



UNIVERSITÀ
DEGLI STUDI DI BARI
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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,
Via Orabona, 4
Bari, 25 Ottobre 2016



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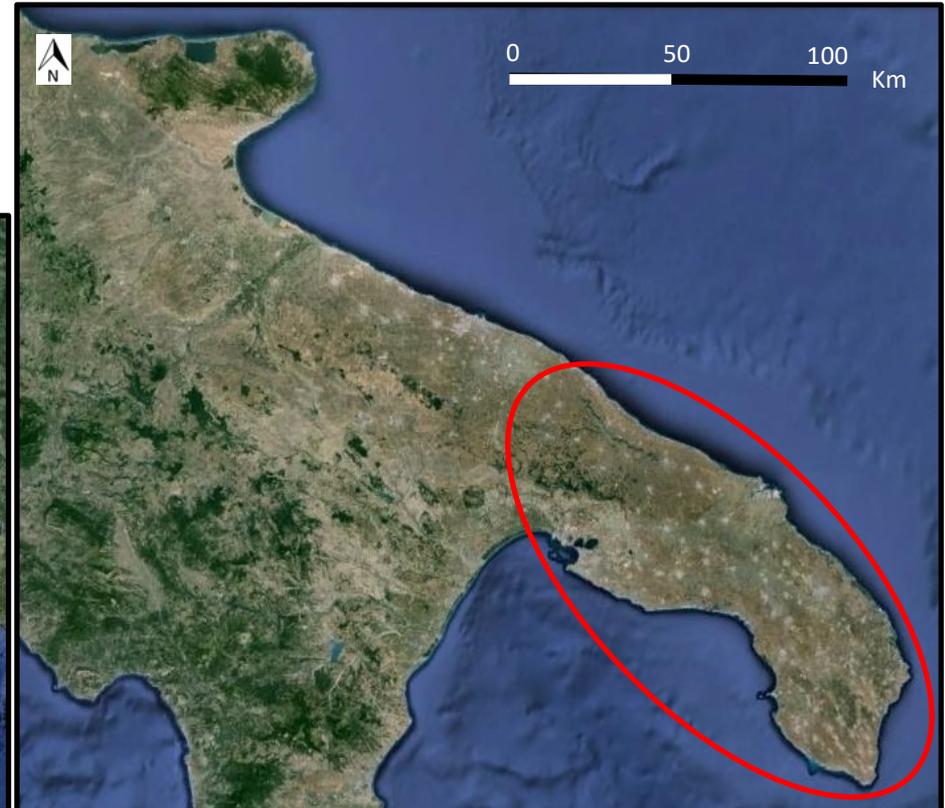
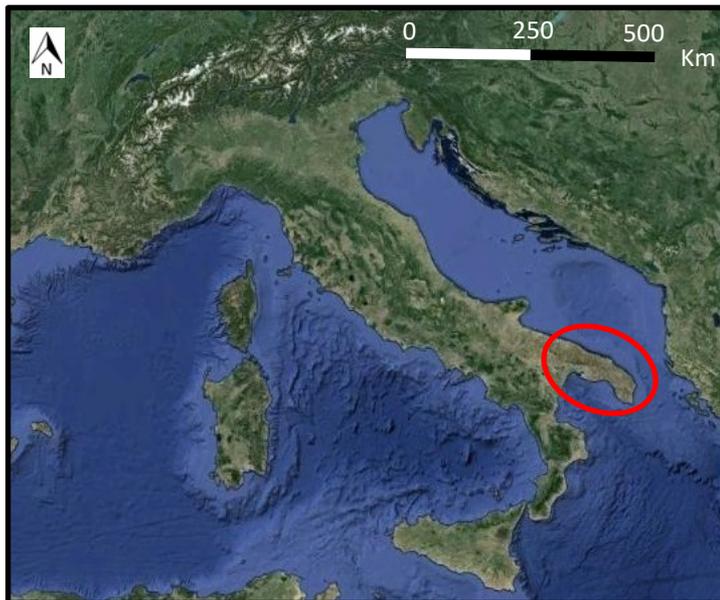


