I Giornata AIGA di Approfondimento ***«Lo studio e la tutela delle acque sotterranee»***

ASSESSMENT OF THE SEA-LEVEL RISE IMPACT DUE TO CLIMATE CHANGE ON COASTAL GROUNDWATER DISCHARGE

Aula Magna del Dipartimento di Scienze della Terra e Geoambientali,
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GOALS AND AIMS

- ✓ Experimental evaluation and forecasts, until 2200, about local sea level rise (LSLR) and its impacts on Salento coastal groundwater

- ✓ Quantification of seawater intrusion advancement in coastal fractured aquifer, using soil digital elevation model (ArcGIS)

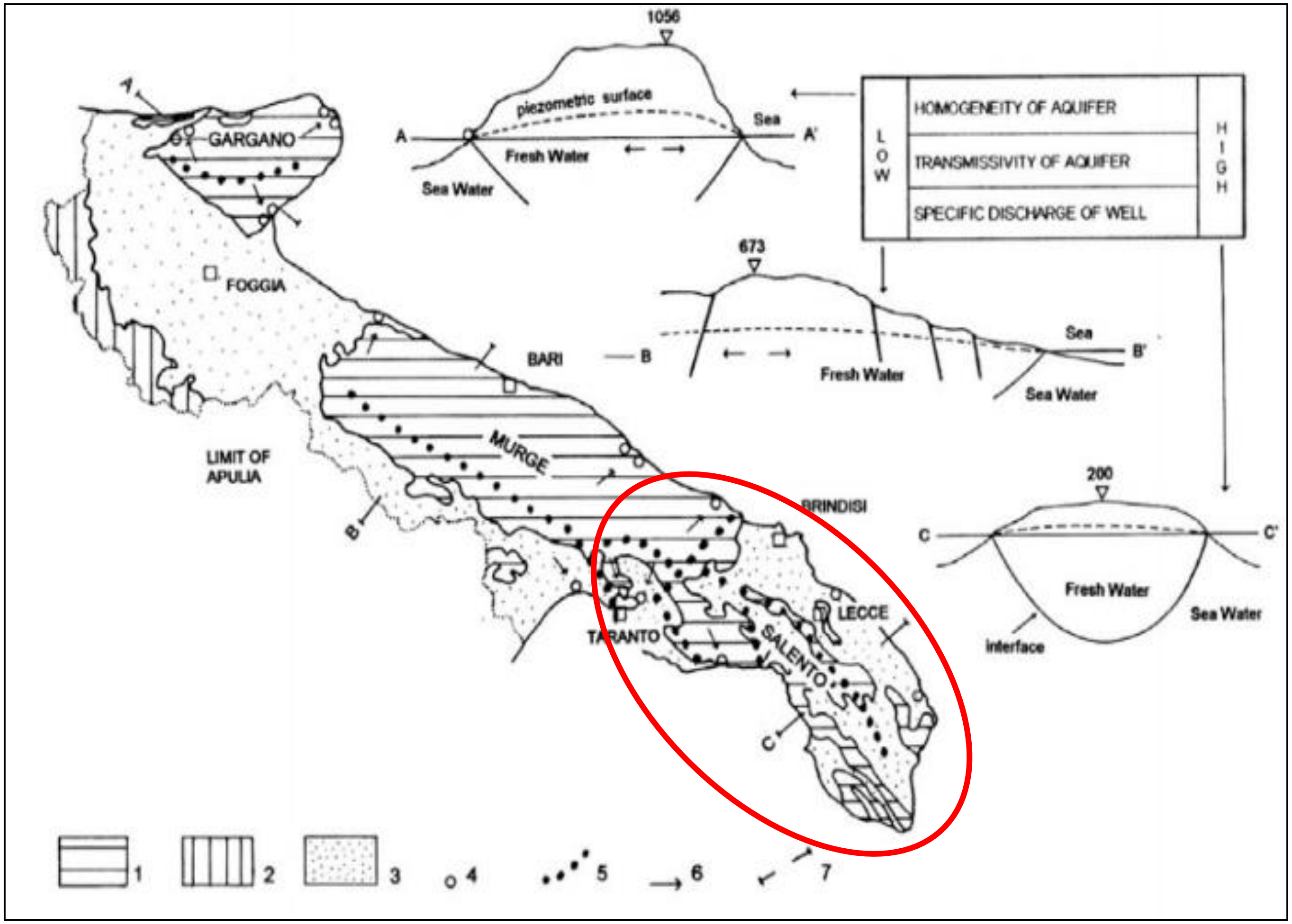
- ✓ A new formula to evaluate groundwater outflow reduction, as a consequence of seawater intrusion, is presented

