XIII Convegno Nazionale GIT-SI
11-13 Giugno 2018
Fortezza Firmafede, Sarzana (Sp)

Società Geologica Italiana
Sezione GIT - Geosciences and Information Technologies
SI - Sezione di Idrogeologia

FORTEZZA FIRMAFEDE
Sarzana, La Spezia - Liguria

Sessione tematica SI: "La gestione quantitativa delle risorse idriche sotterranee: effetti delle variazioni di utilizzo delle risorsa e delle variazioni climatiche".

HYDRO-GEOTECHNICAL MODELLING

OF COMO SUBSIDENCE

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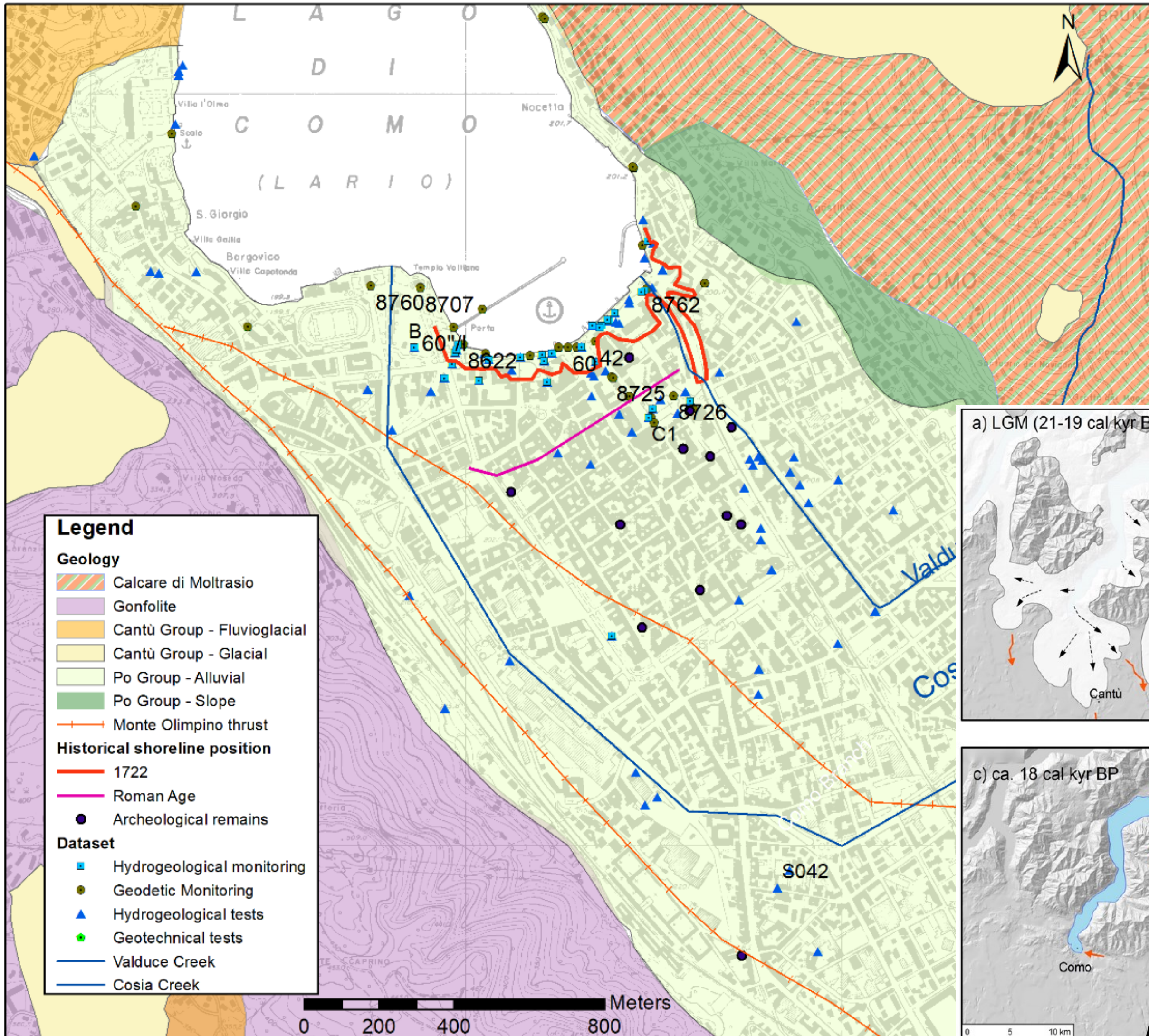
UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI SCIENZE DELLA TERRA

COMO URBAN AREA

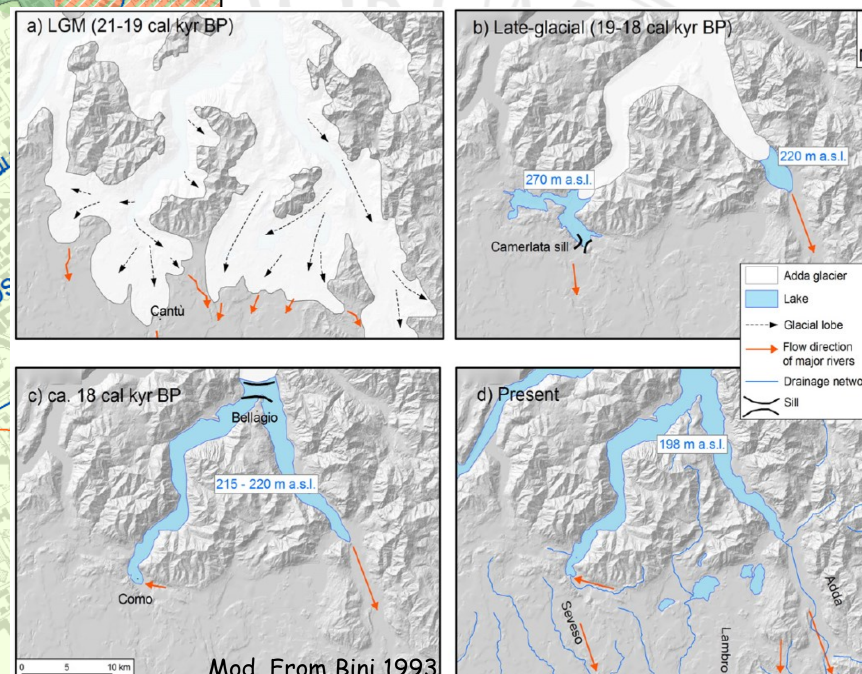


MESOZOIC UNITS

- ***Gonfolite Lombarda Group***
- ***Moltrasio Limestone***

QUATERNARY DEPOSITS

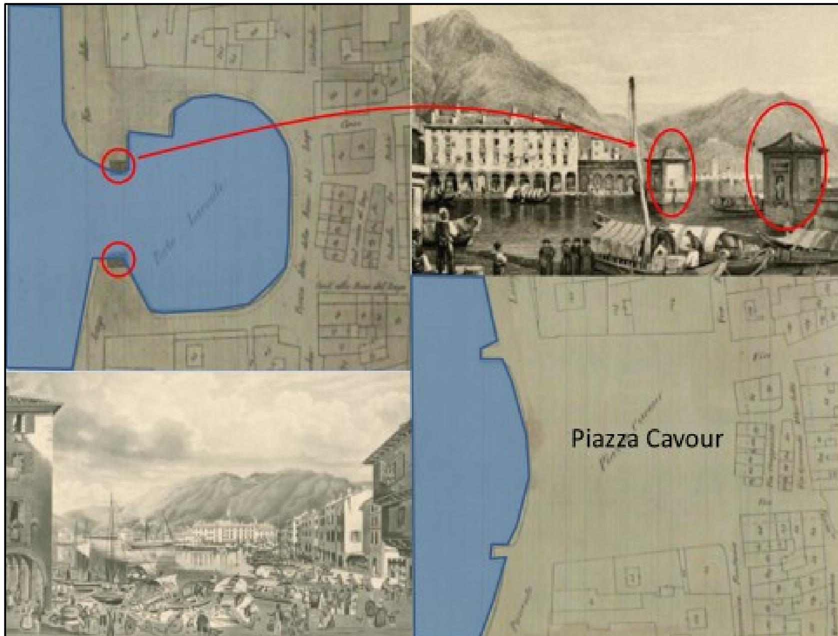
- ***Po Synthem***
- ***Cantù Synthem***