GOALS AND AIMS

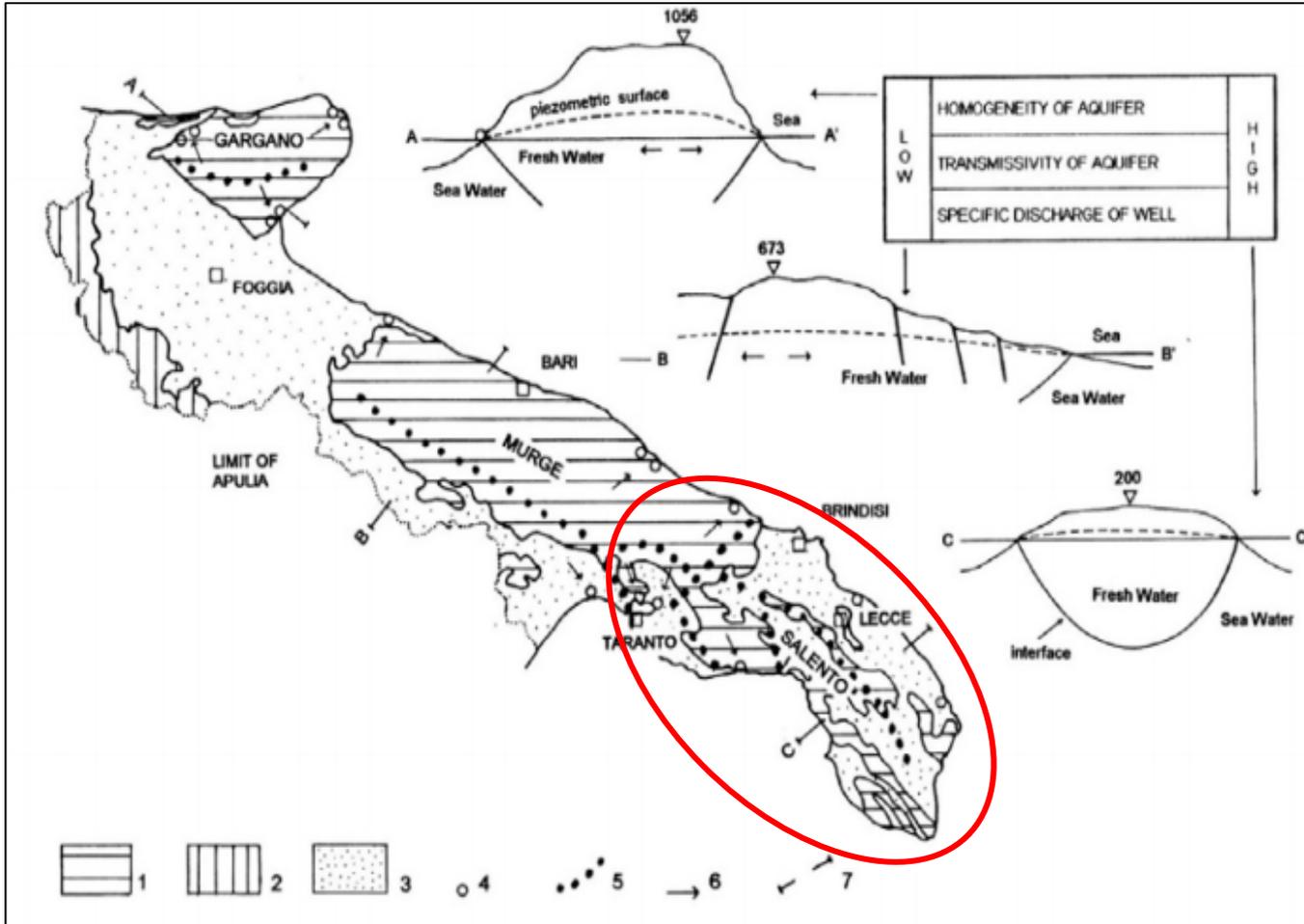
- ✓ **Experimental evaluation and forecasts, until 2200, about local sea level rise (LSLR) and its impacts on Salento coastal groundwater**
- ✓ **Quantification of seawater intrusion advancement in coastal fractured aquifer, using soil digital elevation model (ArcGIS)**
- ✓ **A new formula to evaluate 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

