2^{nd} International LIFE REWAT Summer School

Digital water management and water-related agroecosystem services: geostatistics, hydroinformatics and groundwater flow numerical modelling

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Scuola Superiore Sant'Anna
Pisa, Italy

2^{nd} FREEWAT International Workshop

Investigating climate change and groundwater related causes for eutrophication in Lake Lugano

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Participatory Approach : Local Focus Group

Primary concerns:

- ***Water quality of the lake***.
    - *Can surface water be managed better to reduce phosphorous load to the lake. Is phosphorus entering the lake through the groundwater significant and must/can this be addressed?*

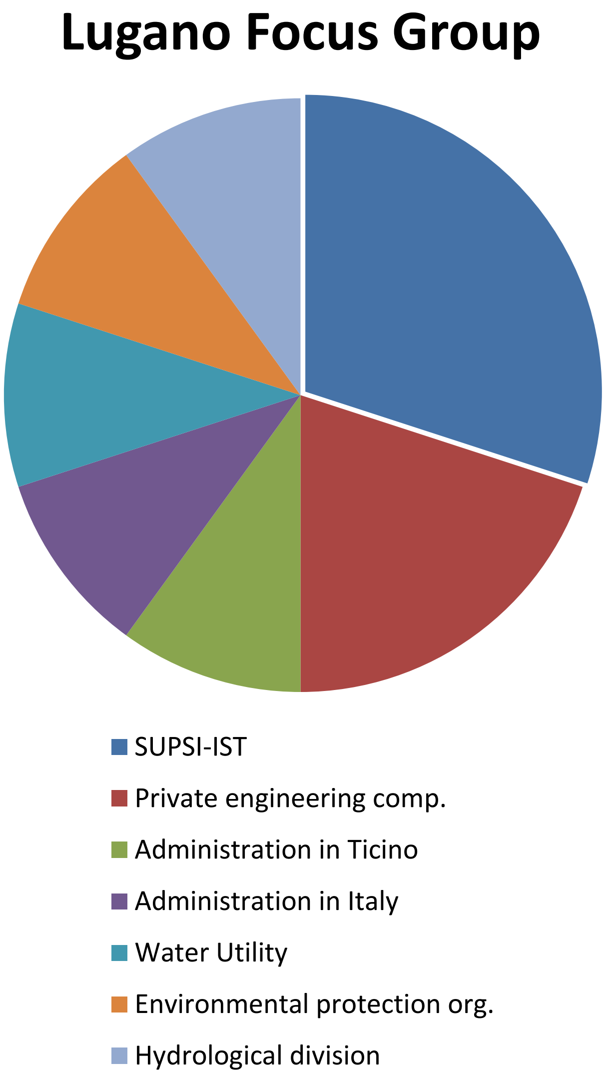
*-A model that can be used for **transport simulation** of a variety of species (phosphorus, nitrogen, pesticides)*

-The possibility to simulate spills for emergency response

*-Delineating **water protection zones***

This topic is very relevant, in the past as a result of an increase in the population and internal migration, the lake became strongly eutrophic with the P concentration reaching 140 mg/m^3. Monitored data still indicates values that still do not meet the objectives of the lake recovery program.

As no GW model existed to date, the application of FREEWAT will enable a better understanding of the lake-GW interactions so that new policies and actions can be designed.



Climate change prognosis for the Southern Alps

The expected conditions in the region are available with low level of confidence but clearly show a substantial impact on the water cycle:

- Temperature: + 1.8 °C (0.9 to 3.1) in winter and +2.8 °C (1.5 to 4.9) in summer
- Precipitation: +11% (1 to 26) in winter and -19% (-6 to -36) in summer

Previous hydrologic investigations show that this is likely to impact the groundwater (aquifers and springs), the river discharges and consequently to the water availability that could be, in some period of the year, limited.

Increased rains in winter and reduction in summer means **less frequent** but **more intense** precipitations. This would produce higher run-off but at the same time less infiltration, reducing the aquifer recharges. At the same time, higher temperature would produce higher evapotranspiration and evaporation increasing the water losses.

Effects of climate change

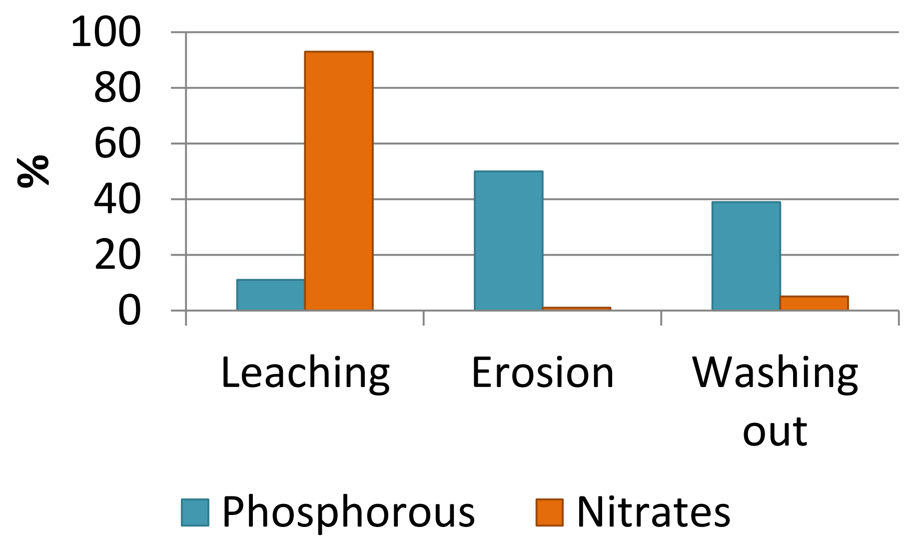
The main concern in the watershed is the **eutrophication** of the Lugano Lake

Controlling factor: orthophosphate load to the lake.

This status of the water could be responsible for anoxic water, algal blooms which can produce harmful toxins, decrease in diversity and habitat destruction.

External load of phosphorous 2014:

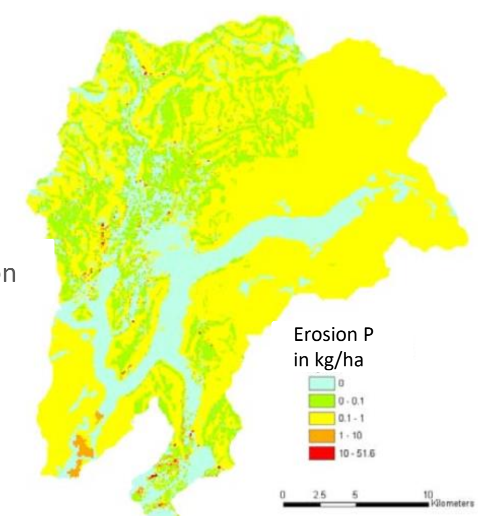
- North basin = 21 tons (Goal =18)
- South basin = 34 tons (Goal = 22)



$$10CO_2 + 16NO_3^- + 1HPO_4^- + 122H_2O + 18H^+$$

Photosynthesis $\Downarrow$ $\Uparrow$ Respiration

$$\{C_{106}H_{263}O_{110}N_{16}P_1\} + 138O_2$$



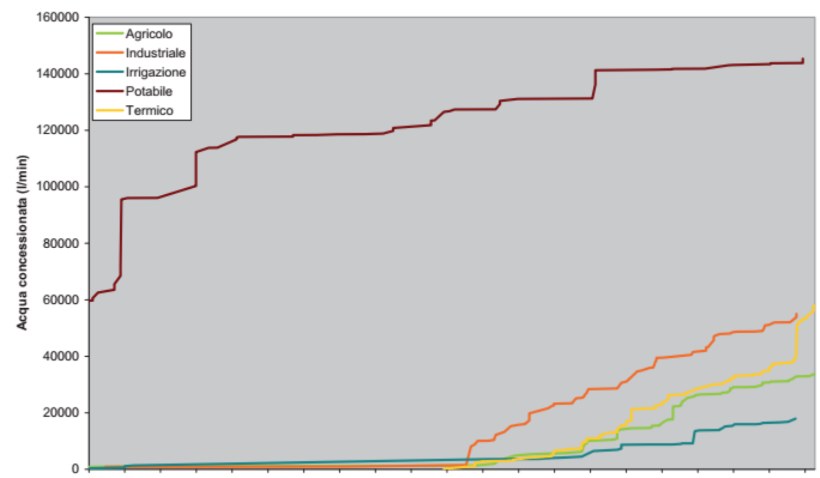
Laura Ferrario (2009) Quantificazione e caratterizzazione dei carichi di nutrienti in entrata al lago di Lugano (Svizzera – Italia), Università degli Studi dell'Insubria.

Observed trends in water use

The registered **water usage** for shows that 41% came from groundwater, 40% from springs and 19% from superficial water. The water use **per capita (PE)** has grown until the 1970, then it has remained almost constant for 15 years and since the 1985 a slight but continuous decrease has been registered. The main reason for this decrease of water usage is mainly due to:

- Structural industrial renewal with introduction of systems with internal water recycle
- Installation of water consume meters
- Promotional campaigns to sensitise citizens on water saving
- Water infrastructure renewal reduced leakages

An important registered trend in the region is the **increase of water concessions** for geothermal use. While form a water balance point of view this is not significant, since generally the pumped water is released back into the aquifer, this type of use from a water **quality perspective** is not risk-free.



Objectives to be reached

Derive a complete and robust groundwater that can be used to calculate water budgets, GW-surface water interactions, alternative water management scenarios, especially related to solute transport.

Investigate the phosphorous exchange dynamics between the surface waters and the groundwater.

The case study will additionally demonstrate the two portions of the FREEWAT environment: the Observation Analysis Tool (OAT) and the Lake package (LAK). The OAT tool will be used to incorporate several monitoring stations already existing around Lugano into the case study model, while the LAK will be used to simulate the interaction between the aquifers and the lake.

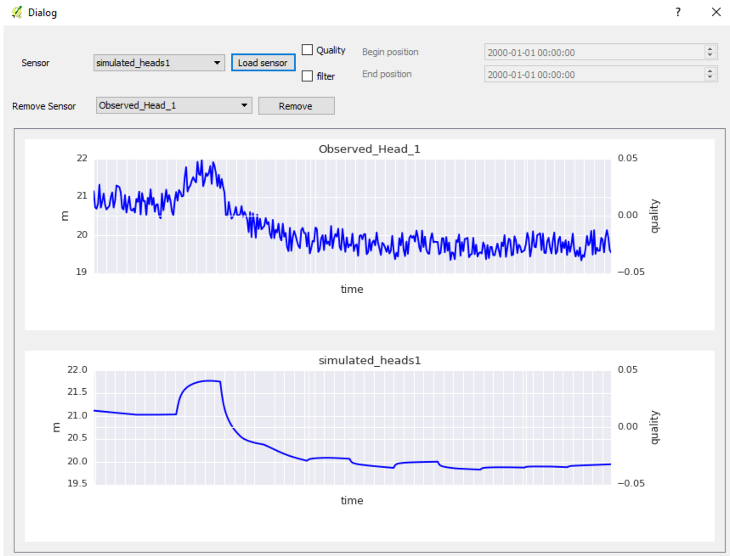
OAT in a nutshell

Time series are a key aspect in environmental modelling, and more and more are getting important with the increasing establishment of diffuse, online and real-time monitoring networks.