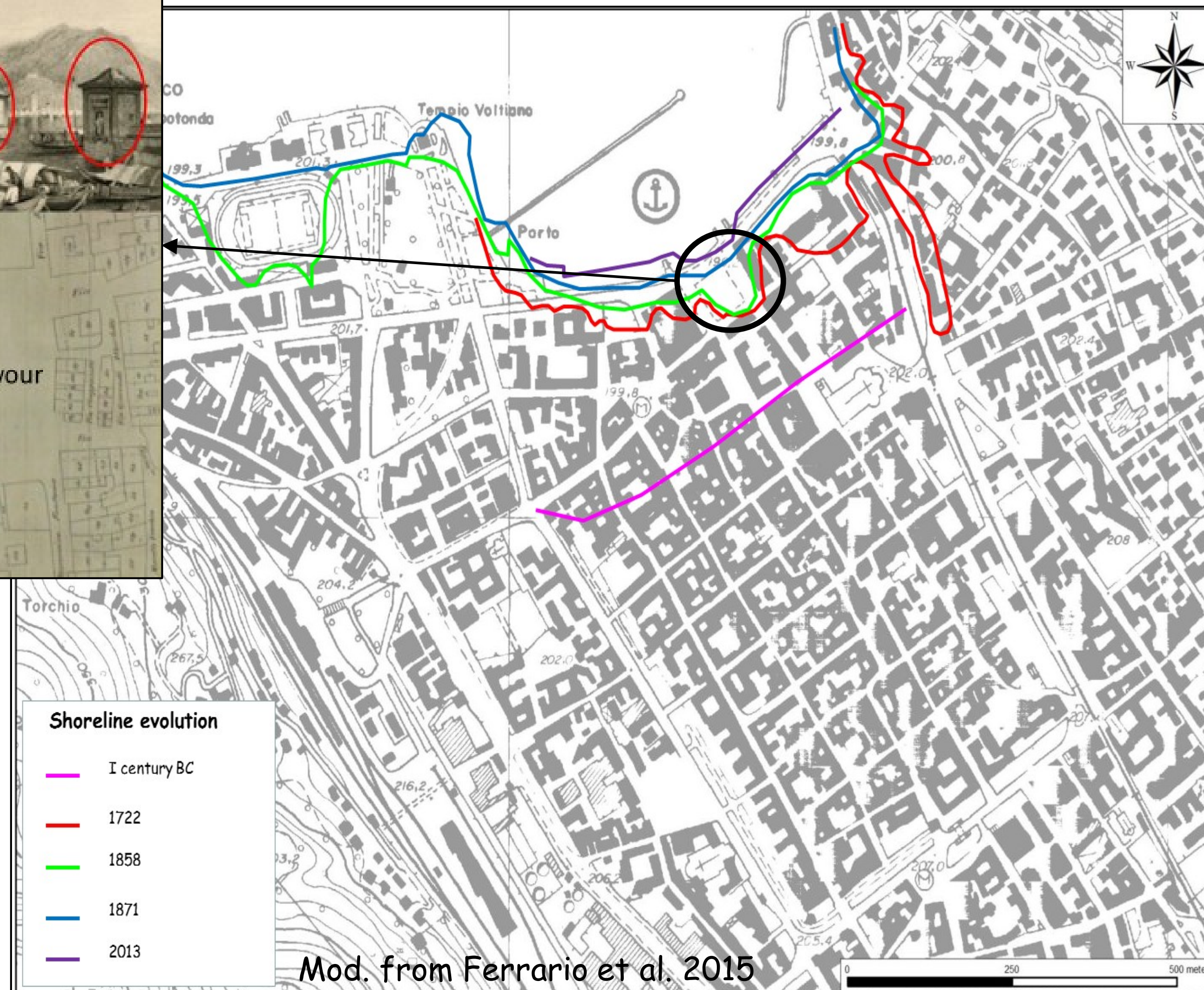


Mod. From Bini 1993

COMO URBAN AREA

Geological Framework | **Shoreline evolution** | Historical subsidence records | Lake Flooding





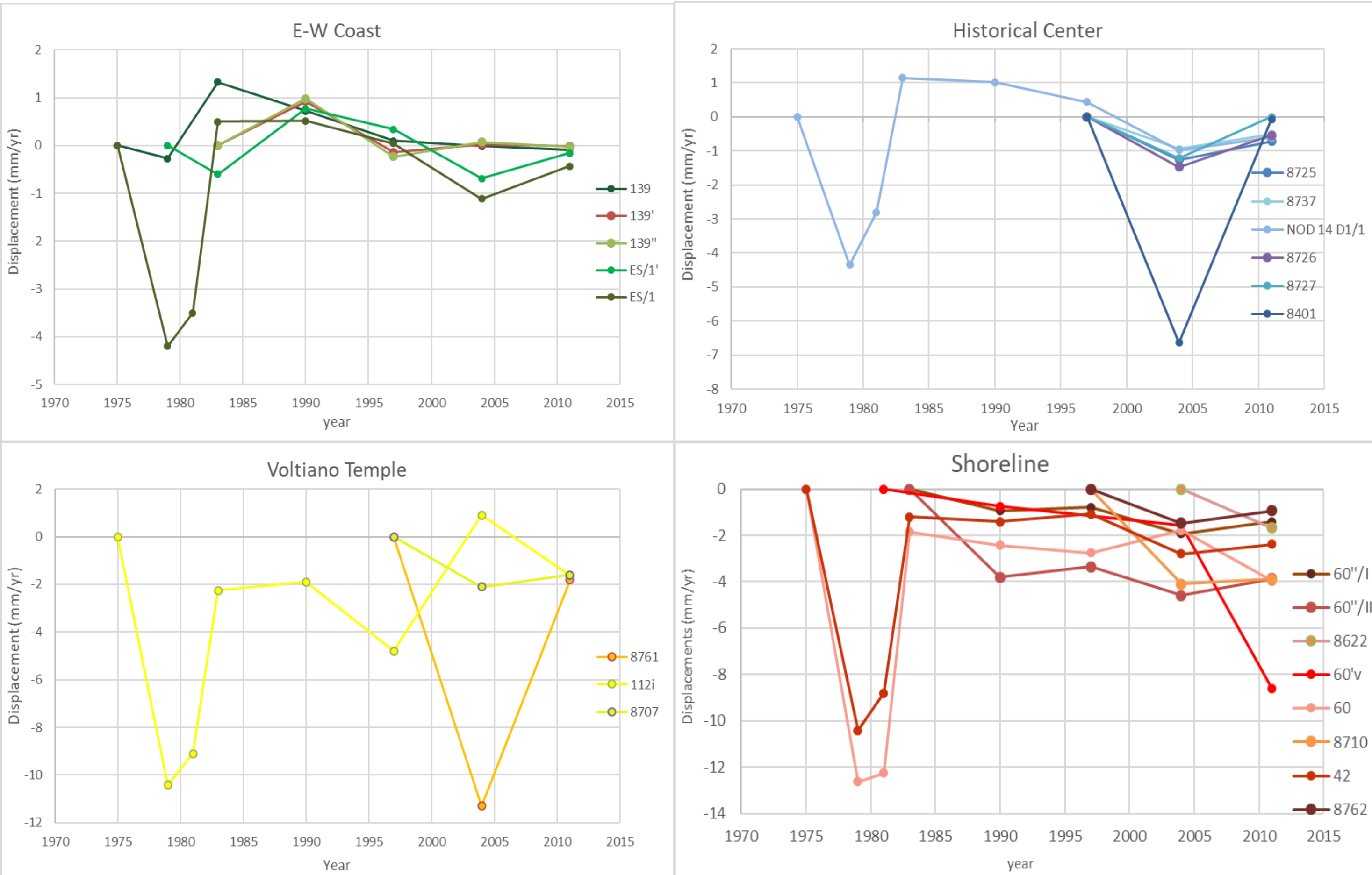
Mod. from Ferrario et al. 2015

SINCE ROMAN AGE:

- Environmental remediation of marshy areas
- Artificial deviation of fluvial streams (Valduce and Cosia)
- Shoreline progradation and rettification by placing artificial reworked material
- Ancient harbor conversion in the modern Cavour Square (1872)

COMO URBAN AREA

Geological Framework | Shoreline evolution | **Historical subsidence records** | Lake Flooding