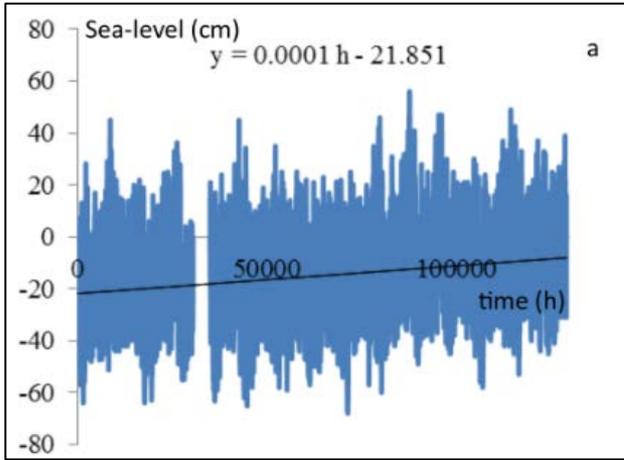


LEGEND

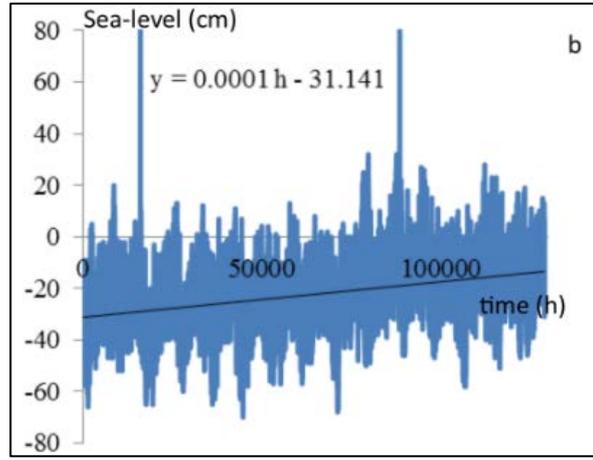
- (1) Mesozoic limestone and dolomite
- (2) Apennines units
- (3) Foredeep Plio-Pleistocene sediment
- (4) coastal springs
- (5) hydrogeological watershed
- (6) groundwater flow direction
- (7) hydrogeological section

*Maggiore and Pagliarulo, 2003

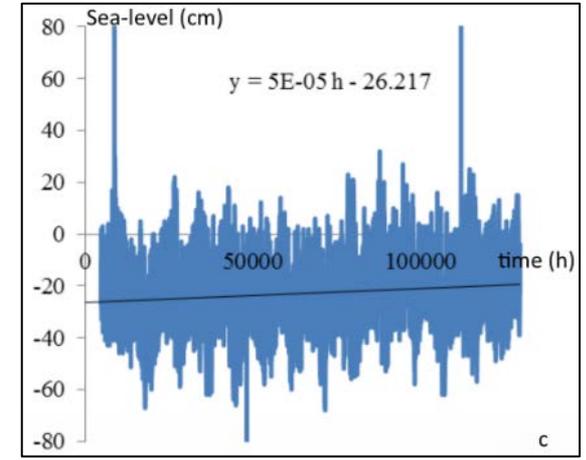
Data collected from tide-gauge stations during 2000-2014