Using OAT you can upload, explore, analyse and get the maximum value out of your observations.

In particular, they are important as a means of:

- understanding the system to be modelled and thus support the **preparation of model input data**
- verification of models results and thus help to **calibrate your model**.



The Lake Package

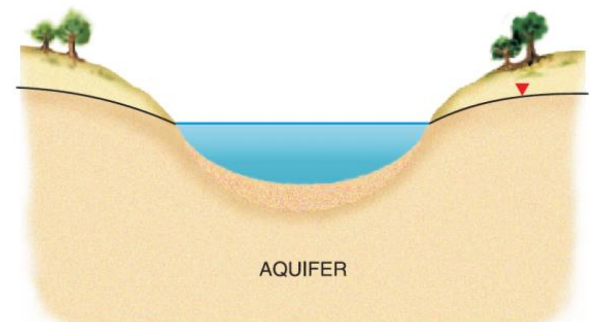
A technique to describe the dynamic hydraulic interaction between a lake and the surrounding aquifer so that the effect of changes in either water body on conditions in the other can be estimated

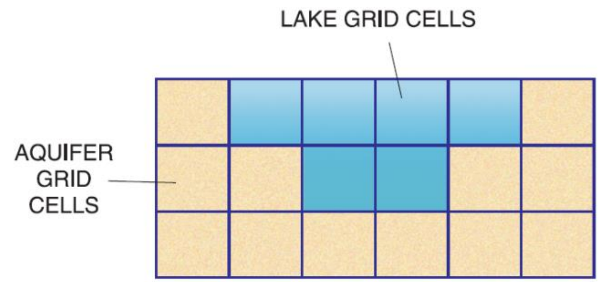
Active cells adjacent exchange water with the lake at a rate **Q** determined by :

- relative head/stage
- hydraulic conductivities of the aquifer materials
- area of lakes

Lake leakance depends on lakebed sediments and aquifer properties

- Can Incorporate:
  - rate of lake atmospheric recharge
  - evaporation,
  - overland runoff rate after precipitation
  - rate of any direct withdrawal





$$Q = qA = \frac{KA}{\Delta l}(h_l - h_a) = c(h_l - h_a)$$

leakance

$$c = \frac{A}{\frac{b}{K_b} + \frac{\Delta l}{K_a}}$$

Conductances of the lakebed and aquifer as if they were in series
(McDonald and Harbaugh, 1988)

Study Area

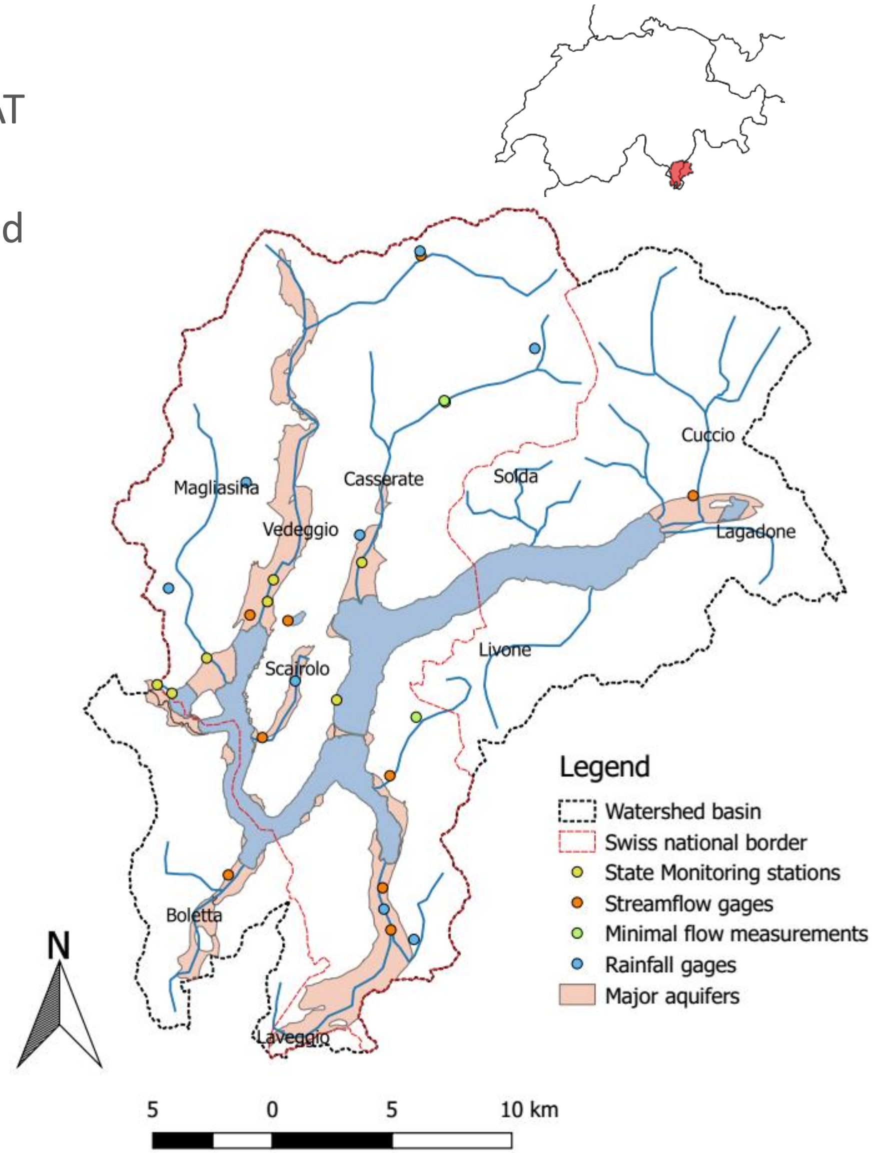
General Objectives

- demonstrate the two portions of the FREEWAT environment:

  The Observation Analysis Tool (OAT) and the Lake package (LAK).

Model

- 5 main aquifers: **Veddegio, Cassarate**, **Cuccio**, **Laveggio**, and **Boletta**.
- Aquifers will be the main areas of interest. These will be connected through the lake.
- Discharge of the watershed is an automatically adjusted weir.



Spatial Discretization

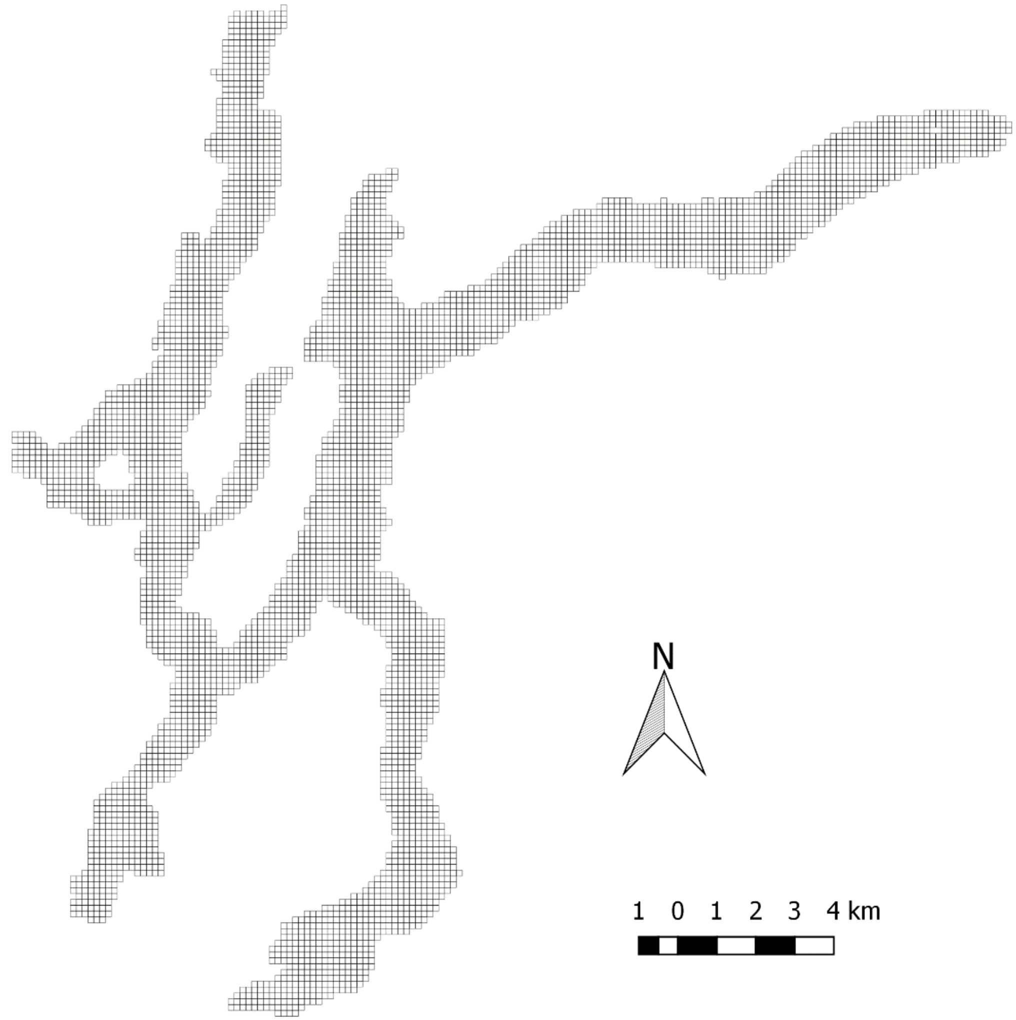
horizontal discretization of 150 by 150 meters

Vertical discretization is currently 2 model layers (irregular depth with DEM, geology and lake bathymetry).