<u>70s-80s</u>

<u>ANTHROPIC SUBSIDENCE</u>
20 mm/year

AQUIFER OVER-EXPLOITATION

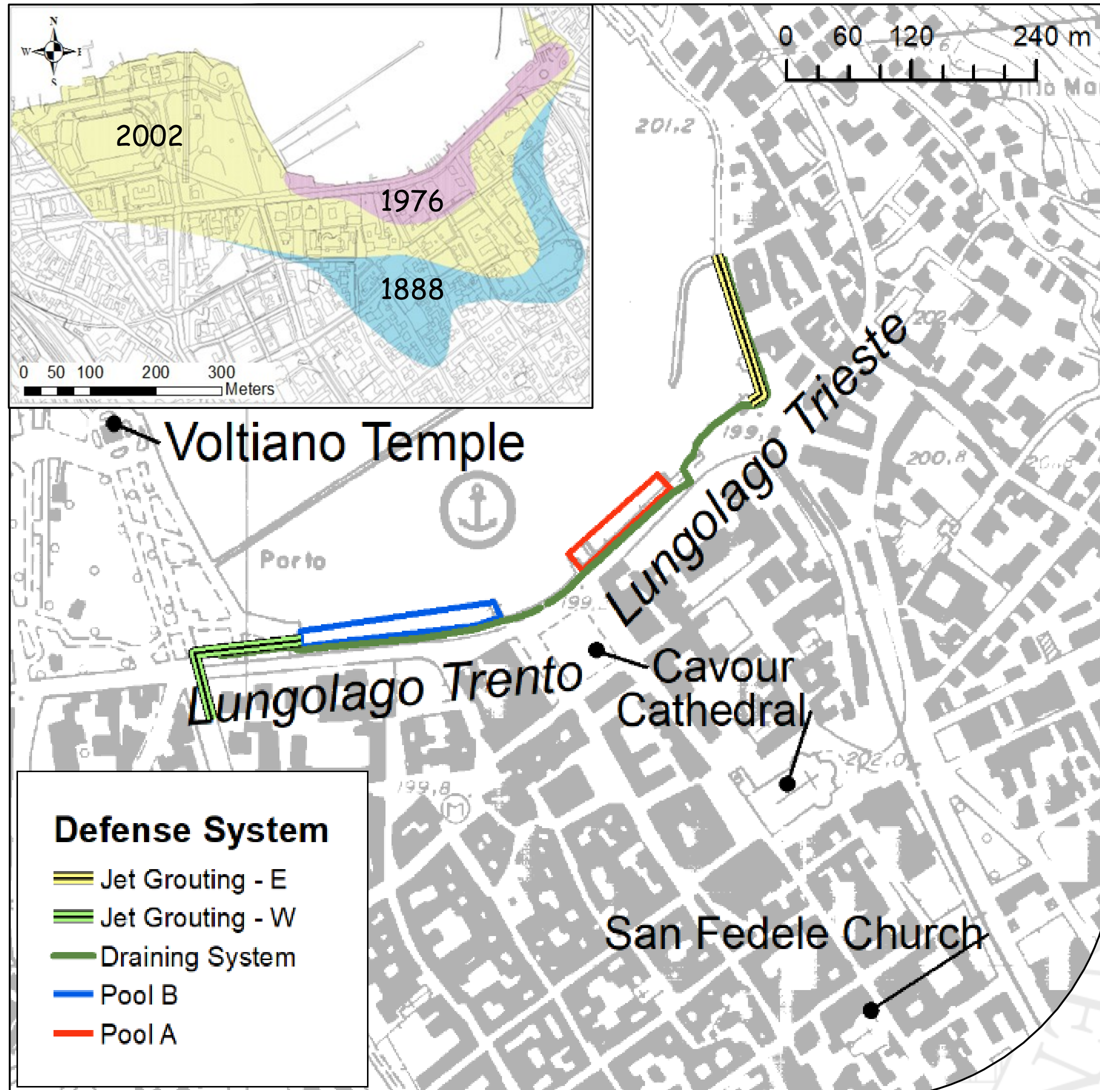
150-160 l/s

Geometric levelling (*1974 - 1984 - 1986 - 1996 - 1997 2004-2011-2014)*
PSInSAR Interferometry (1992 ÷ 2003, 2003 ÷ 2012)

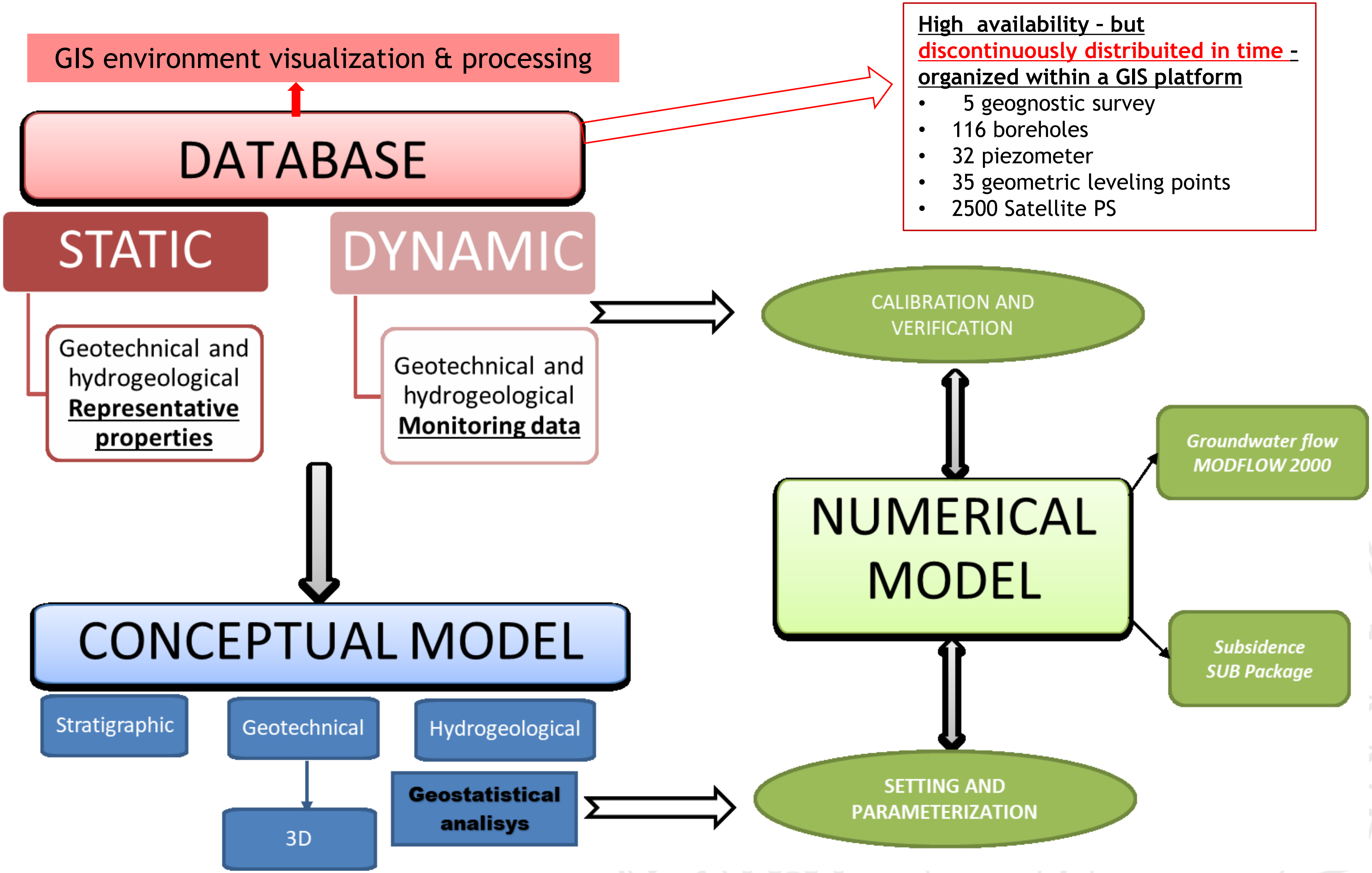
Natural trend: 2/3 mm/year

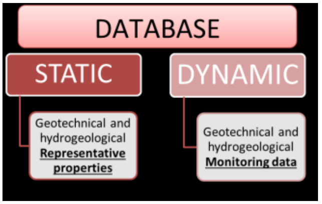
COMO URBAN AREA

Geological Framework > Shoreline evolution > Historical subsidence records > **Lake Flooding**