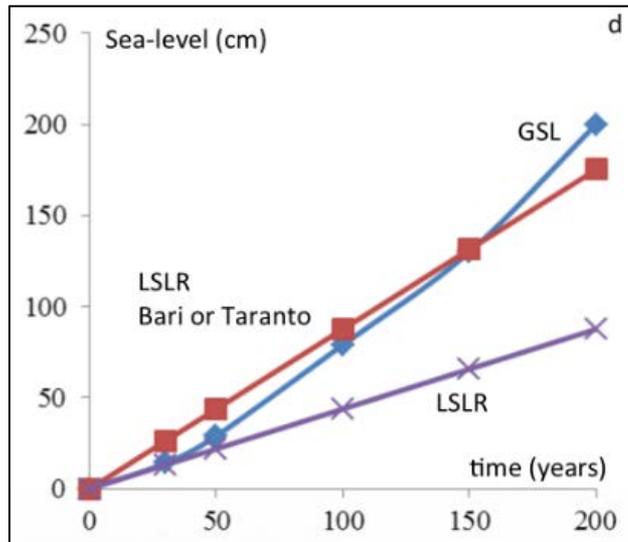
Bari
LSLR 8,76 mm/y



Taranto
LSLR 8,76 mm/y



Otranto
LSLR 4,38 mm/y



Kopp* 2014

GSLR

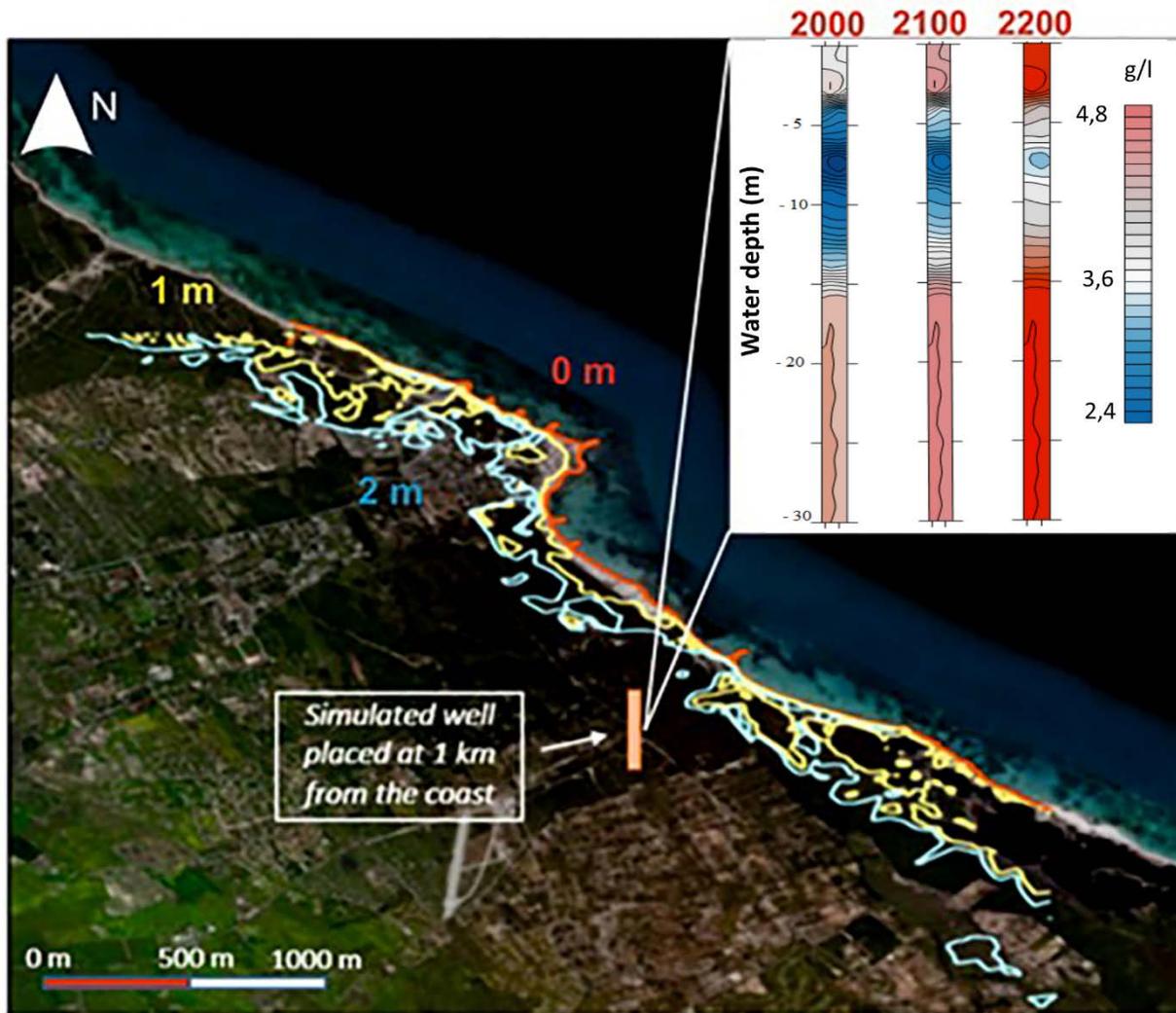
(* Kopp et al. 2014. Probabilistic 21 and 22 century sea-level projections at a global network of tide-gauge sites. Earth's future, 2, 383-406, doi: 10.1002/2014EF000239)