- Absence of relevant surface water reservoir.
- Agriculture is the main economic activity in Apulia Region
- Average rainfall < 600 mm/y: natural recharge is unable to refill groundwater sufficiently with respect to agricultural and drinking water demand.

PILOT AREA

Salento Peninsula

HYDROGEOLOGICAL MAP APULIA REGION

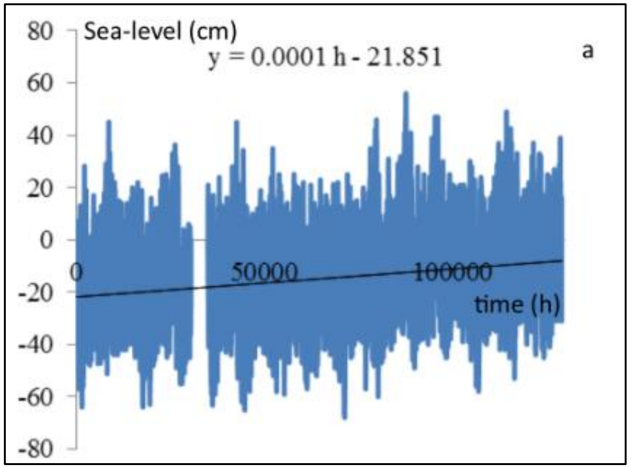


LEGEND

(1) Mesozoic limestone and dolomite
(2) Apennines units
(3) Foredeep Plio-Pleistocene sediment
(4) coastal springs
(5) hydrogeological watershed
(6) groundwater flow direction
(7) hydrogeological section