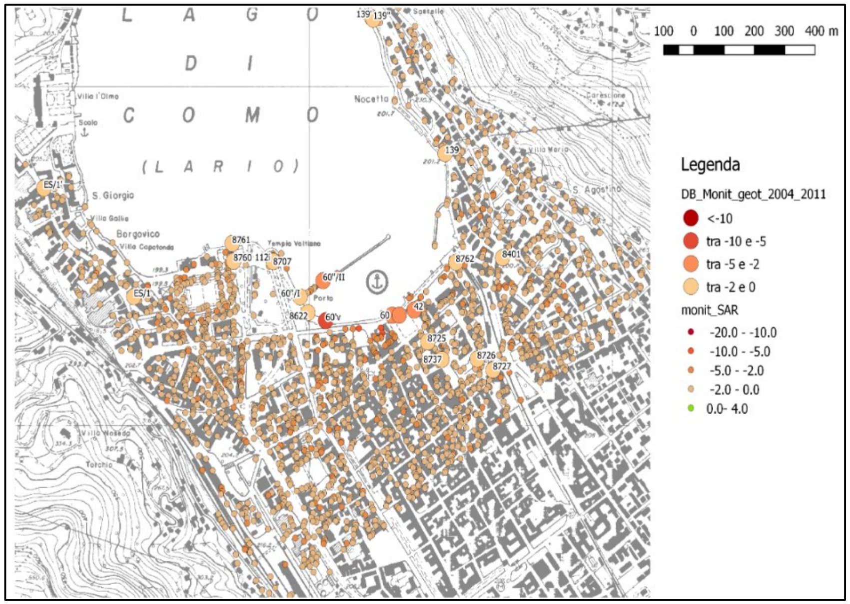
WORKING FLOWCHART



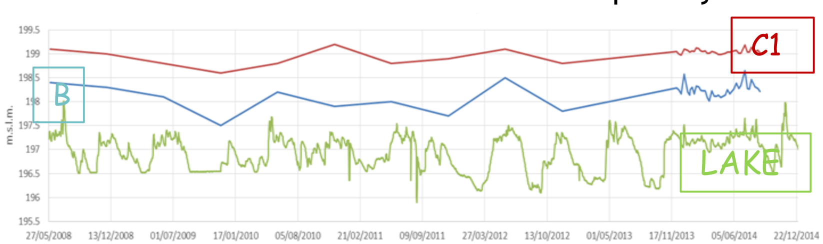


DATABASE CREATION and INTERPRETATION

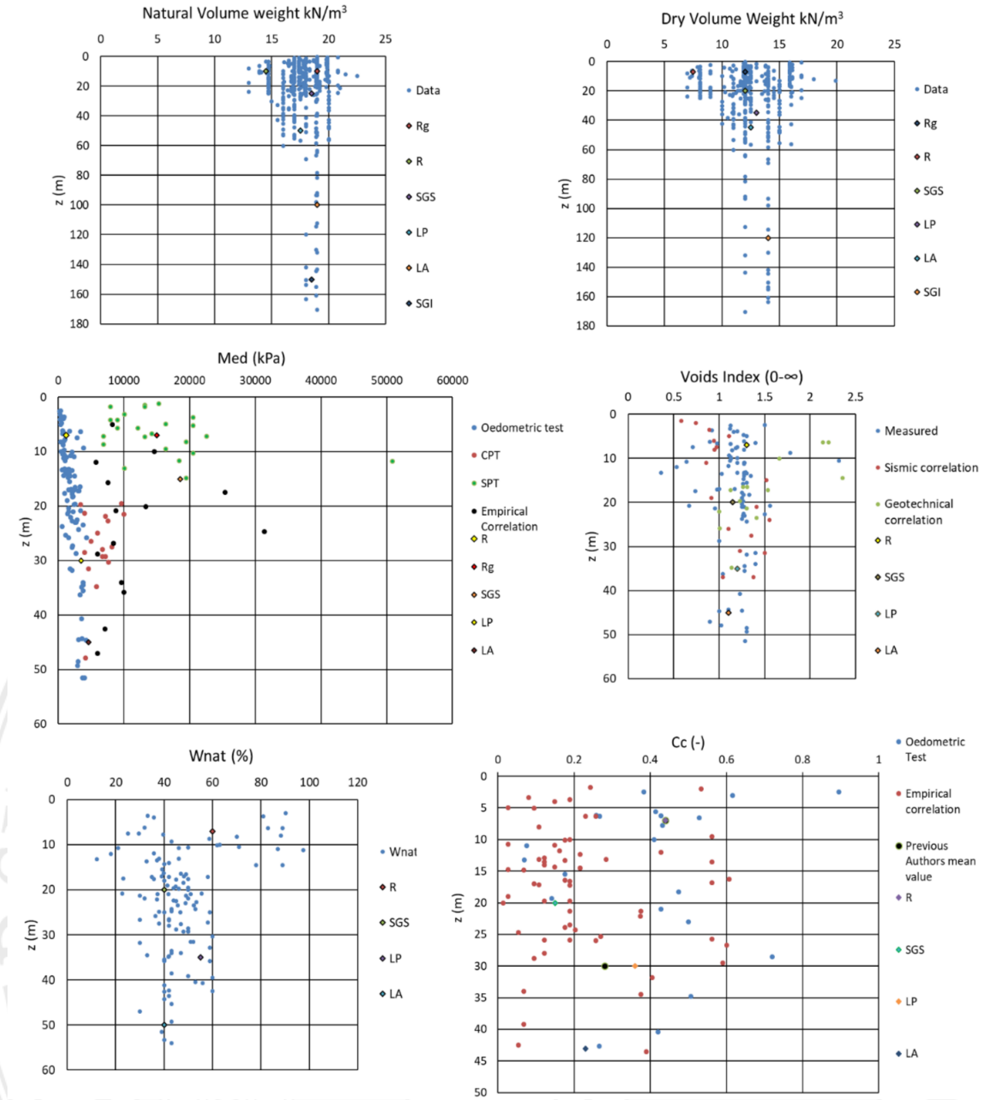
PS SAR and geometric leveling data comparison

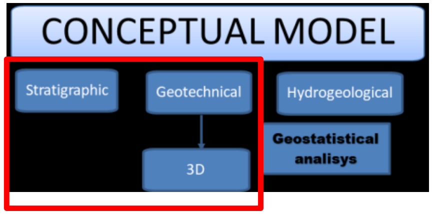


Groundwater and lake mutual relationship analysis



Geotechnical data plotting





CONCEPTUAL MODEL

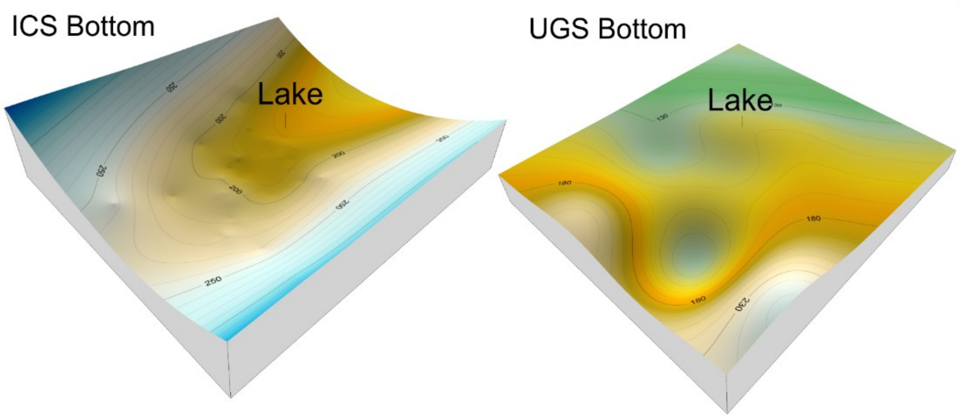
REWORKED ANTHROPIC MATERIAL (R) 0-15 m. from g.l.

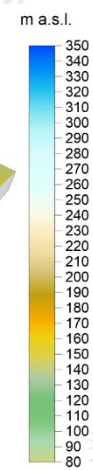
UPPER SAND and GRAVEL (UGS) 3-25 m from g.l.

ORGANIC PALUSTRINE SILTS (POS) 20-40 from g.l.