XXII Century
Maximum local sea
level rise along
Salento coast

2 m



Water Salinity Increase in Simulated Well



SCENARIO UNTIL 2200

- Maximum coastline advancement derived from soil digital elevation model analyses

40-600 m

BEST FIT CONSTANTS

- $C_{s0} = 1,54 \text{ g/L}$
- $A_s = 12,02 \text{ g/L}$
- $D_s = 592,65 \text{ m}$

PARAMETERS

- C_{salt} salt concentration in well
- d distance between well and Ghyben-Herzberg interface

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

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 [Φ_0] is assumed to be constant at a specific distance from the coastline [the origin $x = 0 \rightarrow \Phi = \Phi_0$], 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.

GROUNDWATER FLOW MODEL

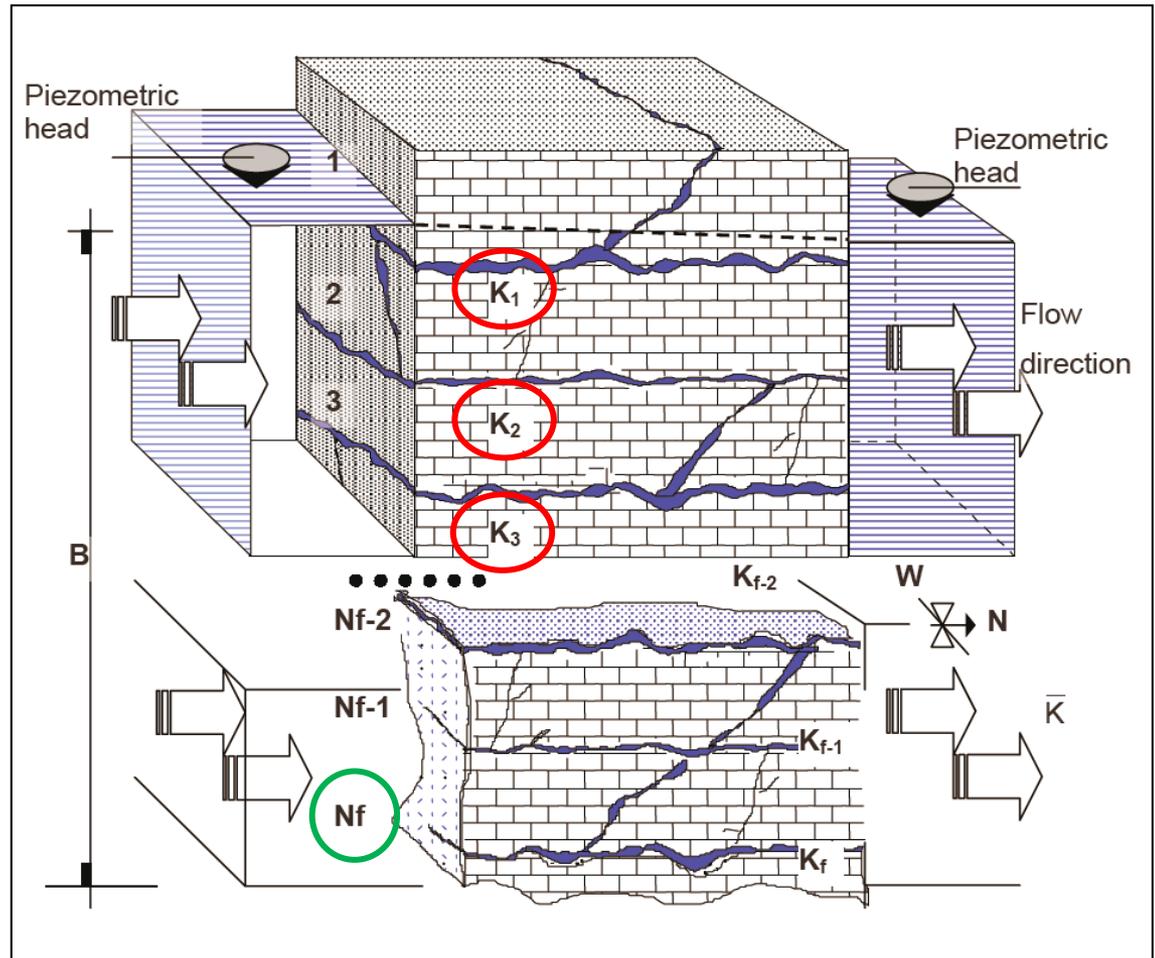
K_1, K_2, K_3

hydraulic conductivity of each single fracture belonging to the modelled parallel set

N_f

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 (Dupuit 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

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

$2b_i$	Mean fracture aperture [L]
$\frac{\gamma_f}{\mu_f}$	Freshwater density/viscosity ratio = $10^7 \text{ m}^{-1}\text{s}^{-1}$ at 20 °C
μ_f	
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