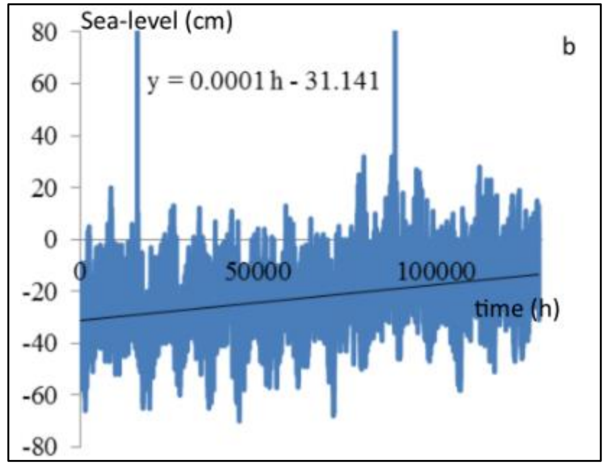
*Maggiore and Pagliarulo, 2003

Data collected from tide-gauge stations during 2000-2014



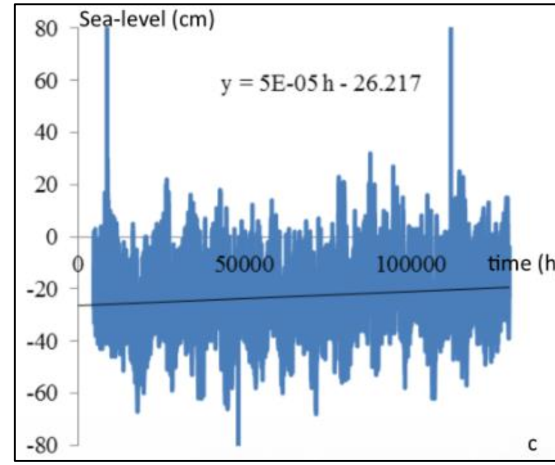
Bari

LSLR 8,76 mm/y



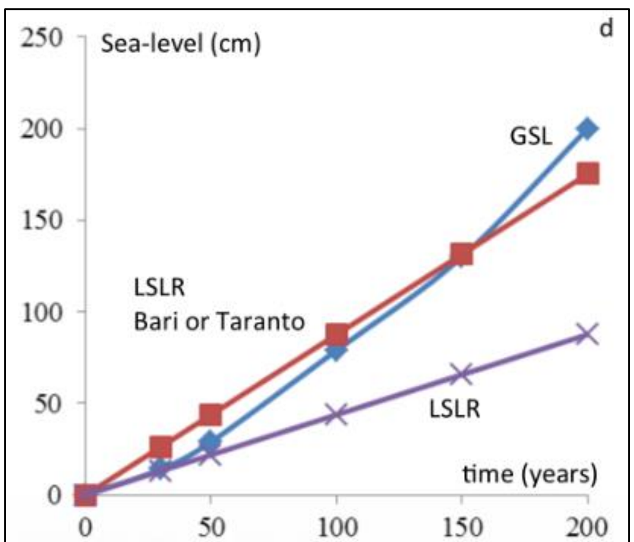
Taranto

LSLR 8,76 mm/y



Otranto

LSLR 4,38 mm/y



Kopp* 2014

GSLR

(Kopp et al. 2014. Probabilistic 21 and 22 century sea-level projections at a global network of tide-gauge sites. Earth's future, 2, 383-406, doi: 10,1002/2014EF000 239)*

XXII Century
Maximum local sea level rise along Salento coast

2 m

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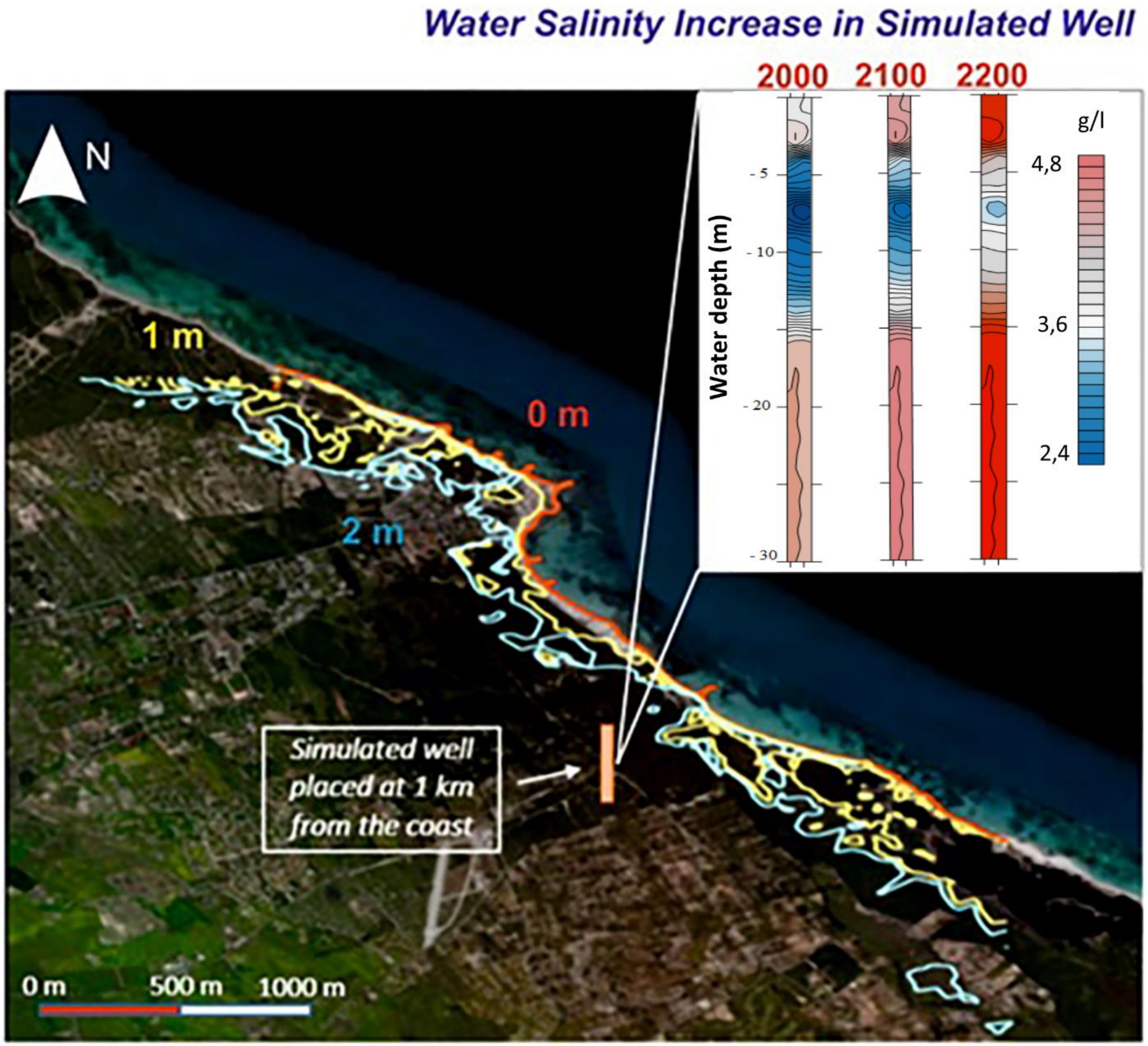