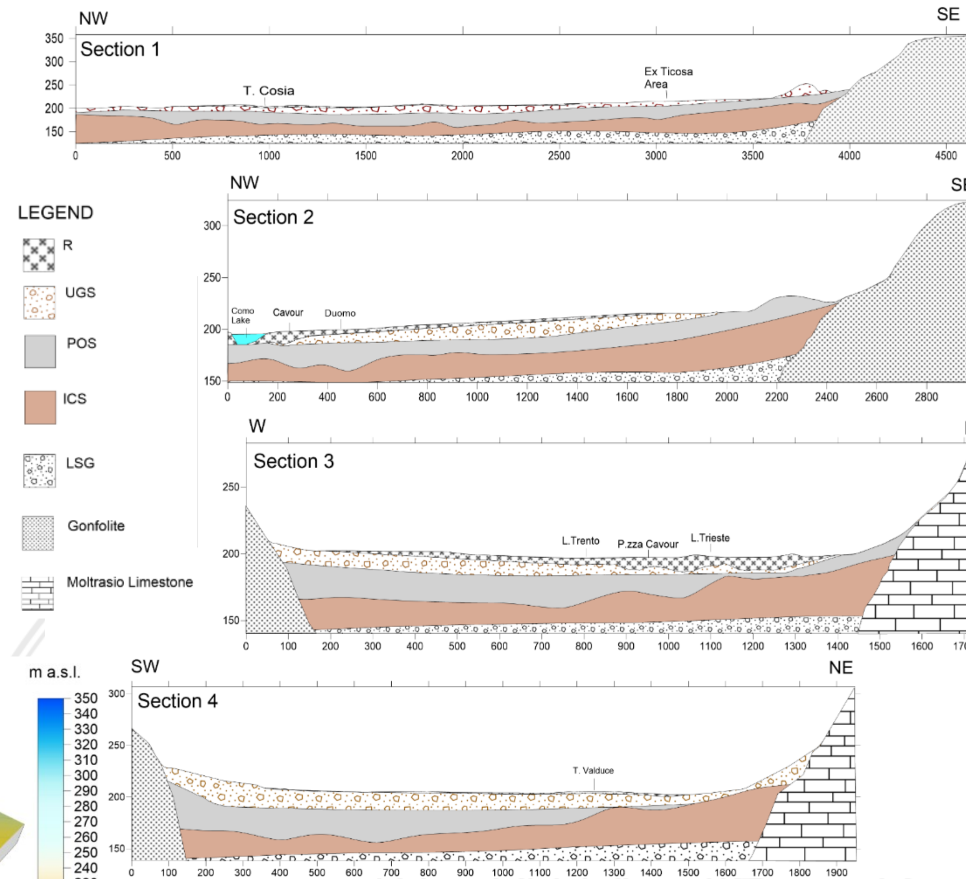
SILTY INORGANIC GLACIOLACUSTRINE CLAYS (ICS) 25-70 m from g.l.

LOWER SAND and GRAVEL (LSG) (60-170 m from g.l.

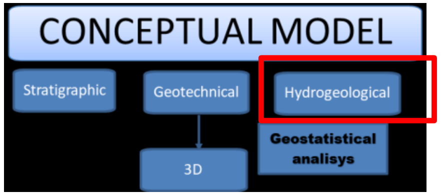




KRIGING GEOSTATISTICAL PROCEDURE



Extreme R stratigraphical, spatial and geotechnical heterogeneity



CONCEPTUAL MODEL

R UGS — Unconfined shallow aquifer

POS ICS — Aquitard

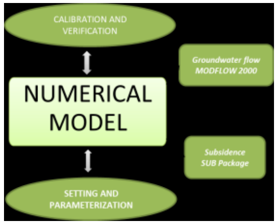
LGS — Confined deep aquifer

MAIN FEATURES

- Unit R k heterogeneity $10^{-2} \div 10^{-4}$ m/s
- Variable Groundwater depth from $1.5 \div 2$ m along the shoreline to $10 \div 15$ m at the SE end of the basin
- Cosia and Valduce creek w/ cemented riverbed and rectified stream.

RECHARGE

- Mainly lateral supply from rocky reliefs
- Local contribute from Respaù creek paleo-channel (SW) recharge anomaly
- Localized karst phenomena



NUMERICAL MODEL
Background theory

Numerical code Modflow 2000

+

SUB Package

→ Graphical interface Groundwater Vistas 6.0

$$\Delta h \rho_w g = \Delta$$

$$\Delta\sigma' = -\rho_w g \Delta h$$

COUPLED HYDRO-GEOTECHNICAL MODEL

Inelastic and elastic deformation depending on the preconsolidation stress – effective stress mutual relationship

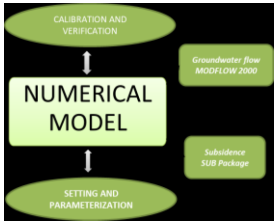
Preconsolidation stress

=

Soil maximum effective stress

=

Piezometric minima (or p minima) of the simulation



NUMERICAL MODEL
Setting and parameterization

1. TEMPORAL and SPATIAL DISCRETIZATION

2. BOUNDARY CONDITIONS

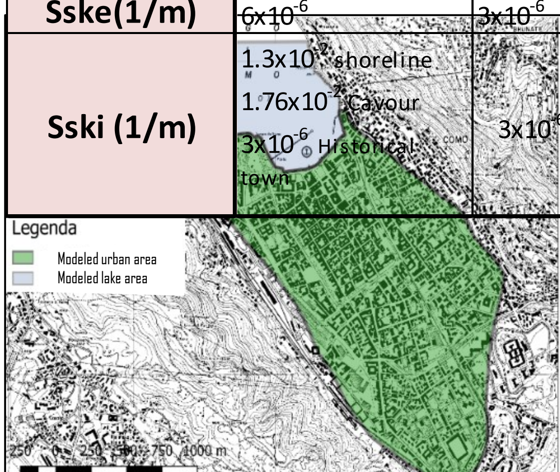
3. MODEL PARAMETERS

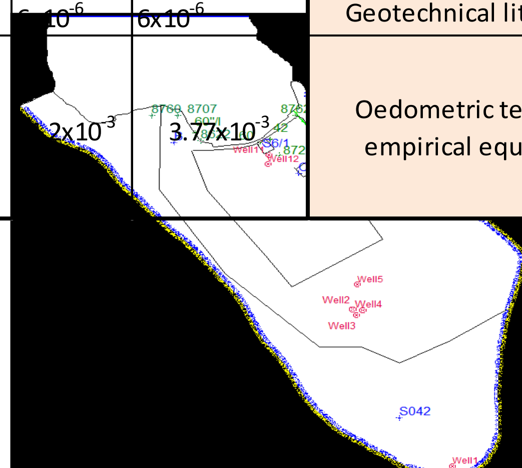
Parameter	UNIT				SOURCE
	R	UGS	POS	LA	
k (m/s)	$5,3x10^{-4}$	$2.6x10^{-3}$	$7x10^{-6}$	$4.73x10^{-9}$	pumping , oedometric, borehole permeability tests
Sy o Ss (-)	0.3	0.2	0.01	0.006	Pumping tests, empirical equations, previous studies
Sske(1/m)	$6x10^{-6}$	$3x10^{-6}$	10^{-6}	$6x10^{-6}$	Geotechnical literature
Sski (1/m)	$1.3x10^{-2}$ shoreline $1.76x10^{-2}$ Cavour $3x10^{-6}$ Historical town	$3x10^{-6}$	$2x10^{-3}$	$3.77x10^{-3}$	Oedometric tests and empirical equations

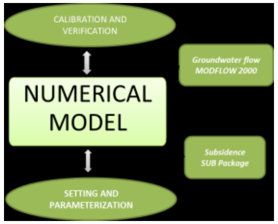
iods: 1 SS e 8 TR
to 2011

- CHD -Medium an
- Pumping Wells -
- Lateral recharge
450 l/s (THORNT
+CN procedure)

Calibration process of the parameters, varying the values within the observed real data ranges, until obtaining an acceptable RMS (<10%)