29,583 cells

→ 4,980 active in Layer 2,

→ 2,578 cells in layer 1 Are lake cells



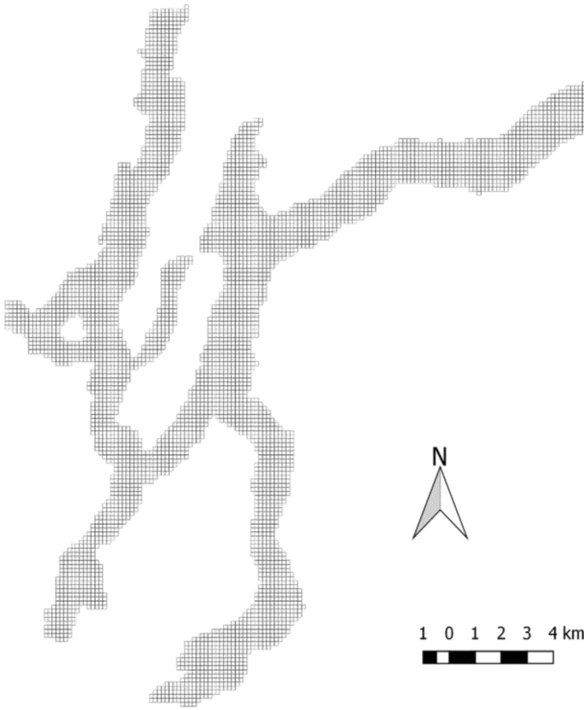
Temporal Discretization

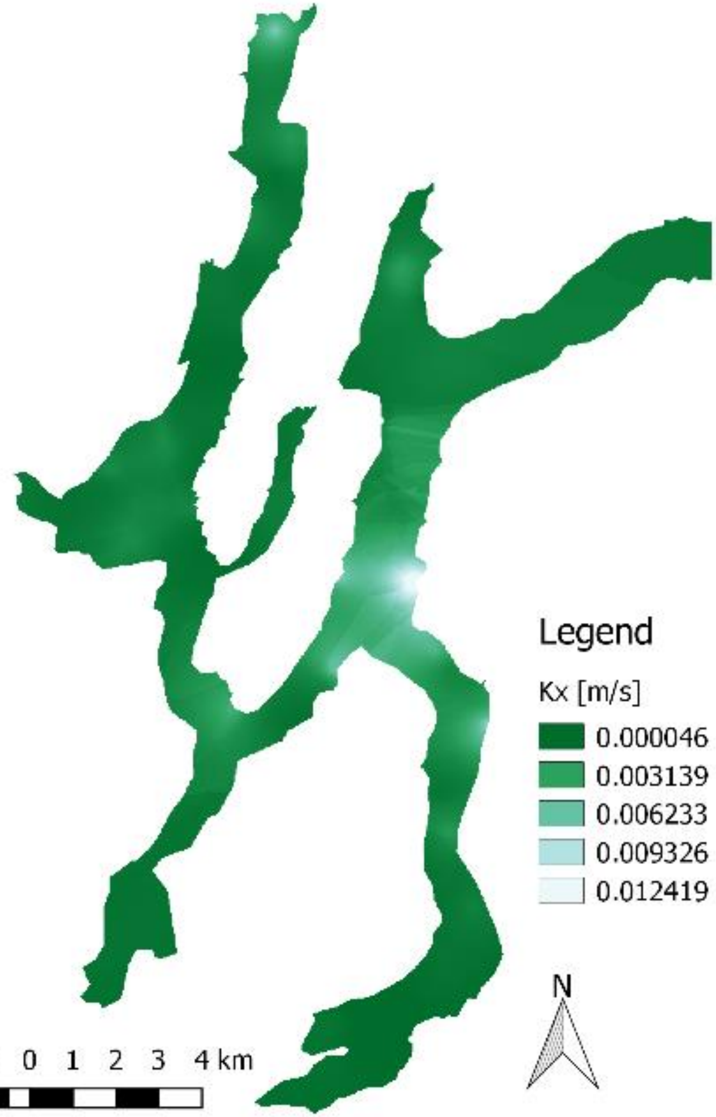
The model time is 52 weekly stress periods with daily time steps from 01.01.2012 to 29.12.2012.

The model time unit is seconds. Each stress period is 604,800 seconds long.

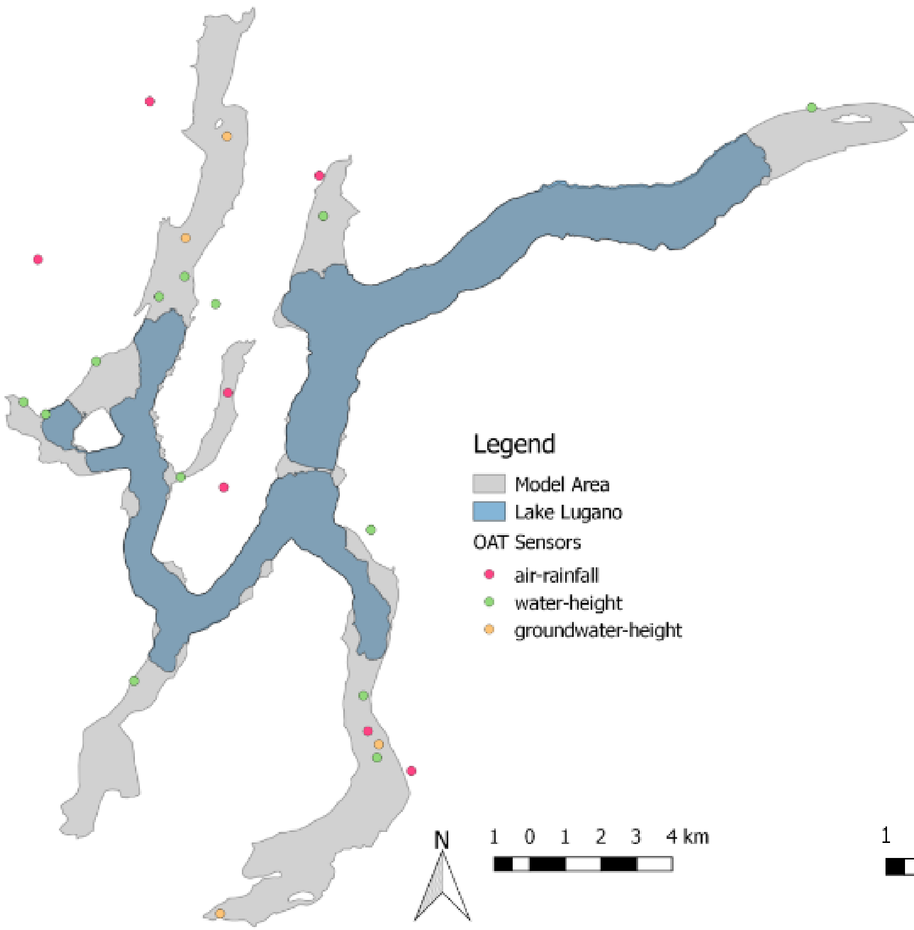
SP number	From	To	Length (days)	Time steps	State
1	01-01-2012	07-01-2012	604800	7	Transient
…	…	…	604800	7	Transient
52	22-12-2012	29-12-2012	604800	7	Transient