$$C_{salt} = C_{s0} + A_s\left[exp - \frac{d}{D_s}\right]$$

SCENARIO UNTIL 2200

- *Maximum coastline advancement derived from soil digital elevation model analyses*

40-600 m

BEST FIT CONSTANTS

- C*so* = 1,54 g/L
- A*s* = 12,02 g/L
- D*s* = 592,65 m

PARAMETERS

- C*salt* salt concentration in well
- *d* distance between well and Ghyben-Herzberg interface

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CONCEPTUAL GROUNDWATER FLOW MODELS*

1. ***Flux-controlled system*** : groundwater discharge to the sea is persistent despite changes in sea level

2. ***Head-controlled system*** : groundwater abstraction or surface features preserve the aquifer head condition despite sea level change

3. **Other models**

PILOT AREA CHARACTERISTICS

- High limestone rock permeability (60-700 m/d)
- Low coast elevation
- General water table inability to migrate vertically. Confined aquifer
- Low LSLR compared to the aquifer thickness

The piezometric head [Φo] is assumed to be constant at a specific distance from the coastline [the origin x = 0 → Φ = Φo], despite 2m of LSLR.

*Werner, A.D., Simmons, C.T., 2009. Impact of sea-level rise on seawater intrusion in coastal aquifers. Ground Water 47 (2), 197–204.