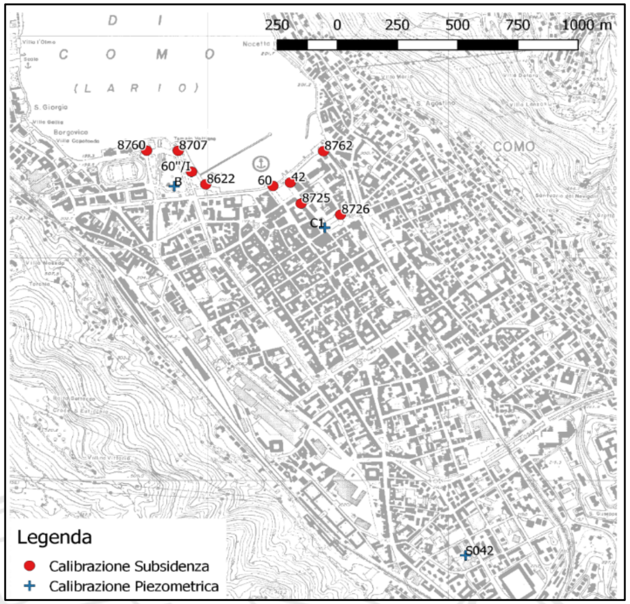


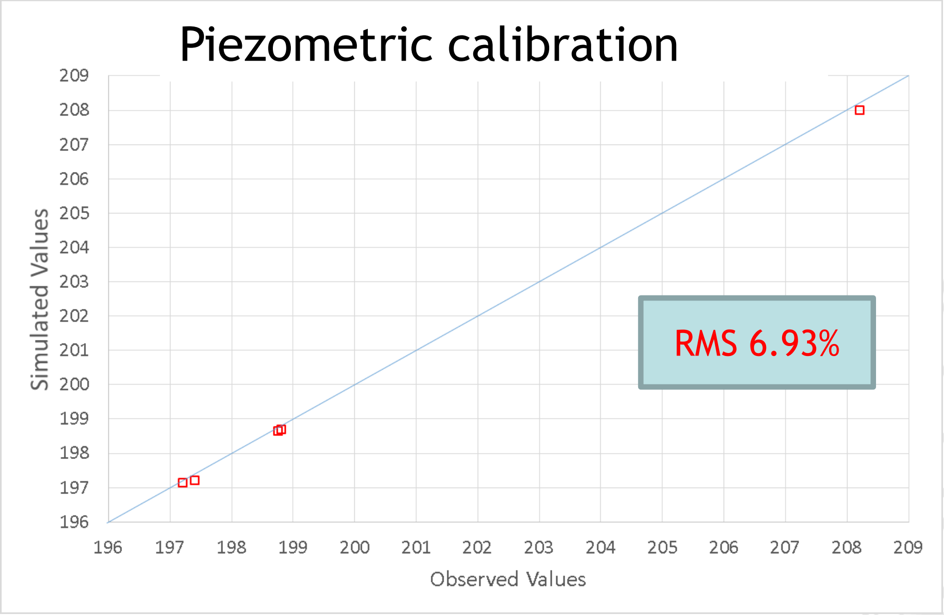


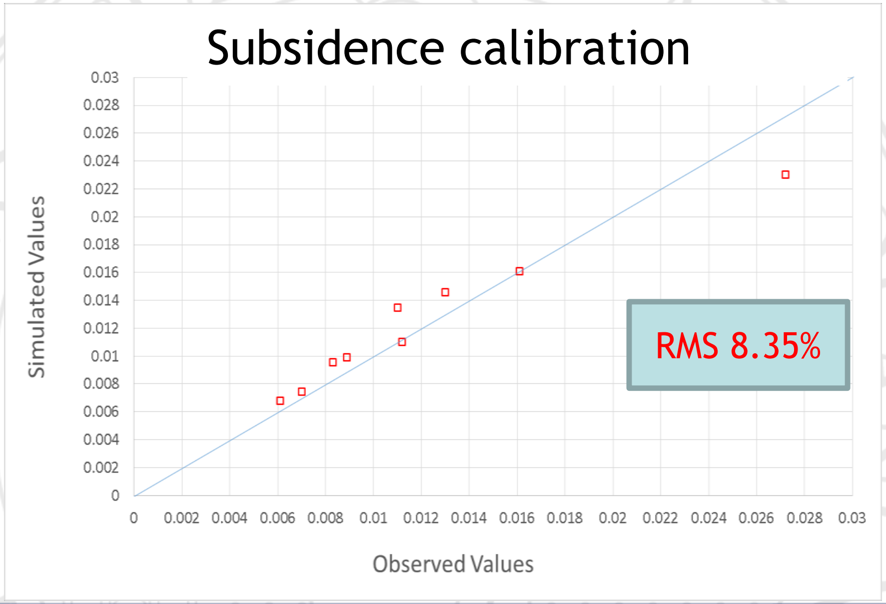


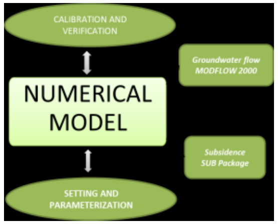
NUMERICAL MODEL
Calibration

Root Mean Square error (RMS)
Anderson & Woessner (1992)