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

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

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

GHYBEN-HERZBERG THEORY for stationary interface leads to

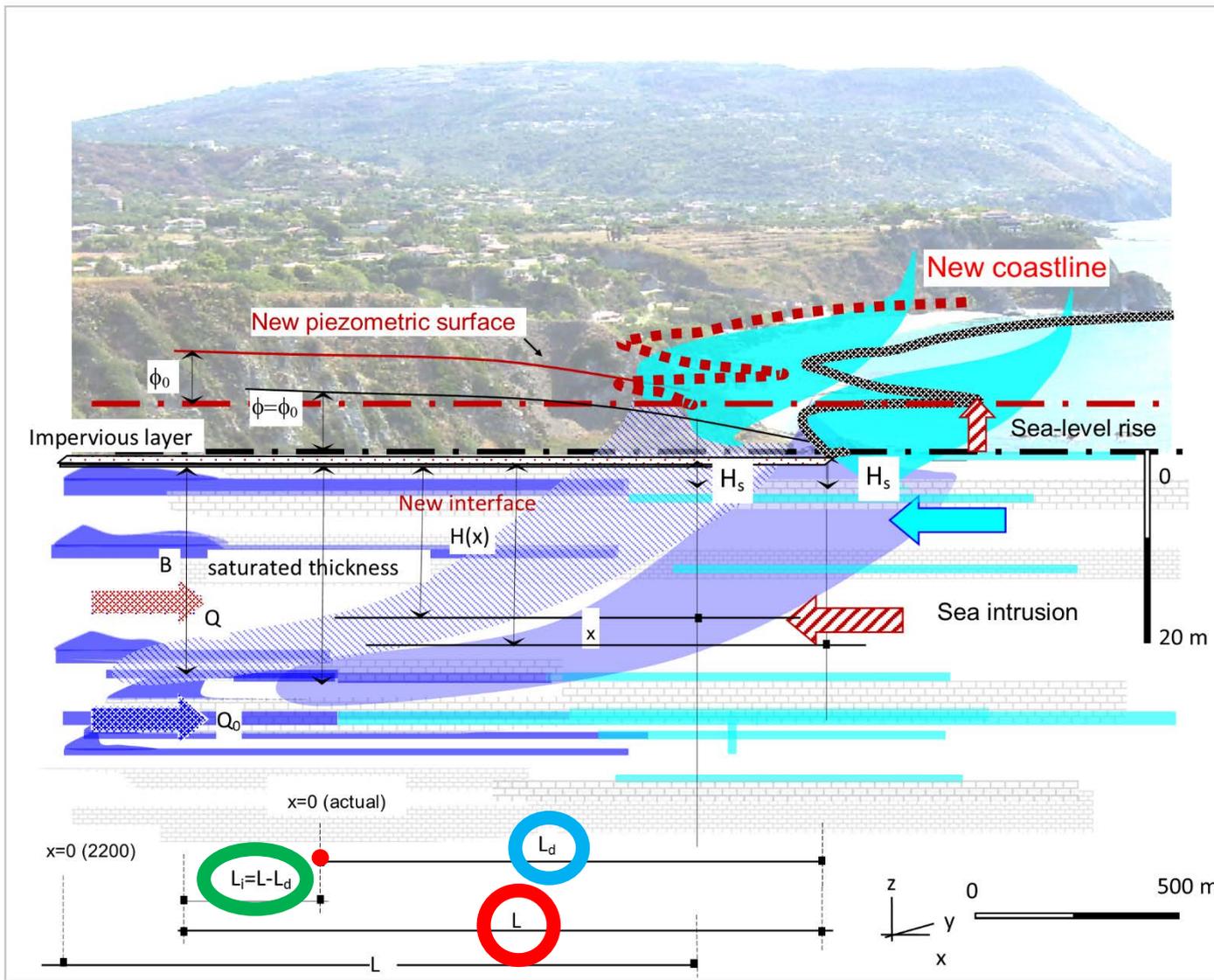
$$H(x) = \Phi(x) \frac{\gamma_f}{\gamma_s - \gamma_f} = \delta_\gamma \Phi(x) \longrightarrow \Phi(x) = \frac{H(x)}{\delta_\gamma}$$

Replacing K and $\Phi(x)$ in Eq. 1: $Q_0 \times \partial x = -K \frac{H(x)}{\delta_\gamma} \partial H(x)$ (Eq.2)

Integrating Eq.2: $X = 0 \rightarrow \Phi(x) = \Phi_0 \rightarrow H = B$
 $X = L \rightarrow \Phi(L) = \delta_\gamma * \Phi(s) \rightarrow H = H_s$

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

L is the minimum extension required to avoid seawater intrusion



L_d

Modelled distance between the origin ($\Phi = \Phi_0$) and the coastline ($\Phi = 0$)

$L_d = L \rightarrow$ groundwater outflow overlaps the coastline, no seawater intrusion

$L_d < L \rightarrow$ inland freshwater outflow, coastal saline lakes formation and seawater intrusion ($L - L_d$)

$L_d > L \rightarrow$ submarine springs

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

Defining:

Q_0 groundwater outflow when **seawater intrusion is absent** $\rightarrow L=L_d$

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

Q groundwater outflow when **seawater intrusion is present** $\rightarrow L > L_d$

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

Difference between Q_0 and Q is the **GROUNDWATER DISCHARGE REDUCTION DUE TO LSLR**
(SEA ADVANCEMENT IS $L_i = L - L_d$)