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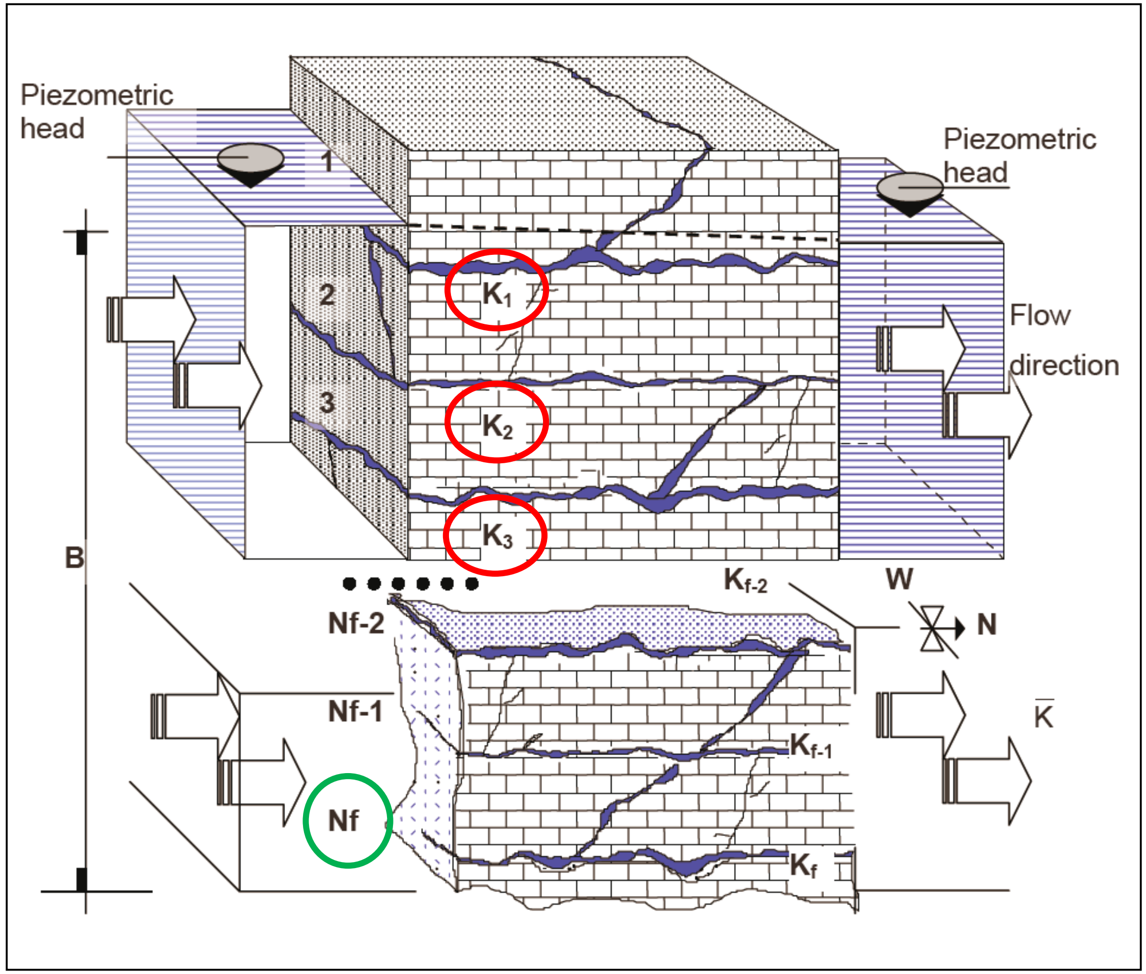
GROUNDWATER FLOW MODEL

K1, K2, K3 hydraulic conductivity of each single fracture belonging to the modelled parallel set

Nf total number of fractures belonging to the modelled parallel set

- Fractured aquifer was idealized in a layered model made by several horizontal fractures bounded by impermeable rocks

- ***Assumptions***: inside fractures, freshwater flows in a horizontal direction (Dupruit assumption); all fractures were assumed to have hydraulic connections between themselves and to have the same mean aperture $2b_i$ [L]



Groundwater discharge per unit of seacoast length Q_0 [$L^3/t/L$] derives from the Navier-Stokes' equations flow solution, in a single fracture bounded by two parallel plates, in a confined aquifer

$Q(x)$ Must be constant due to continuity

(Eq.1) $$Q(x) = -\frac{b_i^2}{3}\frac{\gamma_f}{\mu_f} n H(x)\frac{\partial \phi(x)}{\partial x} = const = Q_0$$

$2b_i$	Mean fracture aperture [L]
$\frac{\gamma_f}{\mu_f}$	Freshwater density/viscosity ratio = $10^7\ m^{-1}s^{-1}$ at 20 °C
n	Effective aquifer porosity [-]
x	Coordinate along the fracture length towards sea direction [L]
$H(x)$	Depth of the sharp interface below sea level [L] (i.e., freshwater thickness)
$\phi(x)$	Piezometric head of freshwater in *x* direction [L]

parameters

$$K = \frac{b_i^2}{3}\frac{\gamma_f}{\mu_f} n$$

$$n = \frac{\sum_{i=1}^{N_f} 2b_i}{B}$$

$\sum_{i=1}^{N_f} 2b_i$	Sum of all horizontal apertures in the vertical aquifer column [L]
B	Aquifer thickness [L]