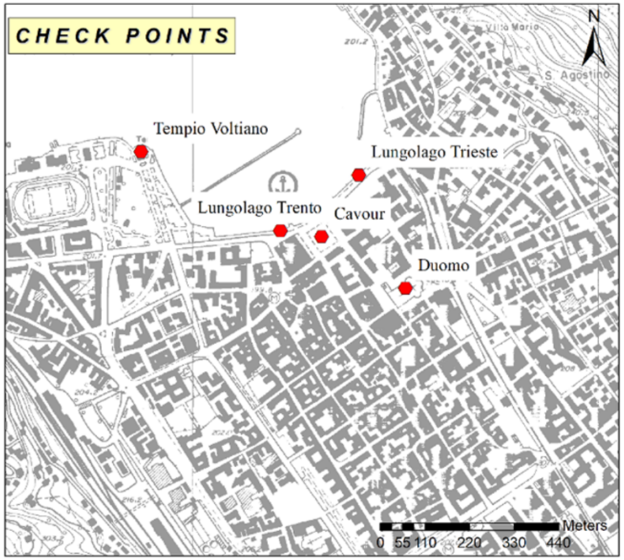


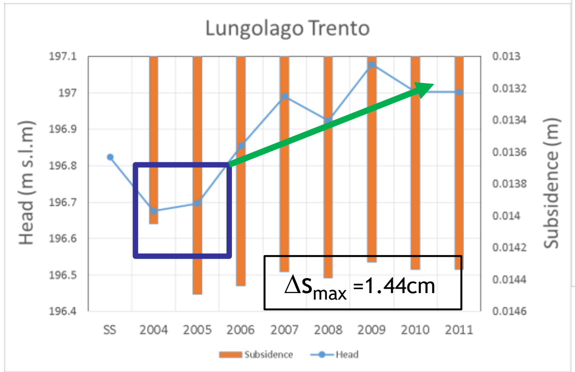


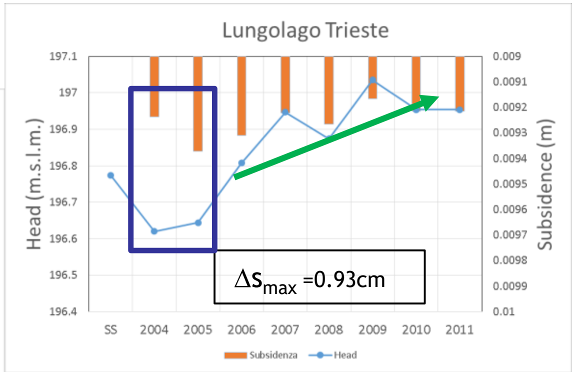
NUMERICAL MODEL
Results

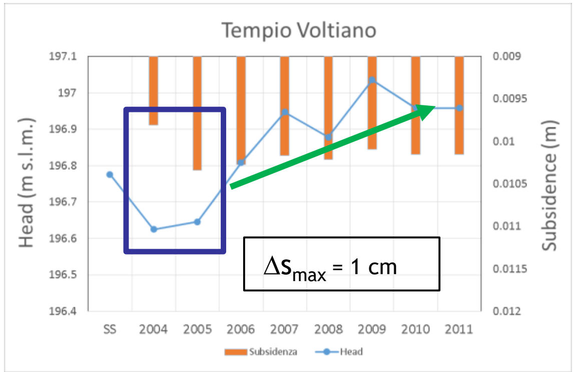
PIEZOMETRIC MINIMA→ 2004-2005

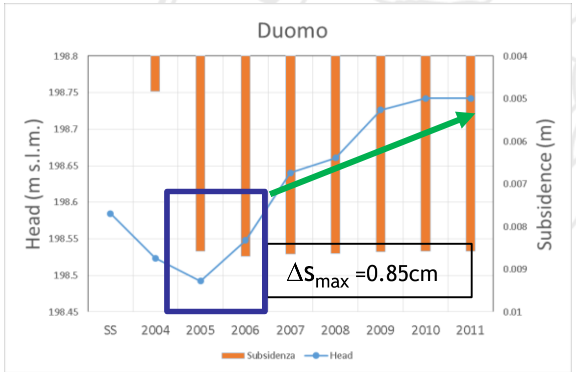
INELASTIC and ELASTIC SUB CYCLES

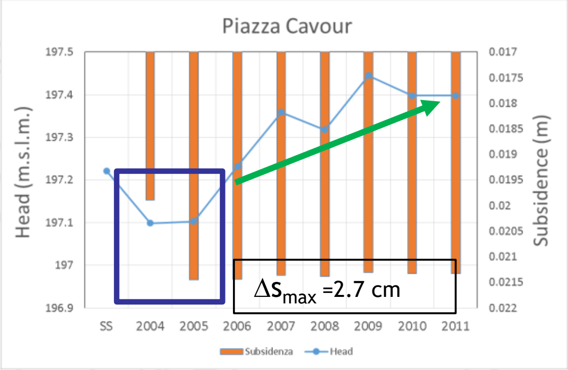




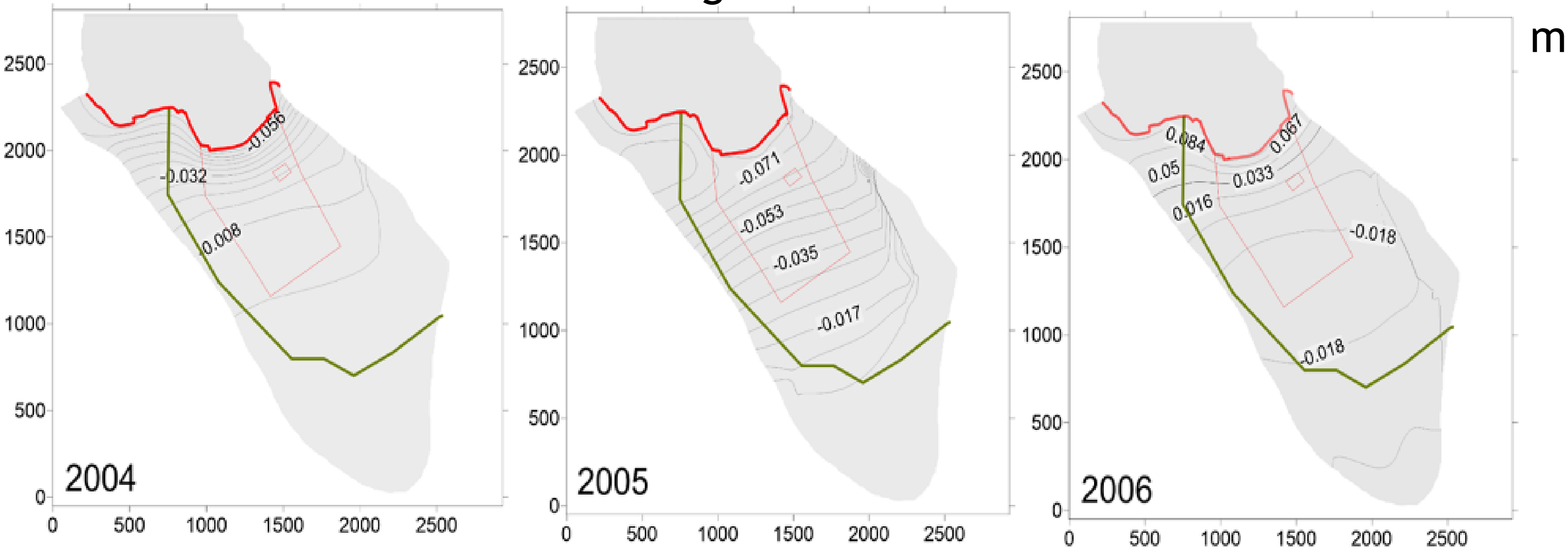


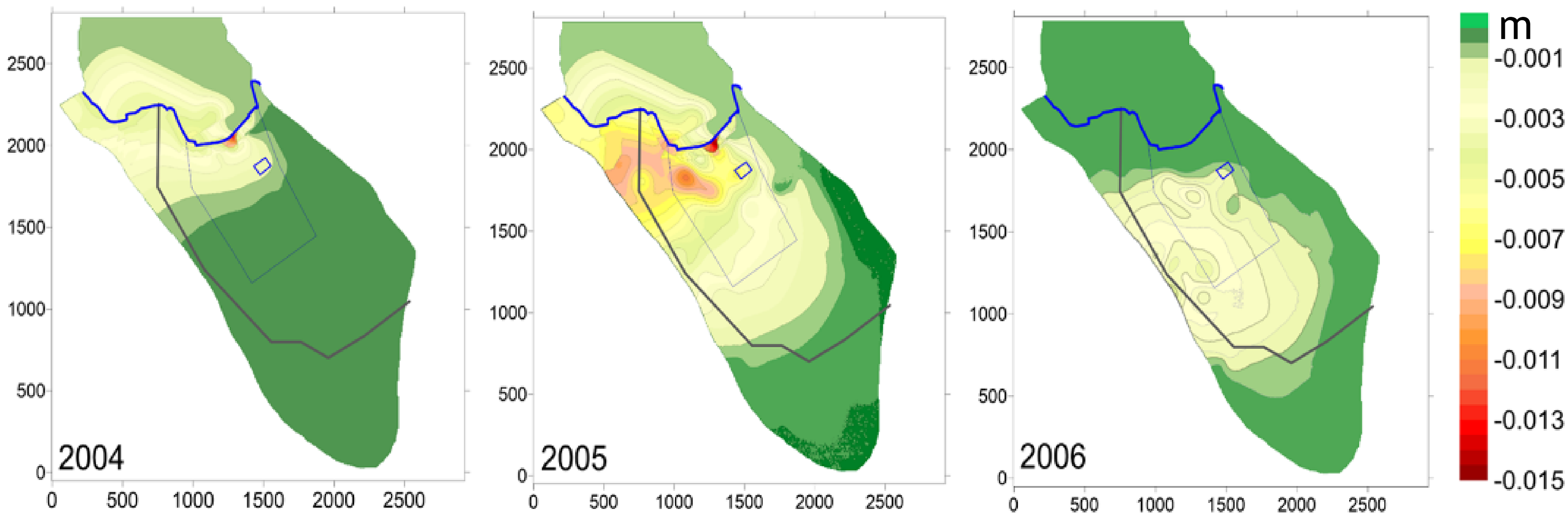




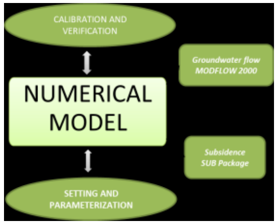


Annual groundwater level variation



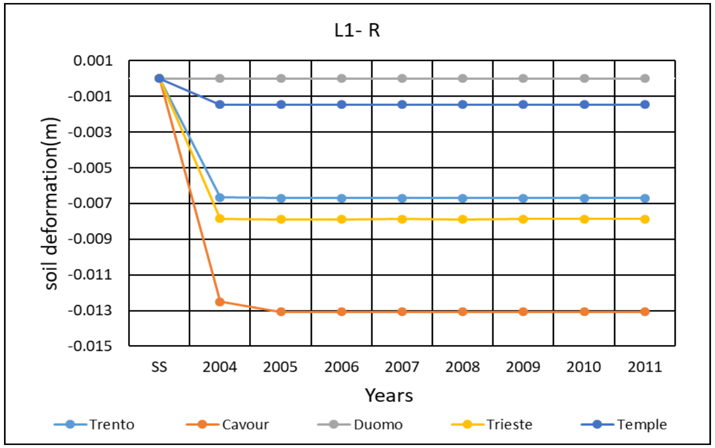


Annual subsidence variation

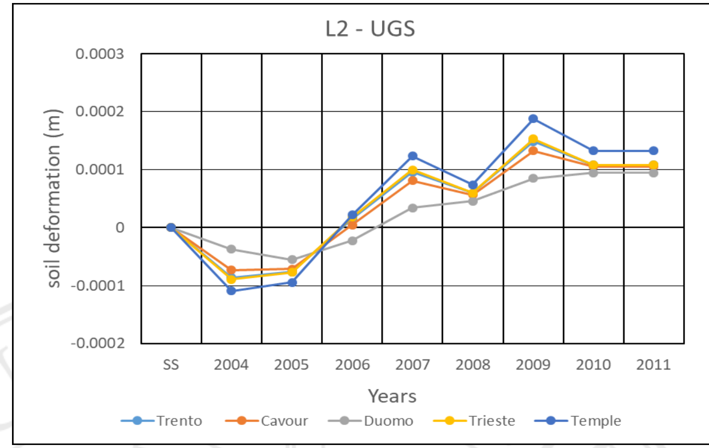


NUMERICAL MODEL
Results

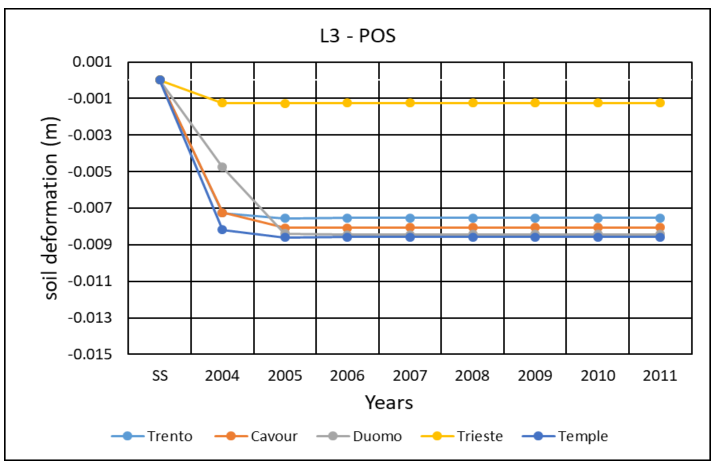
Deformation per layer



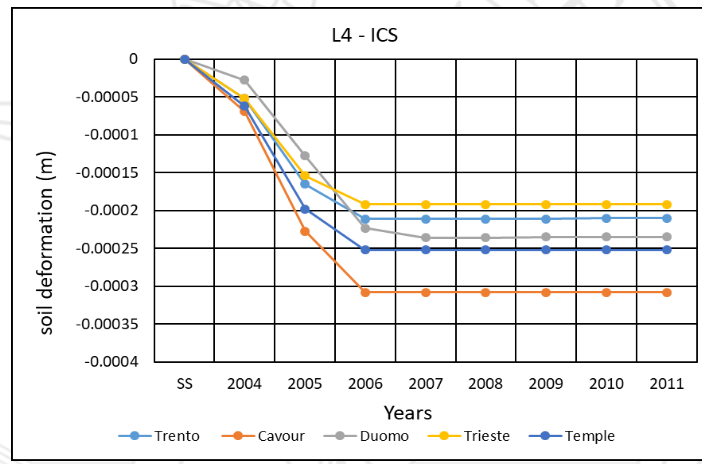
Elastic recovery linked to the coarser unit

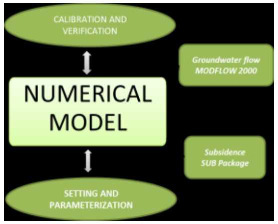


Unit R and POS contribute to almost the whole deformation



ICS contribuite negligibly to the phenomenon due to its depth and low k



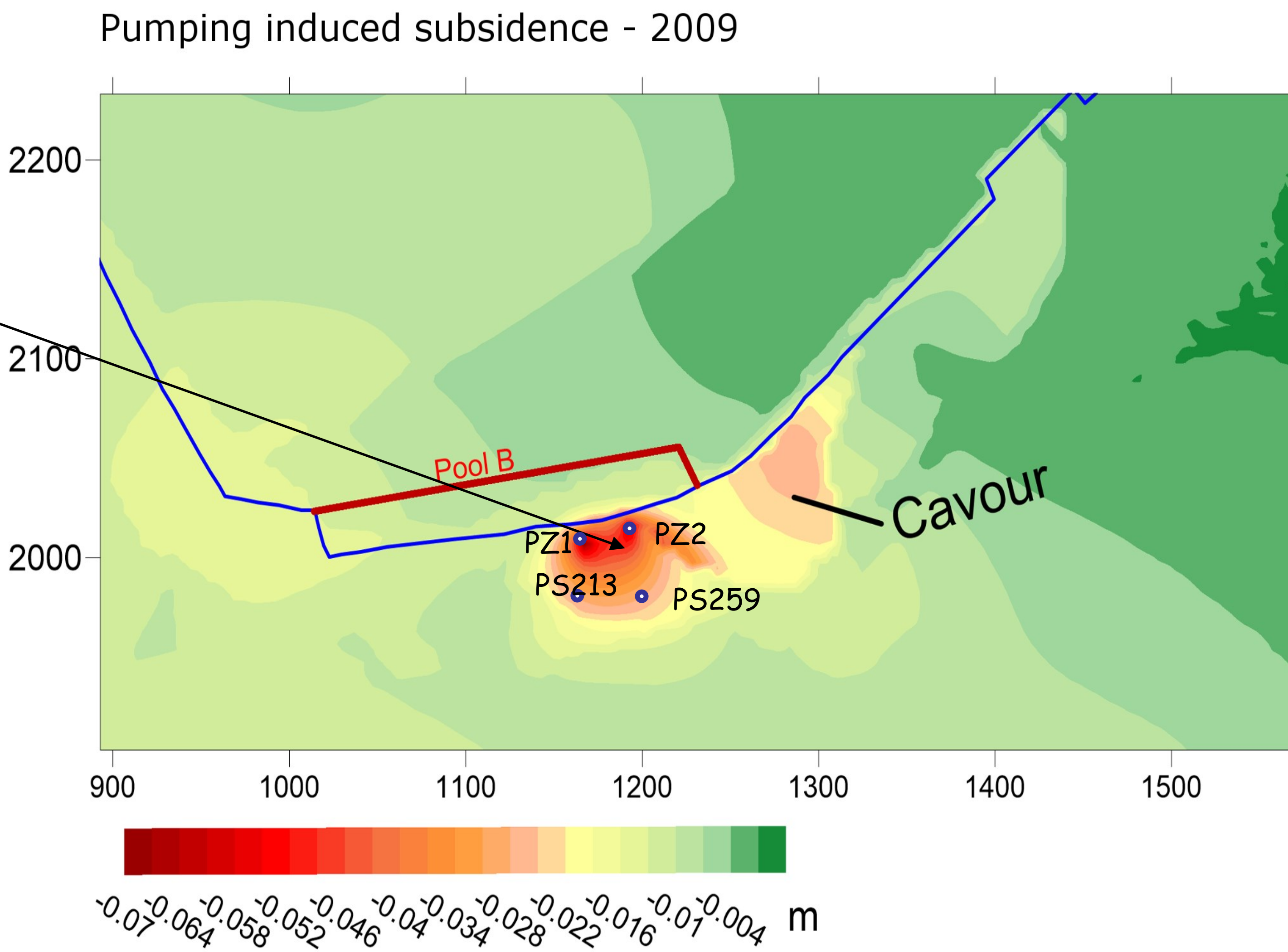


NUMERICAL MODEL
Verification

ANTHROPIC PERTURBATION

100 l/s

LOCALIZED DEFORMATION INCREMENT UP TO A MAXIMUM OF 6-7 cm



CONCLUSIONS – APPLICATIONS - LIMITATIONS

CONCLUSIONS