LPF → Layer property from boreholes db interpolation

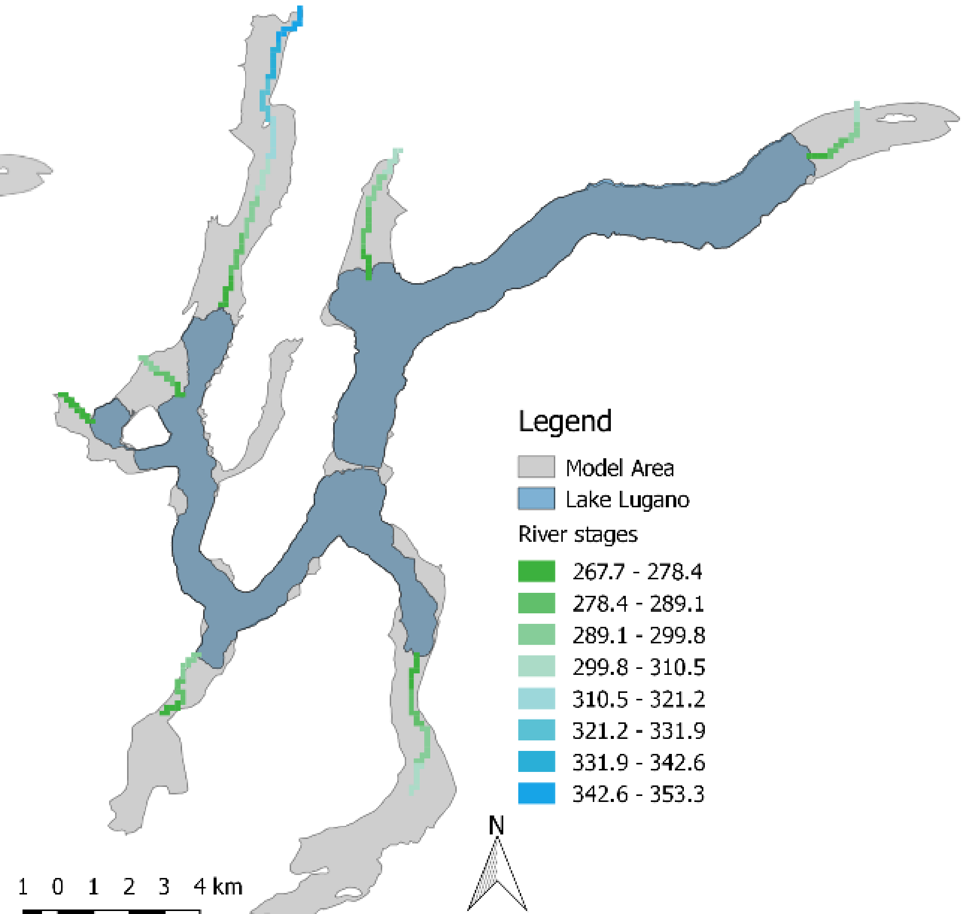


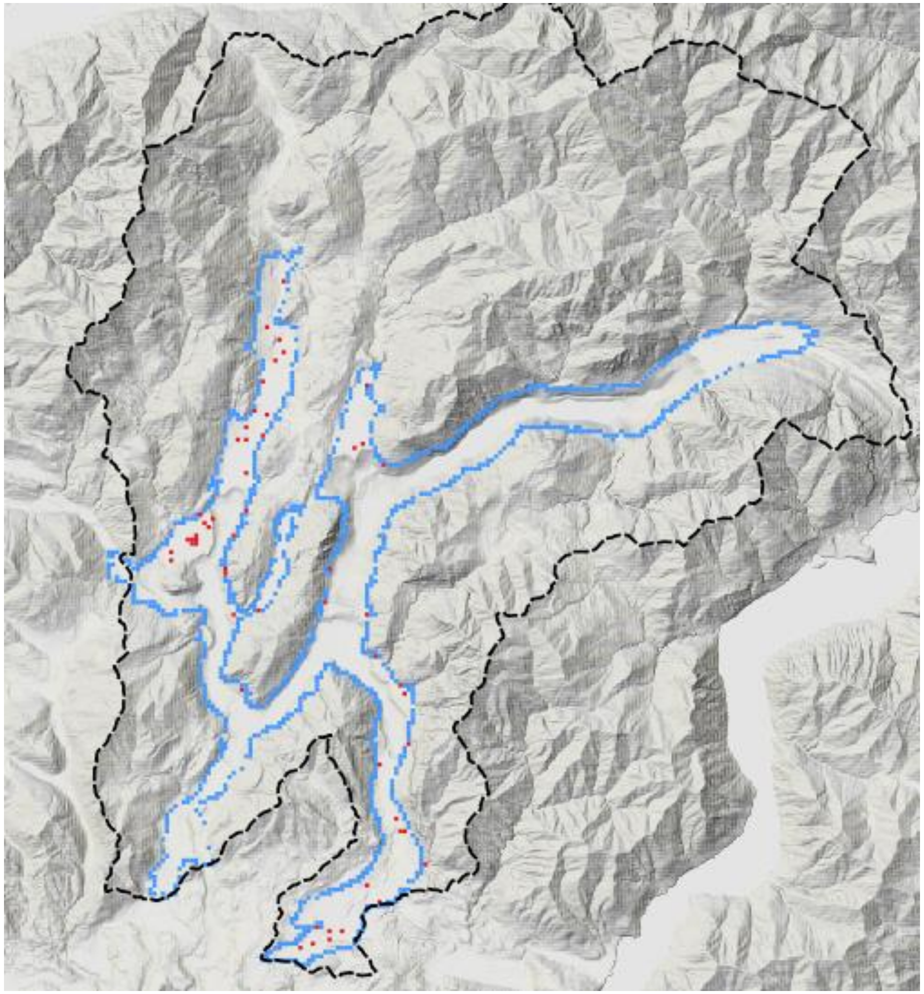


OAT → used sensors

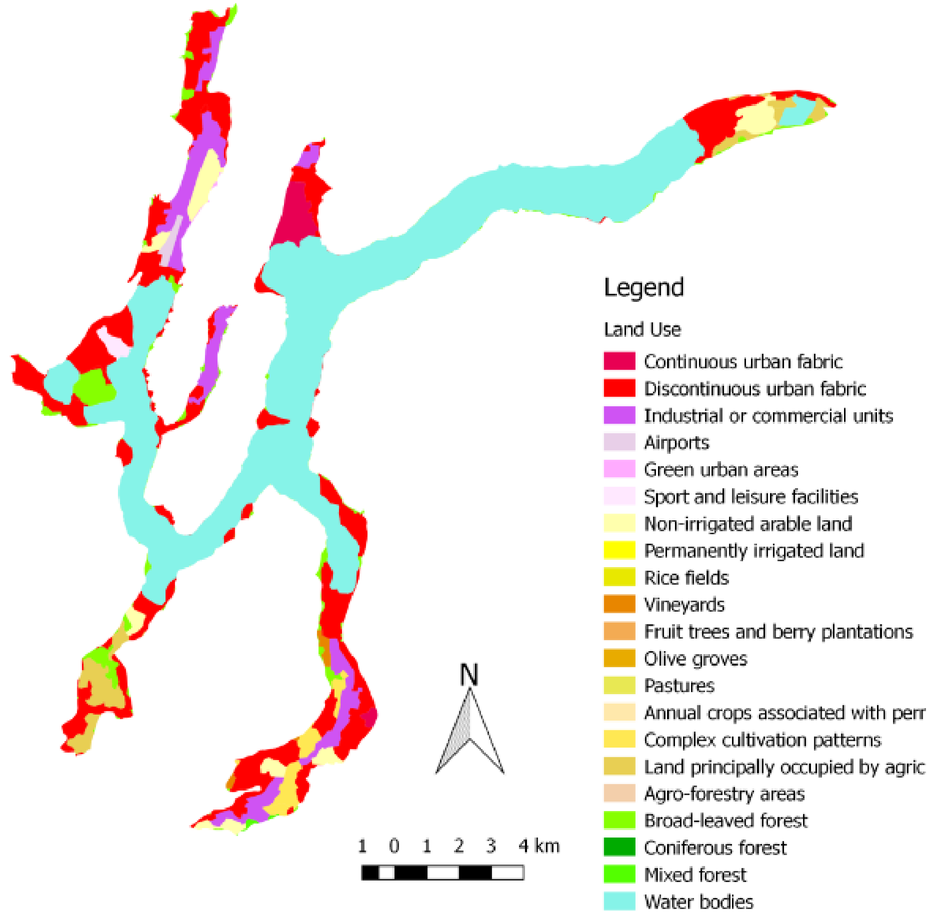


RIV → from stage data



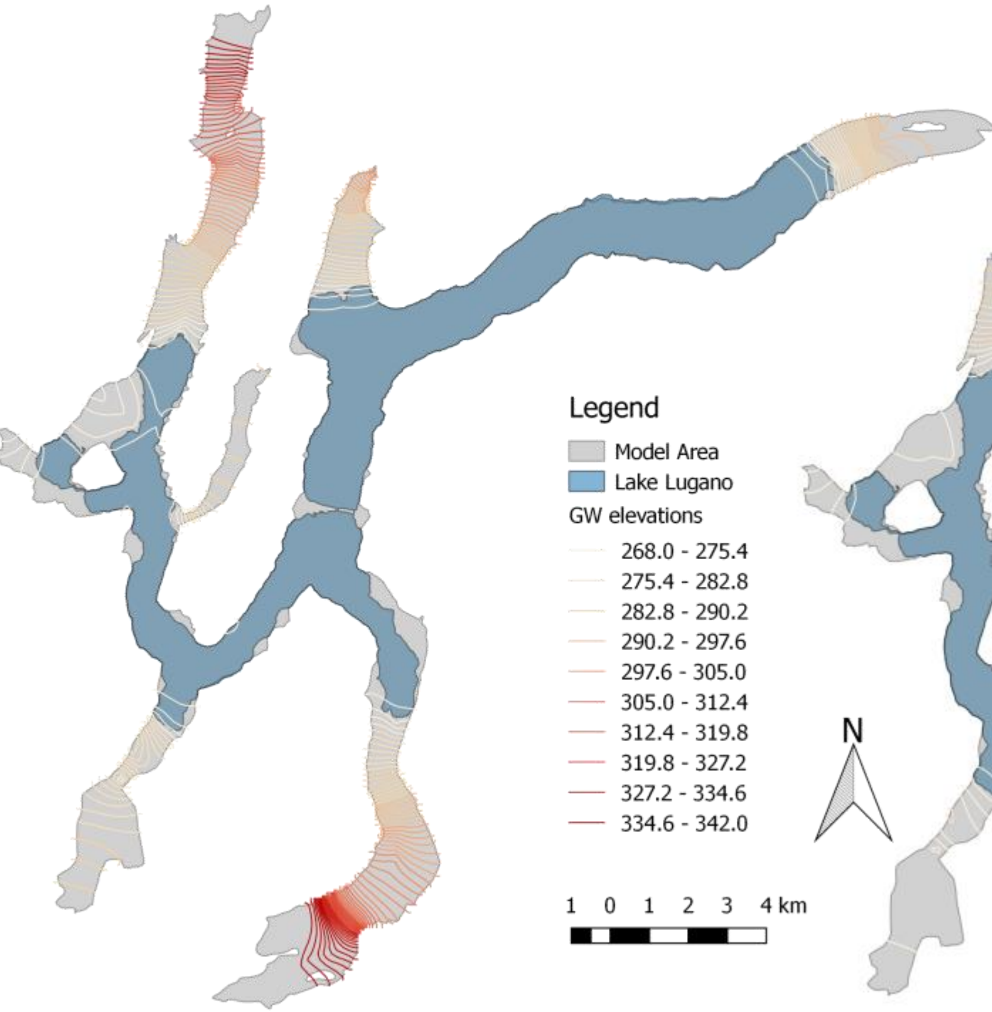


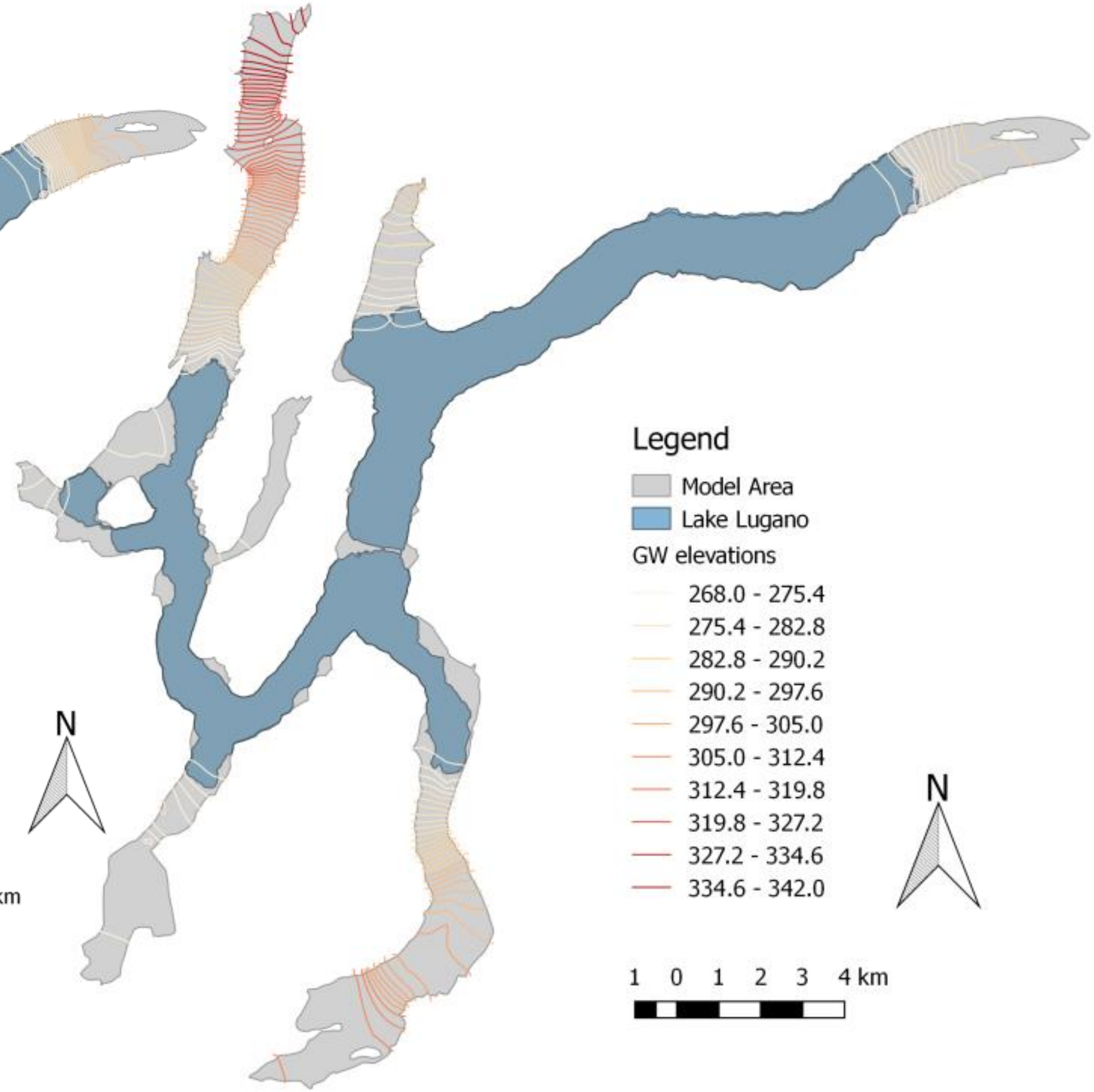
WEL → Recharge lateral bedrock & abstraction



