“Assessment of hydrological flows in Lombardy Alpine rivers, and their connection with the underground aquifer, under potential climate change scenarios in the XXI century”

F. Fuso¹, C. Righetti², M. Gorla², D. Oliva², D. Bocchiola¹

¹ Politecnico di Milano Dip. Ingegneria Civile e Ambientale, Milano, Italy. ² CAP holding, Salazzurra Idroscalo di Milano, Segrate (MI), Italy.
Production of **weather based hydrological scenarios** in the catchment as boundary conditions for **aquifer modeling during 21° century**

- **Climate scenarios:** 4 GCMs models (4 RCPs scenarios)
- **Hydrological scenarios**
**Data based set up of the hydrological model *Poli-Hydro*:**

- It is a weather driven, physically based, semi distributed hydrological model
  - Spatial resolution: 1 km
  - Temporal resolution: daily

- It is based on the Mass conservation equation of the water soil content between two subsequent temporal steps:
  \[ S^{t+\Delta t} = S^{t} + R + M_{s} + M_{i} - ET - Q_{g} \]

  **Condition for the run-off flow:**
  \[
  \begin{cases}
  Q_{s} = S^{t+\Delta t} - S_{\text{max}} & \text{se} \ S^{t+\Delta t} > S_{\text{max}} \\
  Q_{s} = 0 & \text{se} \ S^{t+\Delta t} < S_{\text{max}}
  \end{cases}
  \]

- Evapotranspiration: Hargreaves formula

- Underground flow: \[ Q_{g} = k \left( \frac{S}{S_{\text{max}}} \right)^{kg} \]

- Snow melting: Pellicciotti model
  \[
  \begin{cases}
  M = DDS \times (T - T_{\text{critical}}) & \text{if} \ T > 0 \\
  M = 0 & \text{if} \ T \leq 0
  \end{cases}
  \]

- Flow routing: Nash model \[ Q = \int_{0}^{t} P(\tau) \ast u(t - \tau) d\tau \quad \text{with} \quad u(t) = \frac{1}{k \Gamma(n)} \left( \frac{t}{k} \right)^{n-1} e^{-\frac{t}{k}} \]
Study area – Hydrological modelling

Legend
- CAP model domain
- DEM
  - High: 4449
  - Low: 30

0 10 20 30 40 50 60 70 80 Kilometers

Po river
Hydrological modelling

INPUT

- DEM of the basin
- Meteorological data in the available stations:
  - Daily mean total precipitation (2001-2018)
  - Daily mean temperature (2001-2018)
- Maps:
  - Land use → CurveNumber maps
  - Vegetation covered areas
  - Ice covered areas
- Sub-basins areas for model calibration through the comparison of measured historical flow and modelled flow

Meteo stations:
- 770 EPSON stations
- 5 Toce basin’s stations

Stations with flow-rate scale:
- 16 stations
Hydrological modelling

**INPUT**

- **Irrigation demand**

  The plain area around Milan (CAP model domain) is highly cultivated. The water for irrigation is taken from the main rivers Ticino (*Consorzio est Villoresi*) and Adda (*Consorzio Adda sponda destra*). Therefore, the hydrological model has to take into account the irrigation water which contributes with the precipitation at the hydrological budget of the domain.

Irrigation areas of Lombardy region - http://www.geoportale.regione.lombardia.it/download-ricerca

Mean values of irrigation demand per year
CALIBRATION

DDS (Degree-day-snow)

The snow melting model is tackled using the degree day approach and melt factor [$\text{mm} \, ^\circ\text{C}^{-1} \, \text{day}^{-1}$]. The DDS is calibrated by comparing the Poli-Hydro simulated snow covered Area (SCA) in different periods during melting season (March-July) with the NASA satellite images MODIS SCA.
Hydrological modelling

CALIBRATION

DDS = 2.9 mm °C⁻¹ day⁻¹
Calibration period: 03/2005 – 06/2010

Validation period: 03/2015 – 06/2018
## CALIBRATION

Model accuracy for natural basins

<table>
<thead>
<tr>
<th>Location</th>
<th>Qobs [m³/s]</th>
<th>Qmod [m³/s]</th>
<th>Err%</th>
<th>NSEmonthly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brembate di Sopra</td>
<td>26.480</td>
<td>20.957</td>
<td>20.86%</td>
<td>0.301</td>
</tr>
<tr>
<td>Camerata Cornelio</td>
<td>10.331</td>
<td>10.526</td>
<td>1.89%</td>
<td>0.615</td>
</tr>
<tr>
<td>Cedec</td>
<td>1.067</td>
<td>0.423</td>
<td>60.33%</td>
<td>0.789</td>
</tr>
<tr>
<td>Gaviamonte</td>
<td>1.218</td>
<td>0.471</td>
<td>61.62%</td>
<td>0.723</td>
</tr>
<tr>
<td>Milano via Feltre</td>
<td>9.312</td>
<td>9.842</td>
<td>5.69%</td>
<td>0.591</td>
</tr>
<tr>
<td>Lesmo peregallo</td>
<td>5.644</td>
<td>6.362</td>
<td>12.71%</td>
<td>0.648</td>
</tr>
<tr>
<td>Castellanza</td>
<td>4.166</td>
<td>3.978</td>
<td>4.52%</td>
<td>0.085</td>
</tr>
<tr>
<td>Candoglia Toce</td>
<td>64.927</td>
<td>76.236</td>
<td>17.42%</td>
<td>0.225</td>
</tr>
</tbody>
</table>

Calibration parameters:
- Superficial and sub-superficial lag times
- Hydraulic conductivity $k$
- Exponent of the underground discharge $Q_g$
Phase 2 - Future scenarios

Climate data forecast until 2100

6 Global circulation models (GCM)

AR5
- Ec-Earth
- CCSM4
- Echam6

AR6
- Ec-Earth3
- CESM2
- Echam6.3

RPC (Representatives pathways for CO2 emissions)
- 2.6
- 4.5
- 8.5

RPC (Representatives pathways for CO2 emissions)
- 2.6
- 4.5
- 7.0
- 8.5
Downscaling

Spatial statics disaggregation of the climate projections from the global scale to the local scale
Future concerns – Work in progress

How the climate in the future will affect the water budget in the catchment?

What will be the regulation politics for the big Lakes inside the catchment?

How the irrigation efficiency will change in the future?

Final goal

Understand how these factors will affect the dynamic of the aquifer for a smart management of the hydric resource