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GHYBEN-HERZBERG THEORY for stationary interface ***leads to***

$$H(x) = \Phi(x)\frac{\Upsilon_f}{\Upsilon_s - \Upsilon_f} = \delta_\Upsilon \Phi(x) \longrightarrow \Phi(x) = \frac{H(x)}{\delta_\gamma}$$

Replacing K and $\Phi(x)$ in **Eq. 1**:

$$Q_0 \times \partial x = -K\frac{H(x)}{\delta_\gamma}\partial H(x) \qquad \textbf{(Eq.2)}$$

Integrating **Eq.2**: X = 0 → Φ(x) = Φo → H=B

X = L → Φ(L) = δϒ * Φ(s) → H=Hs

$$Q_0 \times L = K\frac{B^2 - H_s^2}{2\delta_\gamma} = K\frac{(\delta_\gamma \Phi_0\,)^2 - H_s^2}{2\delta_\gamma} \qquad \textbf{(Eq.3)}$$

L is the minimum extension required to avoid seawater intrusion

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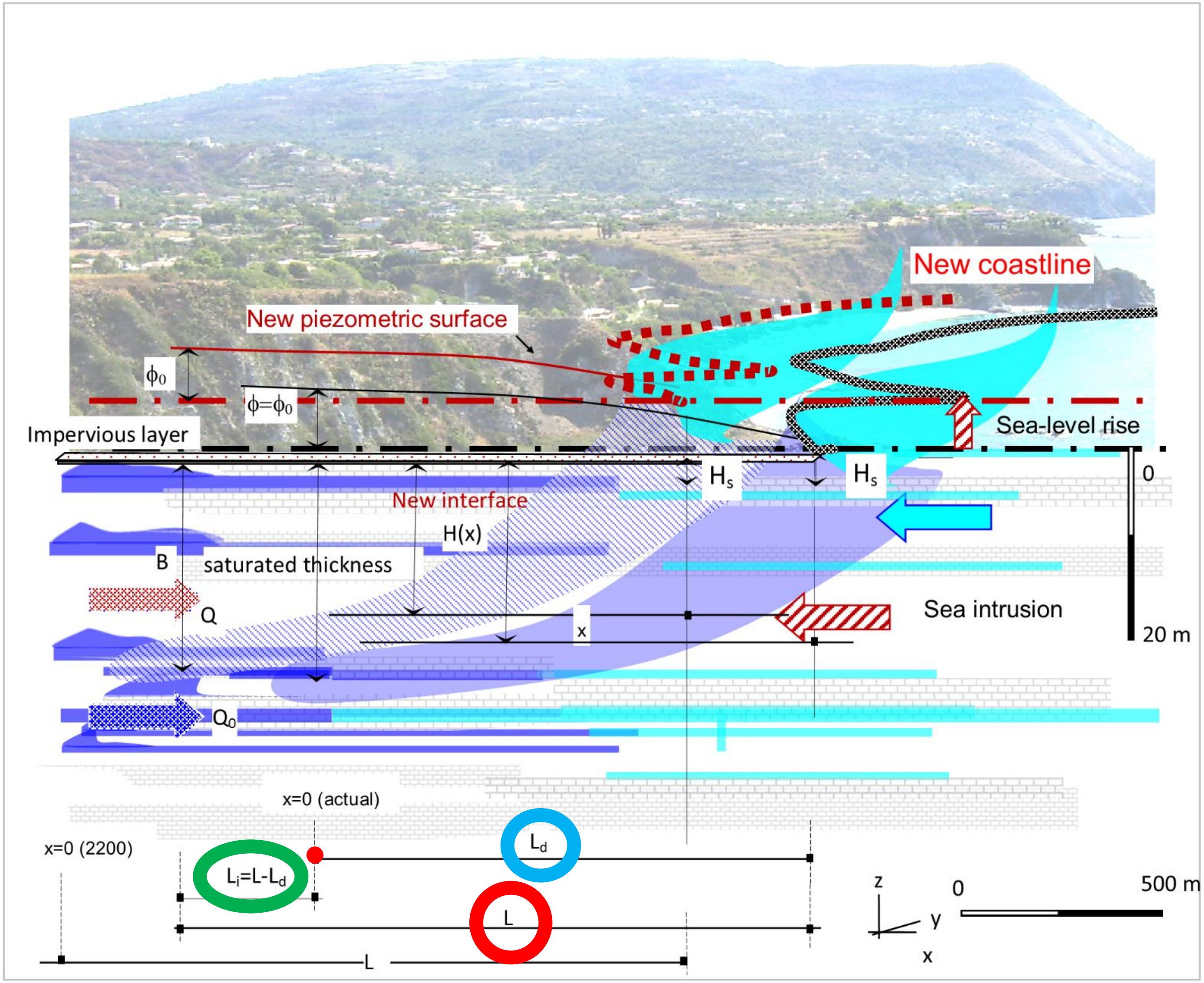