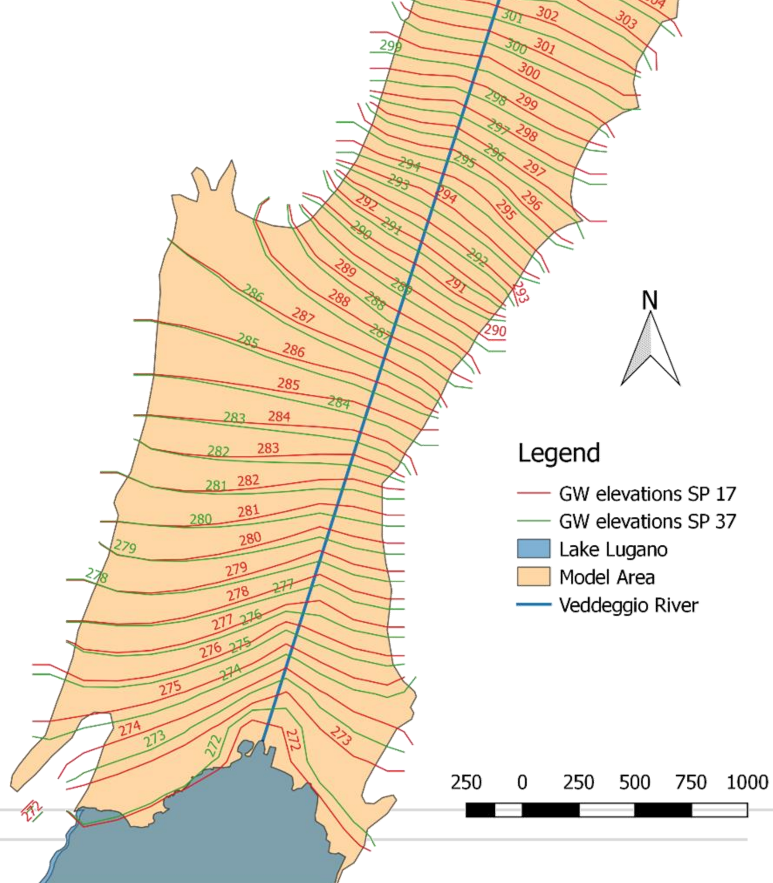
RCH → Recharge from landuse

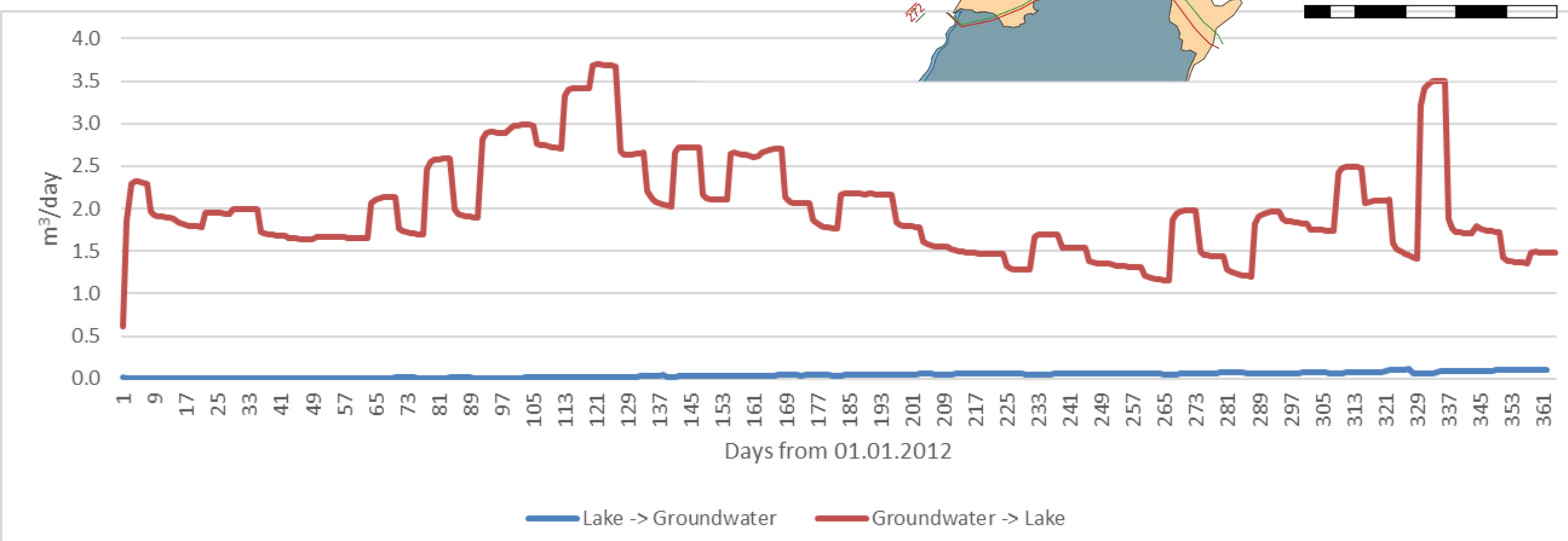
SP 18 (Jun) and SP 37 (Sep)



