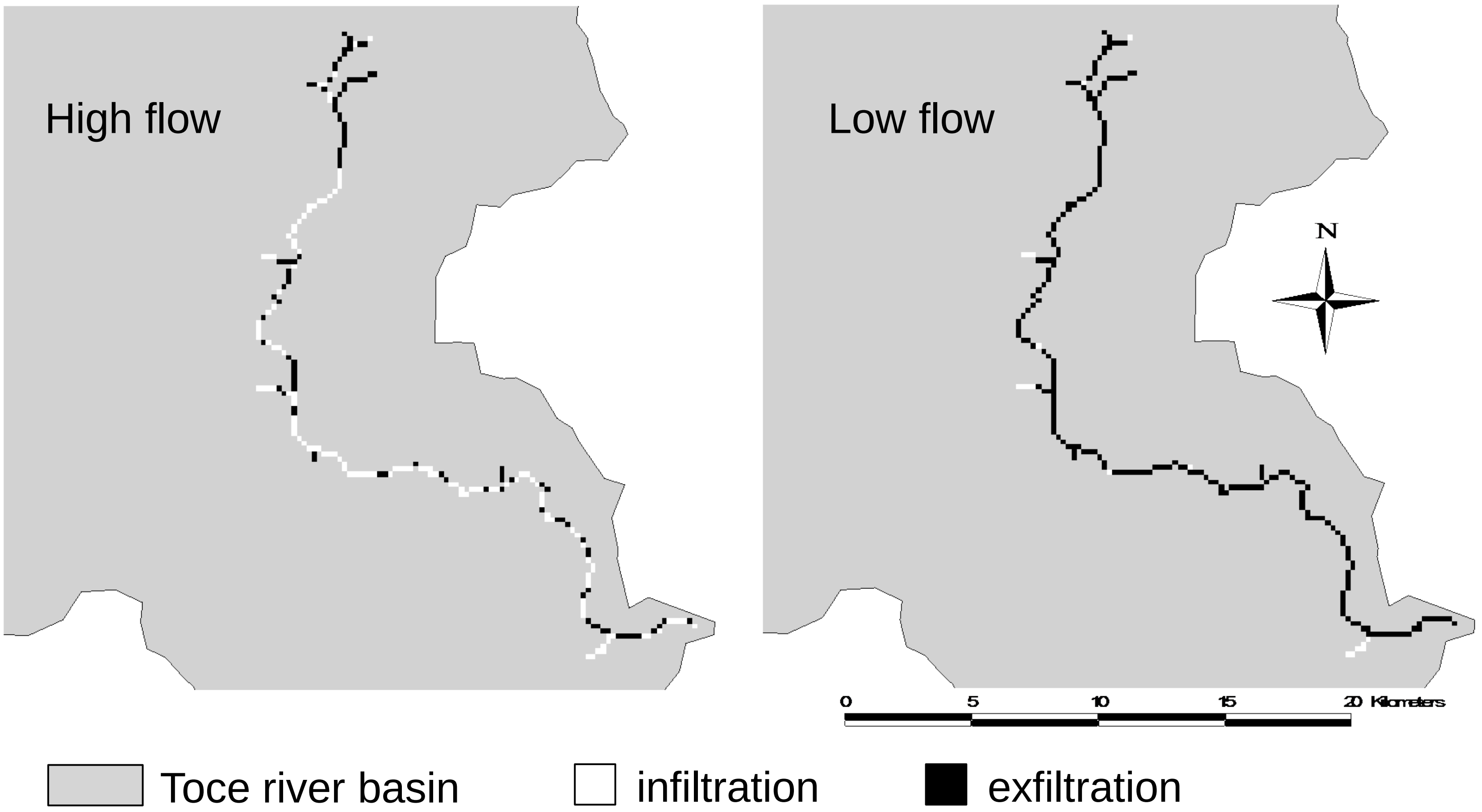
Modelled infiltration and exfiltration condition



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

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THANK YOU FOR YOUR ATTENTION

This presentation is available on www.ravazzani.it

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www.arpa.piemonte.it

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