-Natural or anthropogenic perturbation of the acquifer system could induce a deformation of the relative **solid skeleton** of soils.

-Development of an effective procedural scheme to **analyze and forecast** subsident critical zone: it **cannot prescind from the hydro-geotechnical comprehension of the subsoil**

APPLICATIONS

Urban management

-Pool A induced subsidence evaluation (R ~12 m)

-Groundwater response assesment linked to anthropic or natural perturbations.

LIMITATIONS

-Constant recharge (annual model)

- Most recent and complete available data 2004-2011

-No-delay beds =instantaneous deformation

$$\tau = S_{skv}\left(\frac{b}{2}\right)^2 / K_V$$

→ TIME DELAY ESTIMATION – Riley equation

UNIT	S_{skv} (m^{-1})	b_{av} (m)	K_v (m/s)	τ
R	1.3×10^{-2}	8	5.3×10^{-5}	Instantaneous (<1day)
POS	4.2×10^{-3}	30	7×10^{-7}	15÷30 days
ICS	3.77×10^{-3}	40	4.73×10^{-9}	10 years

Thanks for your attention!

UNIVERSITÀ DEGLI STUDI DI MILANO

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ACKNOWLEDGMENTS

We would like to acknowledge Dr. Jacopo Terrenghi for the precious help in approaching the numerical model.
Additional thanks go to Local Authorities and Municipality of Como for the data made available.