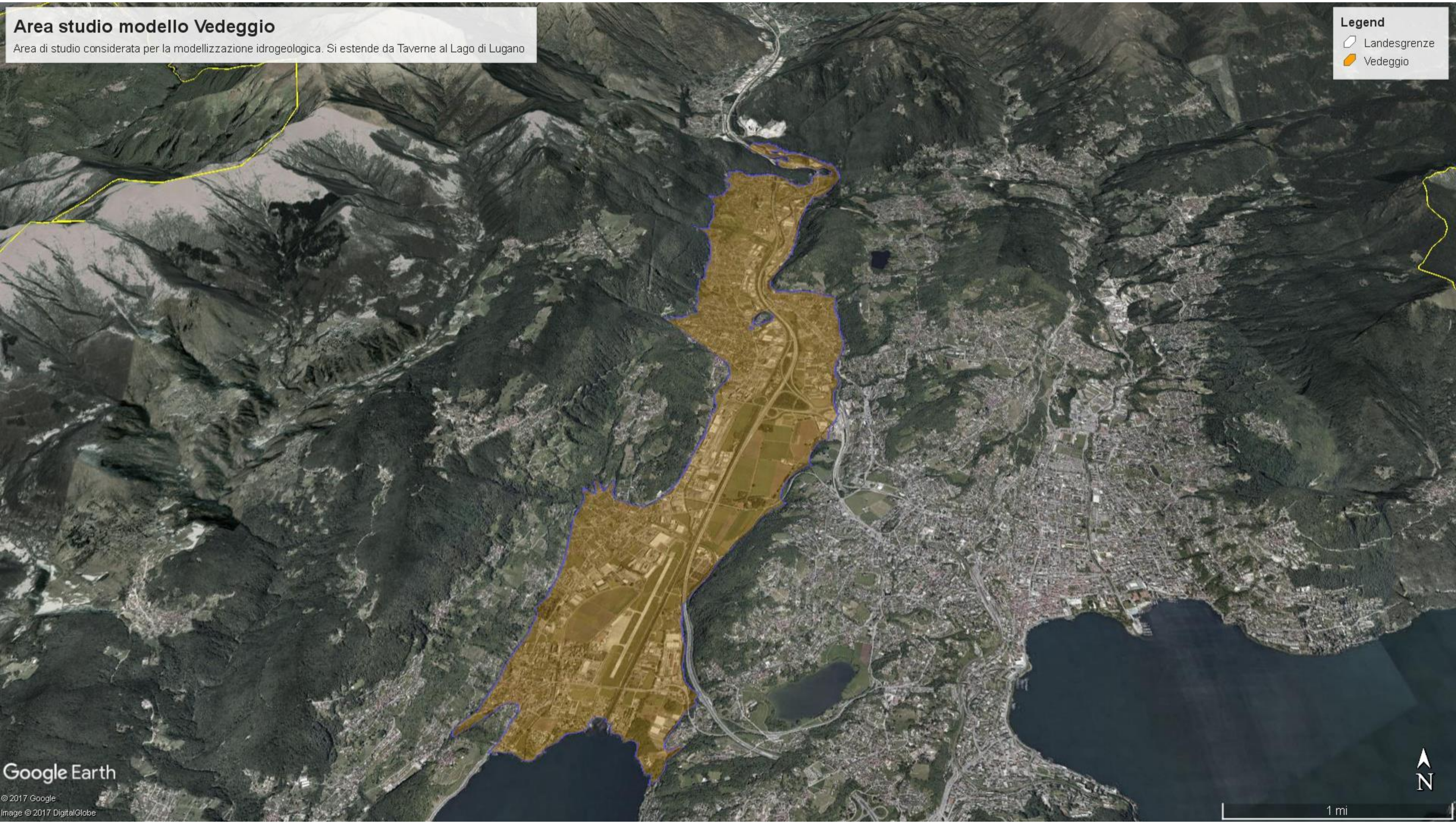


GW → river → lake



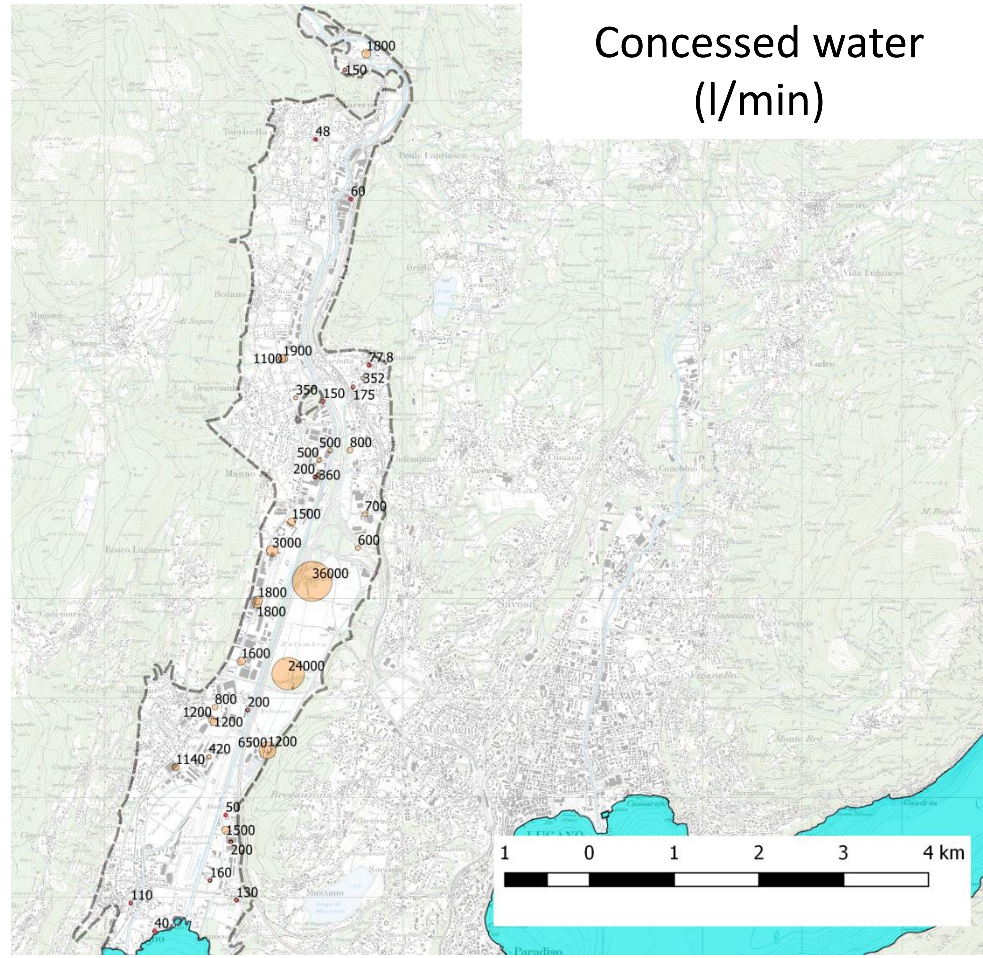


Zoom for a basin

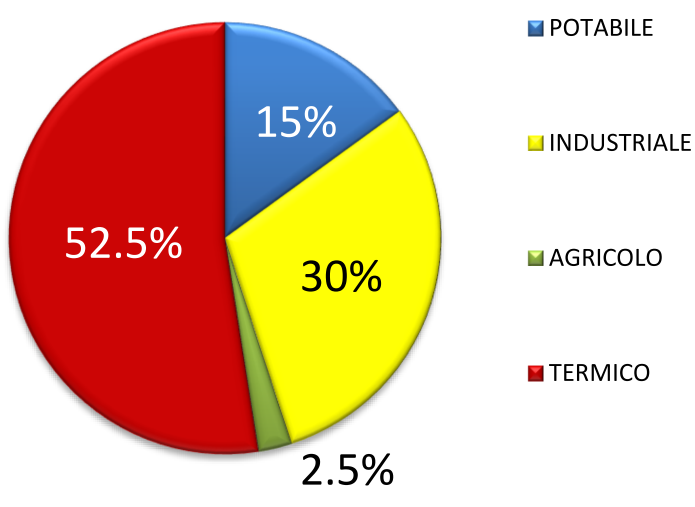


L'acquifero del Vedeggio

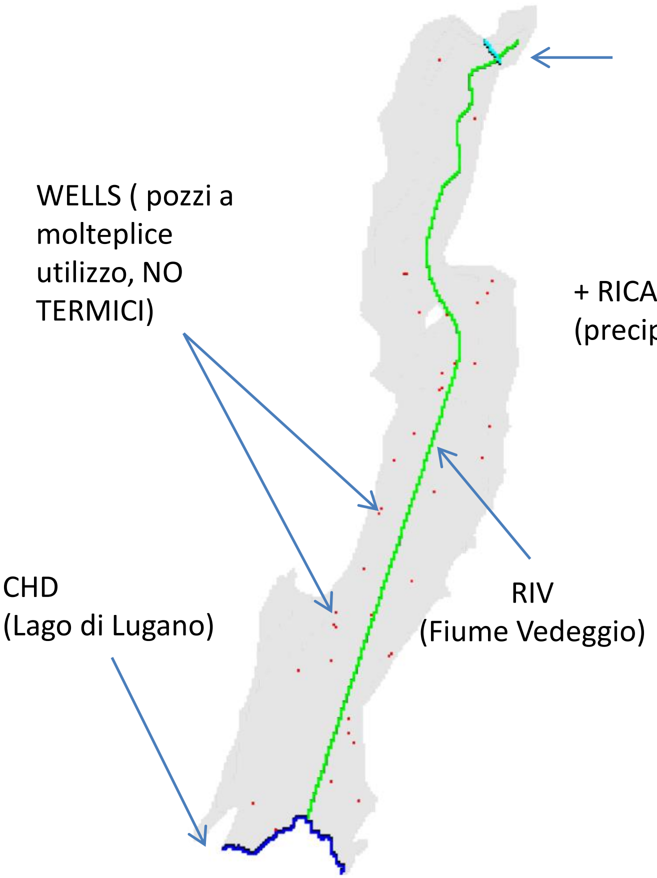
- Extension NS 9 km, EO 1km
- Mainly alluvional gravel-sand
- Two main wells for drinking water supply: Manno (36 m^3/min) e Bioggio (24 m^3/min)

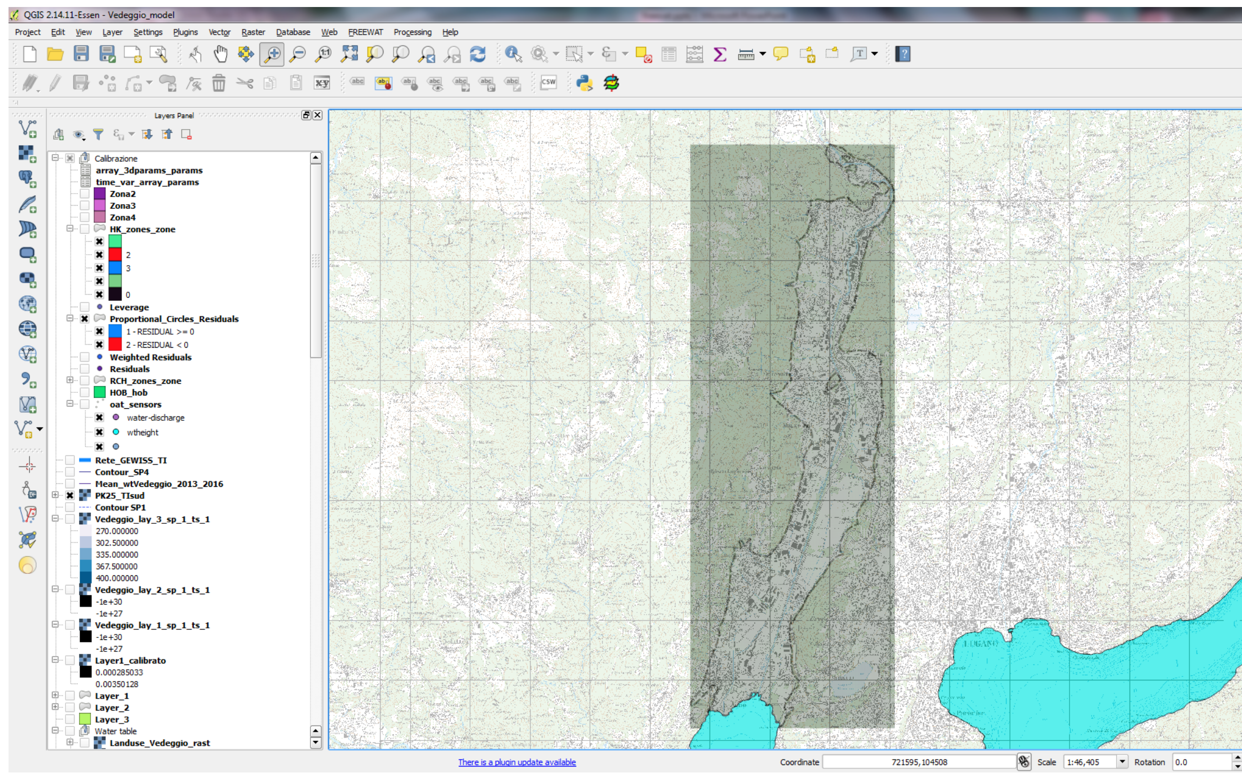


Wells usages (% sul totale)



Implementation





Spatio-temporal discretization

Discretization horizontal : 25m (DEM)

Discretization vertical: 3 layers, 2 of 20m + one of 40m (firstr two layers include the 87% of the wells)

Discretization temporal: 5 Stress Periods

1 Steady State initial of 1 day to stabilize the solution → Yearly average values of all the budget elements

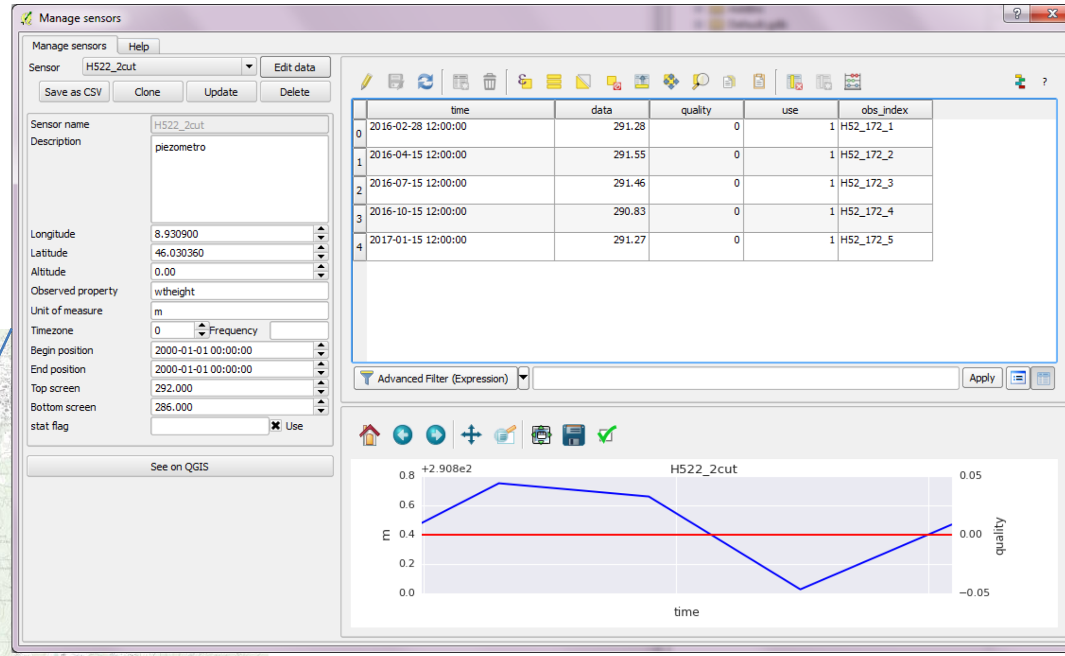
4 transit periods, 1 for season:

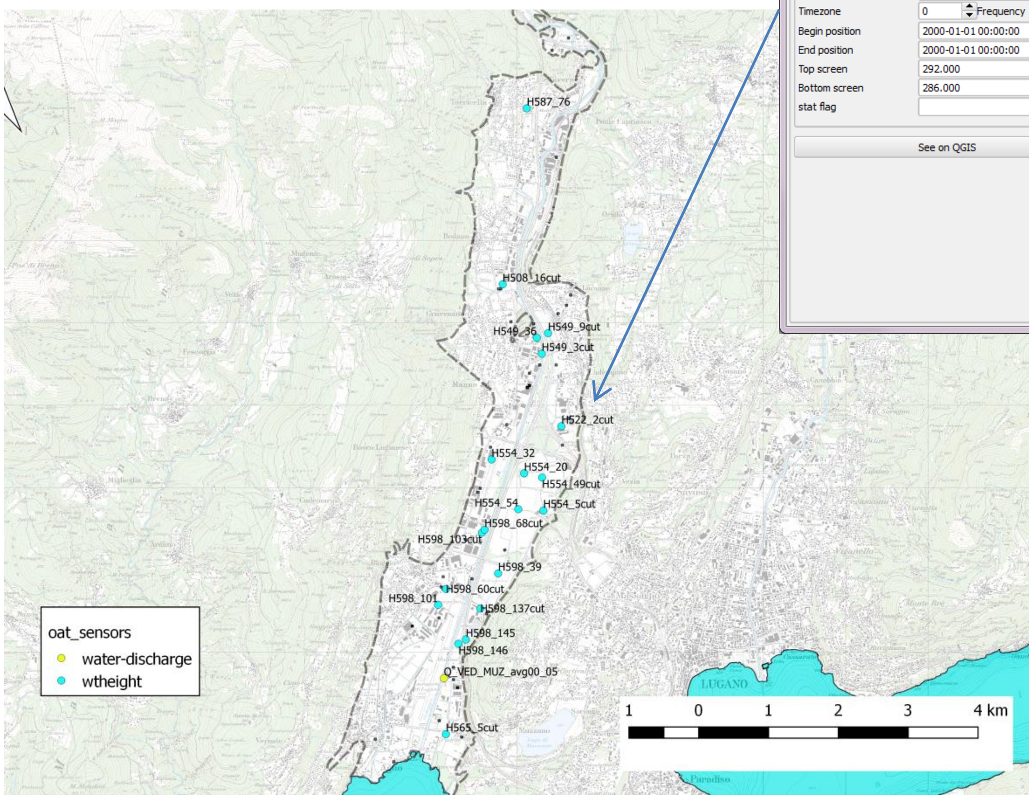
- Average values **spring** (01 Marzo – 30 Giugno);
- Average values **summer** (01 Luglio – 31 Agosto)
- Average values **autumn** (01 Settembre – 30 Novembre)
- Average values **winter** (01 Dicembre – 28 Febbraio)

Averages refers to the period 2013-2018

OAT application

name	desc	prop	unit	lat	lon	altitude	freq	topscreen	bottomscreen	statflag	use
H508_16cut	piezometro	wtheight	m	46.04599	8.92209	327.876		315	307		
H522_2cut	piezometro	wtheight	m	46.03036	8.9309	0		292	286		
H549_3cut	piezometro	wtheight	m	46.03832	8.92802	308.651		302	282		
H549_36	piezometro	wtheight	m	46.04008	8.92729	310.527		310.5	294.527		
H549_9cut	piezometro	wtheight	m	46.04055	8.92908	0		307	295		
H554_20	pozzo	wtheight	m	46.02528	8.9249	292.2		272.82	246.3		
H554_32	piezometro	wtheight	m	46.02686	8.91983	0		286	268		
H554_49cut	piezometro	wtheight	m	46.02478	8.92771	292.93		290	273		
H554_5cut	piezometro	wtheight	m	46.02118	8.92781	289.85		284	269		
H554_54	piezometro	wtheight	m	46.02137	8.92387	287.95		287	227.95		
H565_5cut	piezometro	wtheight	m	45.99692	8.91185	273.356		273	256.35		
H587_76	pozzo	wtheight	m	46.06519	8.92642	0		328	318.63		
H598_101	piezometro	wtheight	m	46.01108	8.911	283.808		283	273.97		
H598_103cut	piezometro	wtheight	m	46.01887	8.91808	287.924		287	275.924		
H598_137cut	piezometro	wtheight	m	46.01059	8.91763	282.31		282	257.31		
H598_145	piezometro	wtheight	m	46.00723	8.91525	282.049		282	257.05		
H598_146	piezometro	wtheight	m	46.00677	8.91409	279.439		279	254.44		
H598_2	pozzo	wtheight	m	46.01698	8.92156	287		286.5	238.5		
H598_39	piezometro	wtheight	m	46.01439	8.92052	283.85		282.94	242.94		
H598_68cut	piezometro	wtheight	m	46.0192	8.91851	288.373		288	263.373		
H799_47cut	piezometro	wtheight	m	46.07369	8.93194	366.96		362	358		
H598_60cut	piezometro	wtheight	m	46.01279	8.91228	289.9		289	258.9		





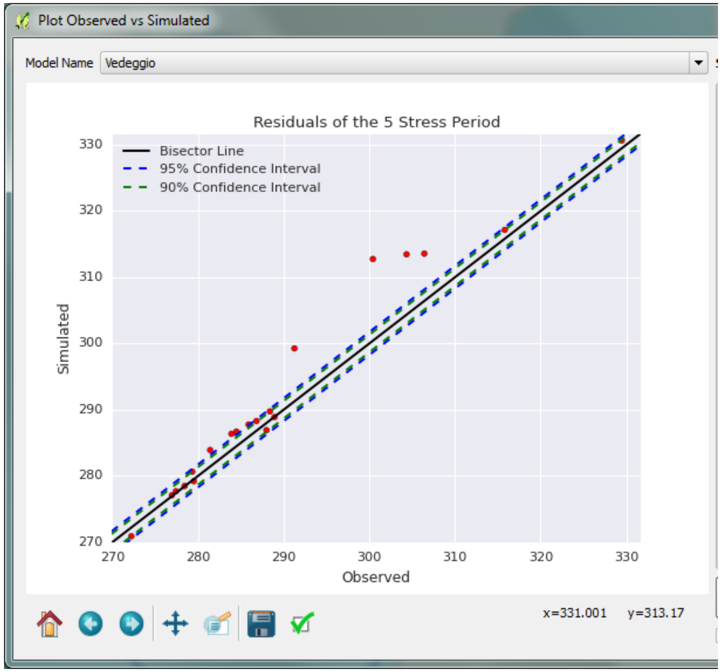
MONITORING OBS

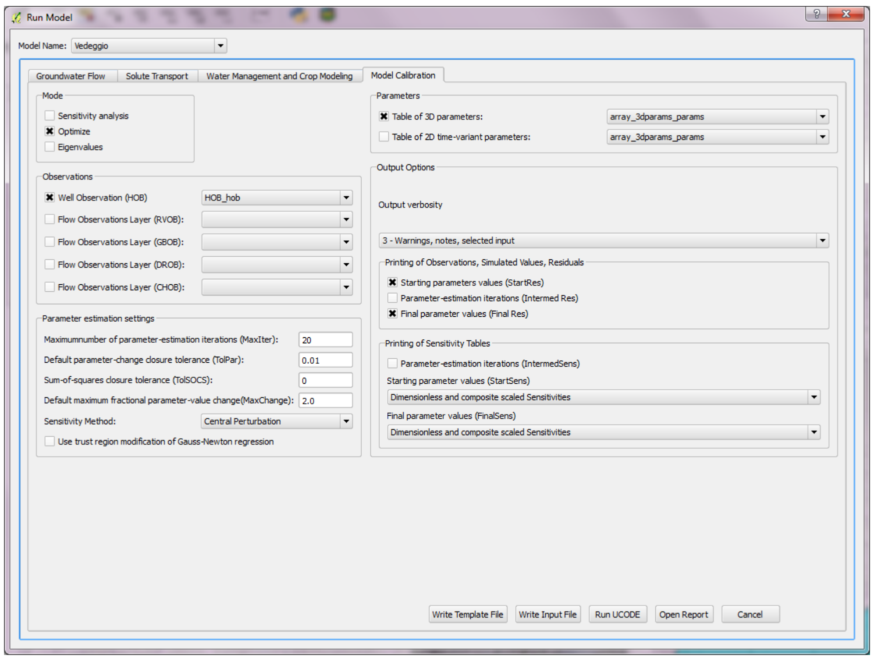
- grouped
- georeferenced
- processed
- Used for calibration

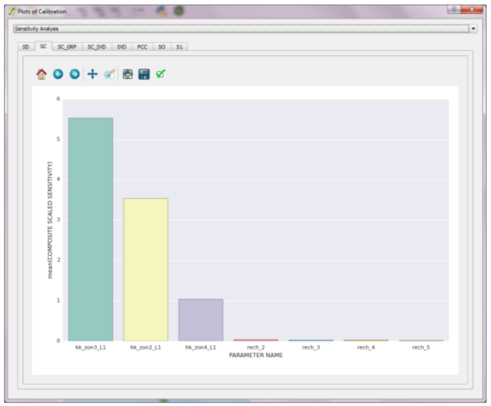
UCODE : sensitivity analysis and inverse modeling

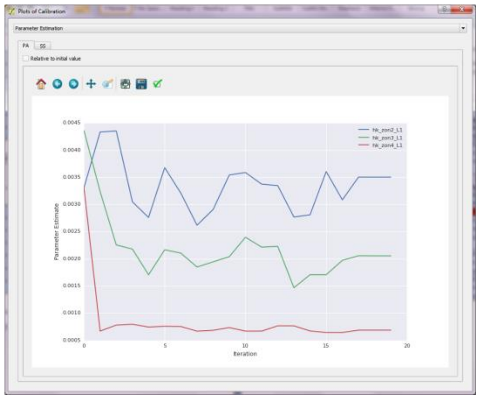
- 20 pitzometers monitored* 5 SP = 100 targets for calibration