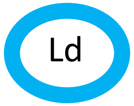

Modelled distance between the origin ● (Φ = Φo) and the coastline (Φ = 0)

Ld = L → groundwater outflow overlaps the coastline, no seawater intrusion

Ld < L → inland freshwater outflow, coastal saline lakes formation and seawater intrusion **(L-Ld)**

Ld > L → submarine springs

(L-Ld) represents the seawater intrusion due to LSLR, according to local coast morphology

Defining:

Q_0 groundwater outflow when **seawater intrusion in absent** → **L=Ld**

Eq.3 becomes → $$Q_0 = K\frac{B^2 - H_s^2}{2\delta_\gamma L_d}$$

Q groundwater outflow when **seawater intrusion is present** → **L>Ld**

Eq.3 becomes → $$L_i = K\frac{B^2 - H_s^2}{2\delta_\gamma Q} - L_d > 0 \rightarrow Q = K\frac{B^2 - H_s^2}{2\delta_\gamma (L_i + L_d)}$$

Difference between Qo and Q is the **GROUNDWATER DISCHARGE REDUCTION DUE TO LSLR**
(SEA ADVANCEMENT IS **Li = L-Ld**)

$$\boxed{\Delta Q = Q_0 - Q = Q_0 - K\frac{B^2 - H_s^2}{2\delta_\gamma (L_i + L_d)}}$$ **(Eq.4)**

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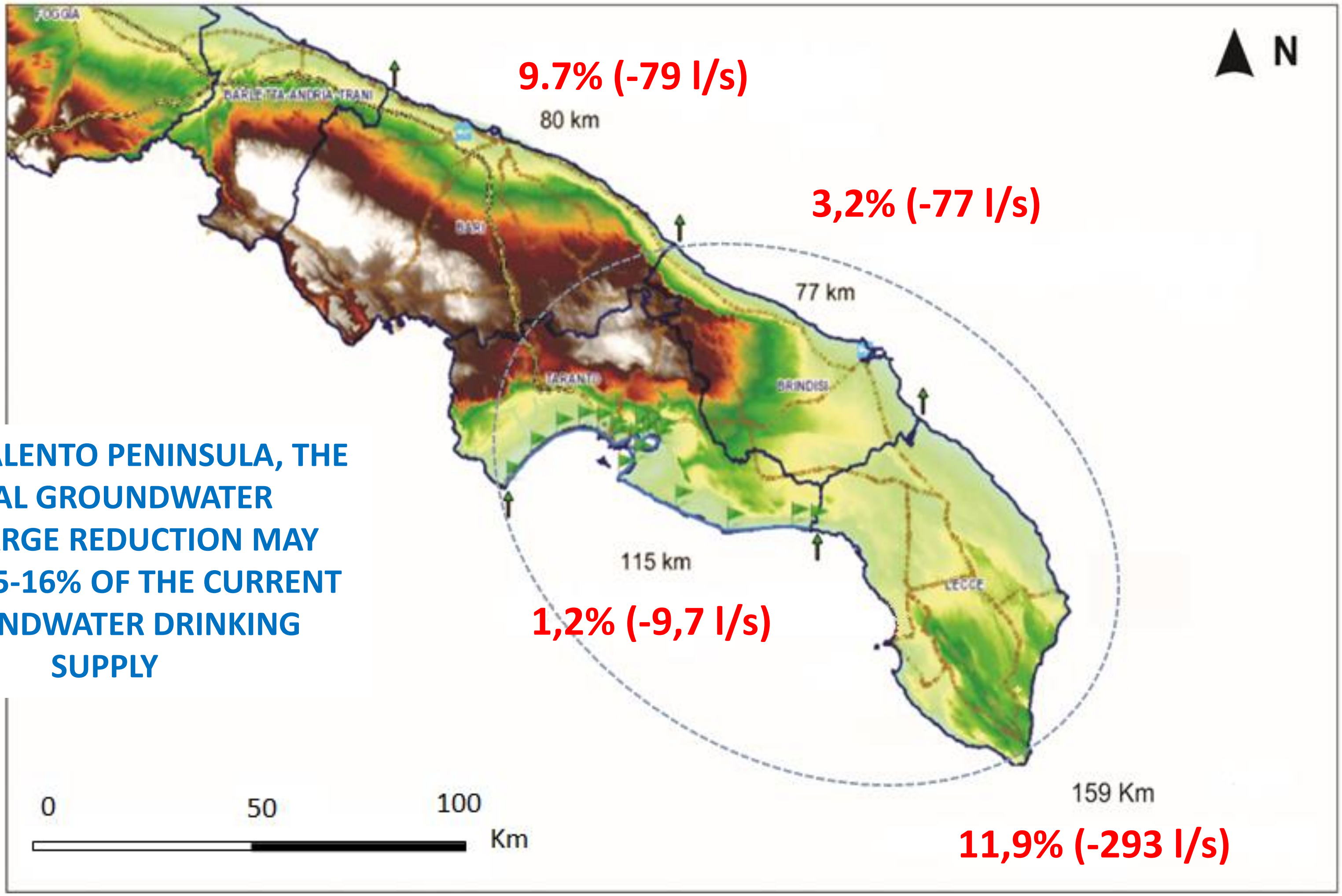
$$\Delta Q = Q_0 - Q = Q_0 - K\frac{B^2 - H_s^2}{2\delta_\gamma(L_i + L_d)} \quad \text{(Eq.4)}$$