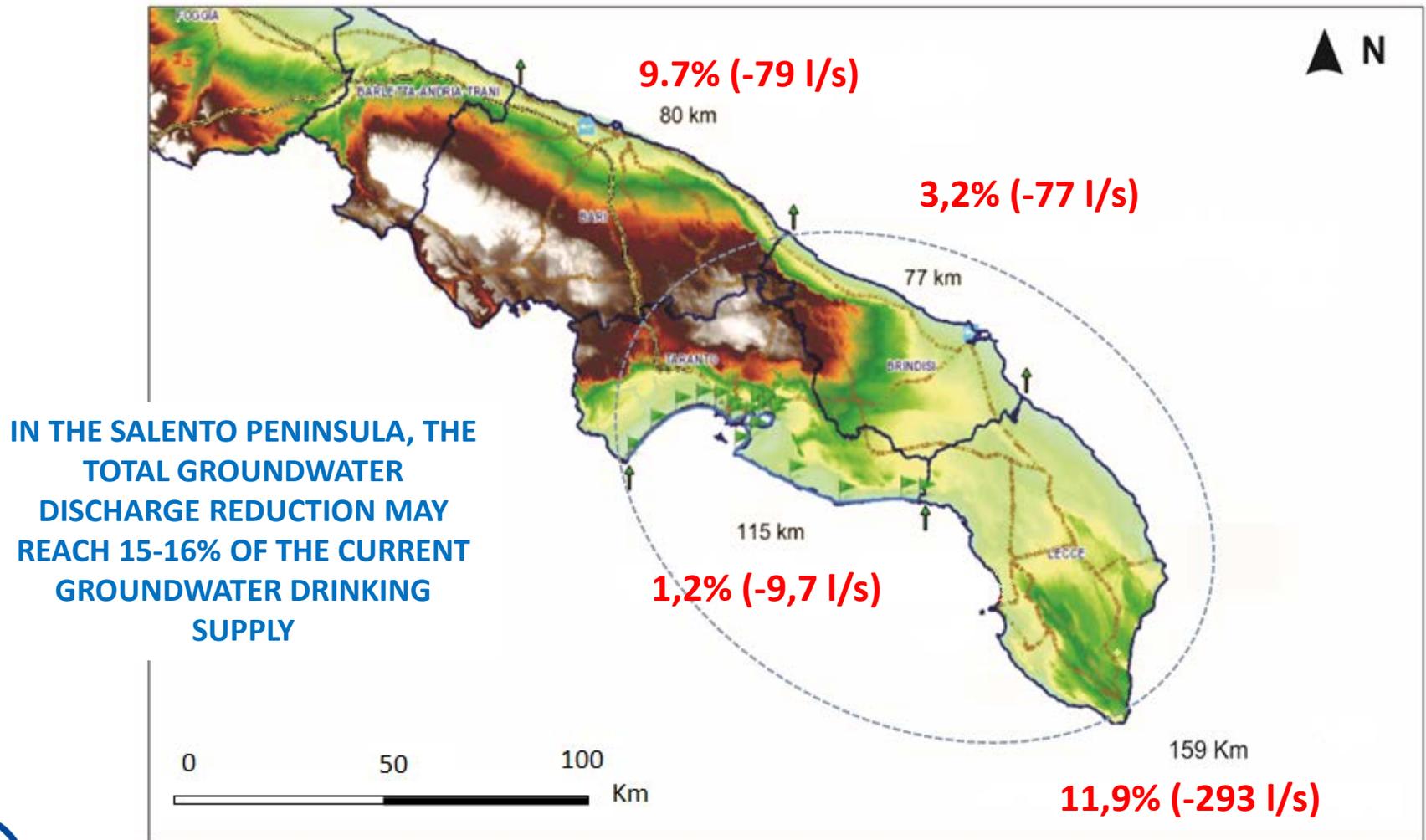
$$\Delta Q = Q_0 - Q = Q_0 - K \frac{B^2 - H_s^2}{2\delta_\gamma (L_i + L_d)}$$

(Eq.4)

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

Mean value related to specific sea coast length	<i>Bari</i>	<i>Brindisi</i>	<i>Lecce</i>	<i>Taranto</i>
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



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 (Φ_0 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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