- Most sensitive parameters: conductivity
- Calibration of 3 macro lito-zone

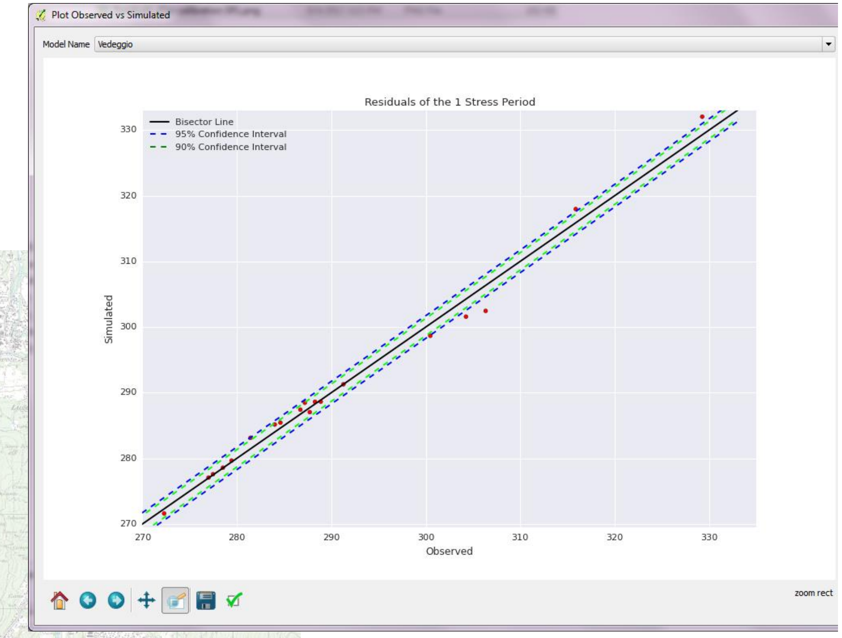


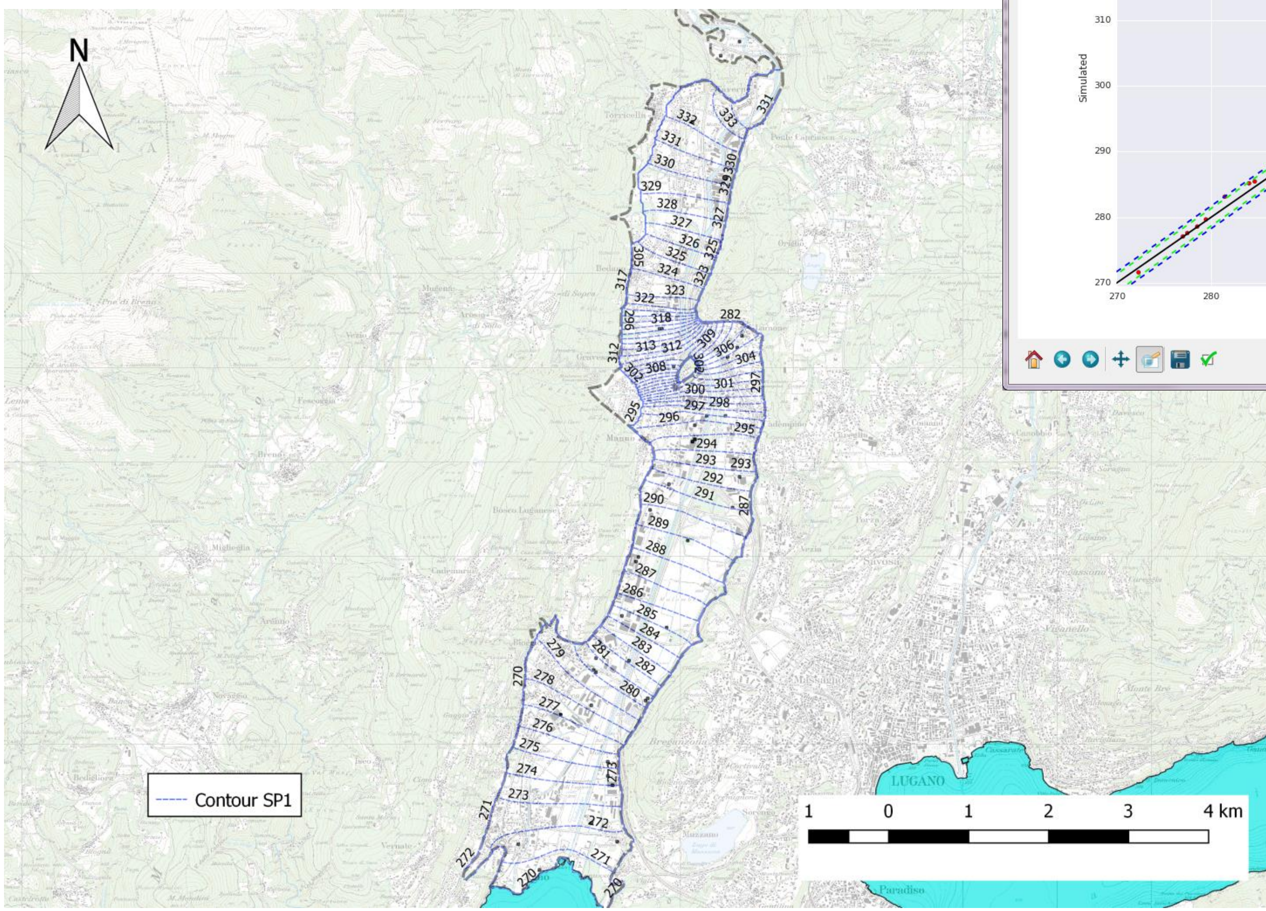




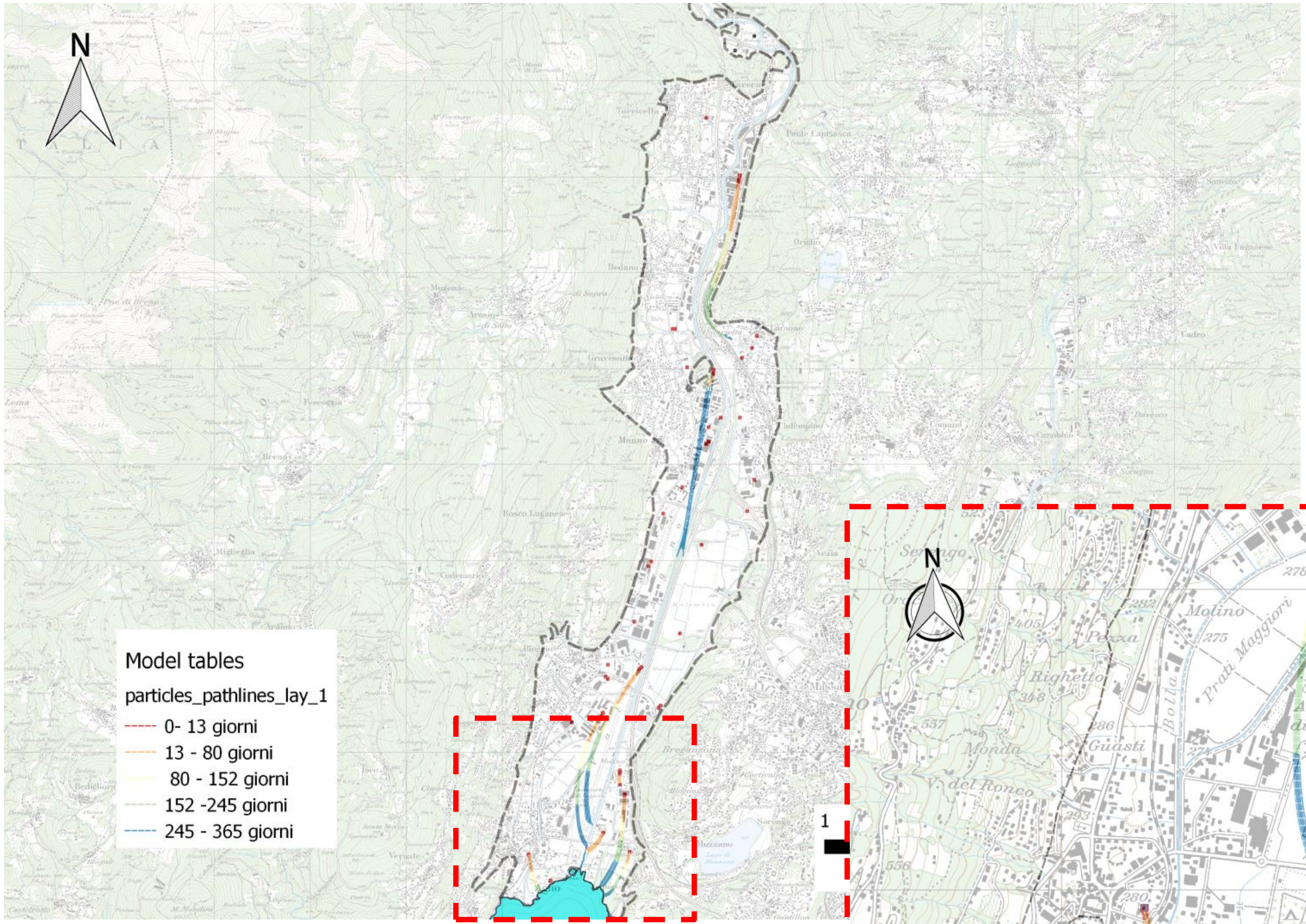


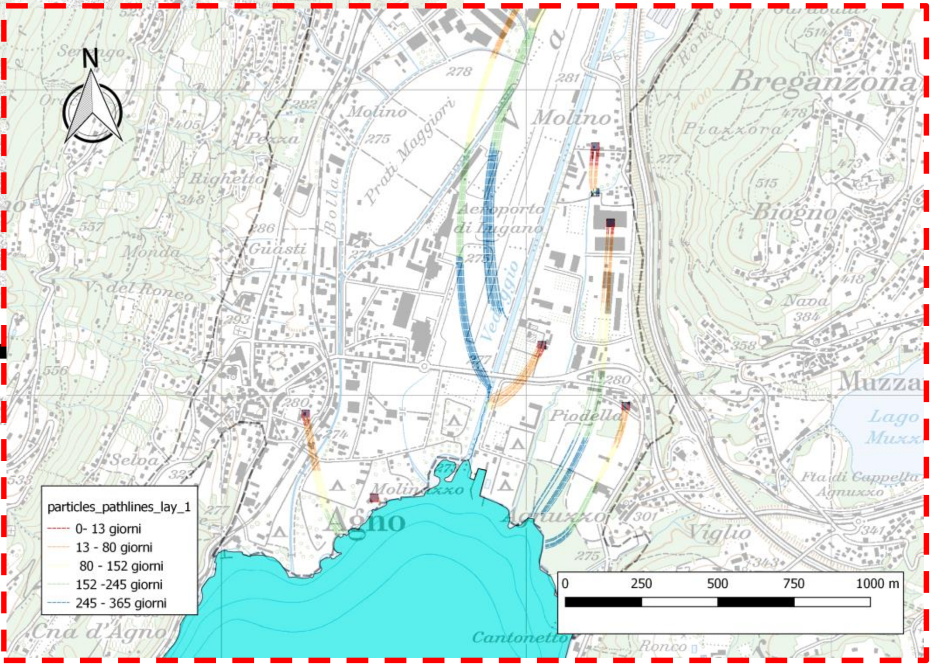
Model fit and piezometric levels





MODPATH


N
Model tables
particles_pathlines_lay_1
0- 13 giorni
13 - 80 giorni
80 - 152 giorni
152 -245 giorni
245 - 365 giorni


N
Breganzona
Molino
Aeroporto di Lugano
Agno
Muzzano
Biogno
Piodella
Viglio
particles_pathlines_lay_1
0- 13 giorni
13 - 80 giorni
80 - 152 giorni
152 -245 giorni
245 - 365 giorni
0
250
500
750
1000 m

Conclusions

- **Regional model → GW management + scenario analysis**: new wells, hydraulic works (renaturations, river diversion, tunnel creation etc
- **FREEWAT e OAT → reliable open-source solution for modelling and monitoring data analyses**
- **FUTURE**: Heat transport model within FREEWAT for geothermal-heat-pump concession?

OAT

Version 0.0.4 released:

- Porting to python3
- Release of pypi package (pip install oatlib)
- Added new method for statistsics, sensor gathering

What next:

- Capacity to handle multiple variables
- Migration of geometry to geo-pandas

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