Mean value related to specific sea coast length	*Bari*	*Brindisi*	*Lecce*	*Taranto*
K (m/s)	$3.7 * 10^{-3}$	$3.7 * 10^{-3}$	$8.0 * 10^{-3}$	$8.0 * 10^{-4}$
B (m)	15	15	20	15
L (m)	1700	1357	3280	2690
L_d (m)	1400	1250	2800	2500
L_i (m)	300	125	480	190
Φ_0 (m)	0.5	0.5	0.5	0.5
Coastline length (m)	53600	60060	126630	85840
Q_0 ($m^3/s/m$)	$1.1 * 10^{-5}$	$1.1 * 10^{-5}$	$1.9 * 10^{-5}$	$1.2 * 10^{-6}$
ΔQ ($m^3/s/m$)	$1.8 * 10^{-6}$	$1.0 * 10^{-6}$	$2.8 * 10^{-6}$	$8.4 * 10^{-8}$
Discharge reduction (Mm^3/year)	3.03	2.03	10.5	0.23
% GROUNDWATER AVAILABILITY REDUCTION WITH RESPECT TO CURRENT DRINKING SUPPLY	**9.7%**	**3.2%**	**11.9%**	**1.2%**

SCENARIO UNTIL 2200



IN THE SALENTO PENINSULA, THE TOTAL GROUNDWATER DISCHARGE REDUCTION MAY REACH 15-16% OF THE CURRENT GROUNDWATER DRINKING SUPPLY

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CONCLUSIONS

- The new proposed formula is useful to evaluate the groundwater discharge reduction due to seawater intrusion.
- In the Salento peninsula, 2m LSLR will produce a groundwater availability reduction of about 16% with respect to the current drinking supply
- The groundwater availability reduction does not take into account quality impairment due to seawater intrusion
- LSLR impacts on groundwater discharge reduction depend on coast morphology and its elevation.
- The head-controlled system assumption (Φo is constant at specific distance from coastline, despite 2m of LSLR) leads to approximate solutions.
- In the near future, the goal will be to make plans and to build a physical model to validate the model, also, in high cliff areas.

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