ACC DAR Adapting to Climate Change in Coastal Dar es Salaam

International Workshop

TOWARDS SCENARIOS FOR URBAN ADAPTATION PLANNING

Assessing seawater intrusion under climate and land cover changes in Dar es Salaam, Tanzania

Session 1. Monitoring Urban Environmental Changes: Seawater intrusion

MONITORING SEAWATER INTRUSION IN THE COASTAL AQUIFER OF APULIA REGION

Rome, 22th April 2013

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Working on conceptual models….

Truth is much too complicated to allow anything but approximations”

John von Neumann, *quoted in*

Fractals, Chaos, Power Laws: Minutes from an Infinite Paradise, by Manfred Schroder

Simplicity is the ultimate sophistication.

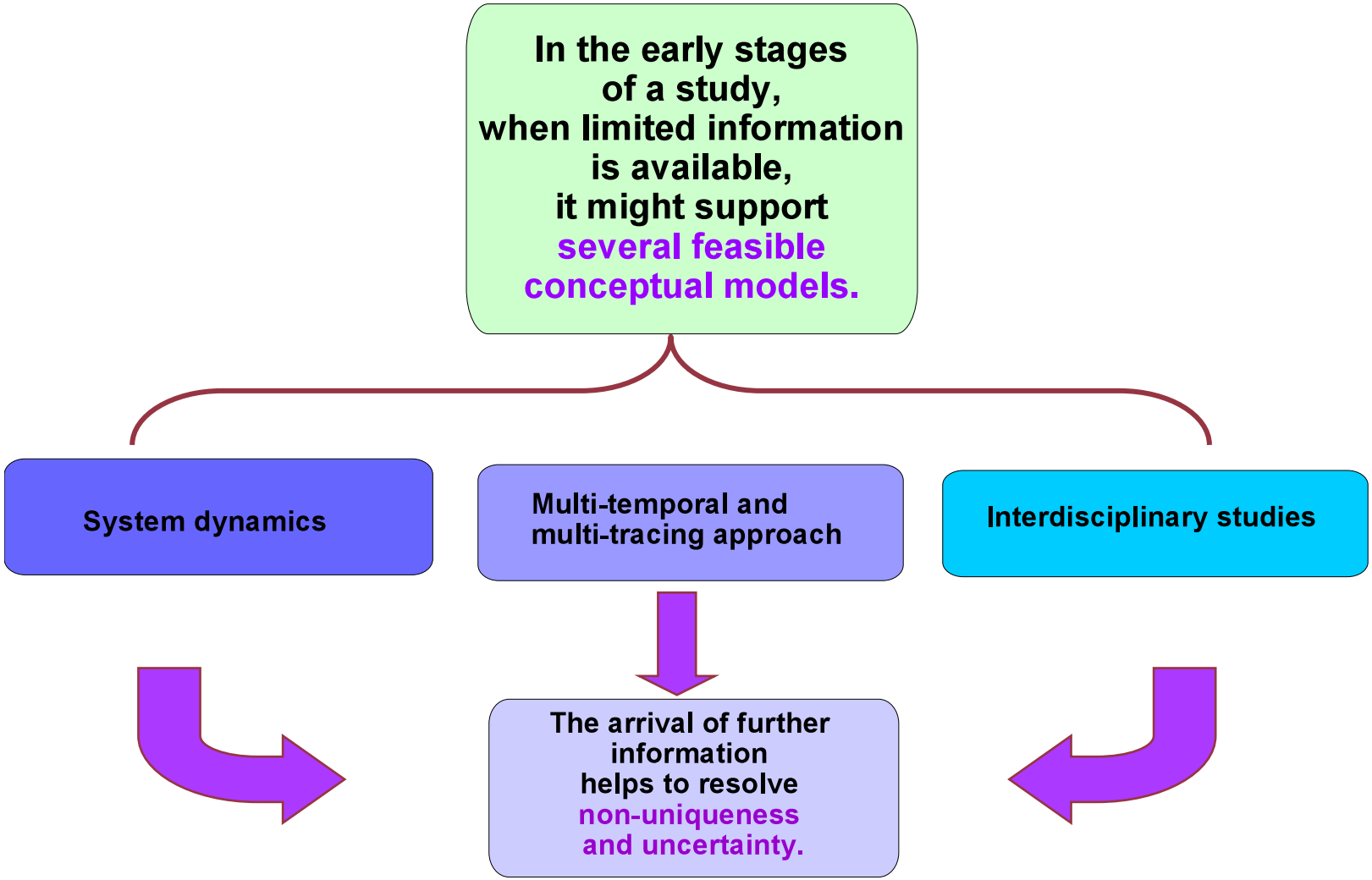
Leonardo da Vinci

Topics

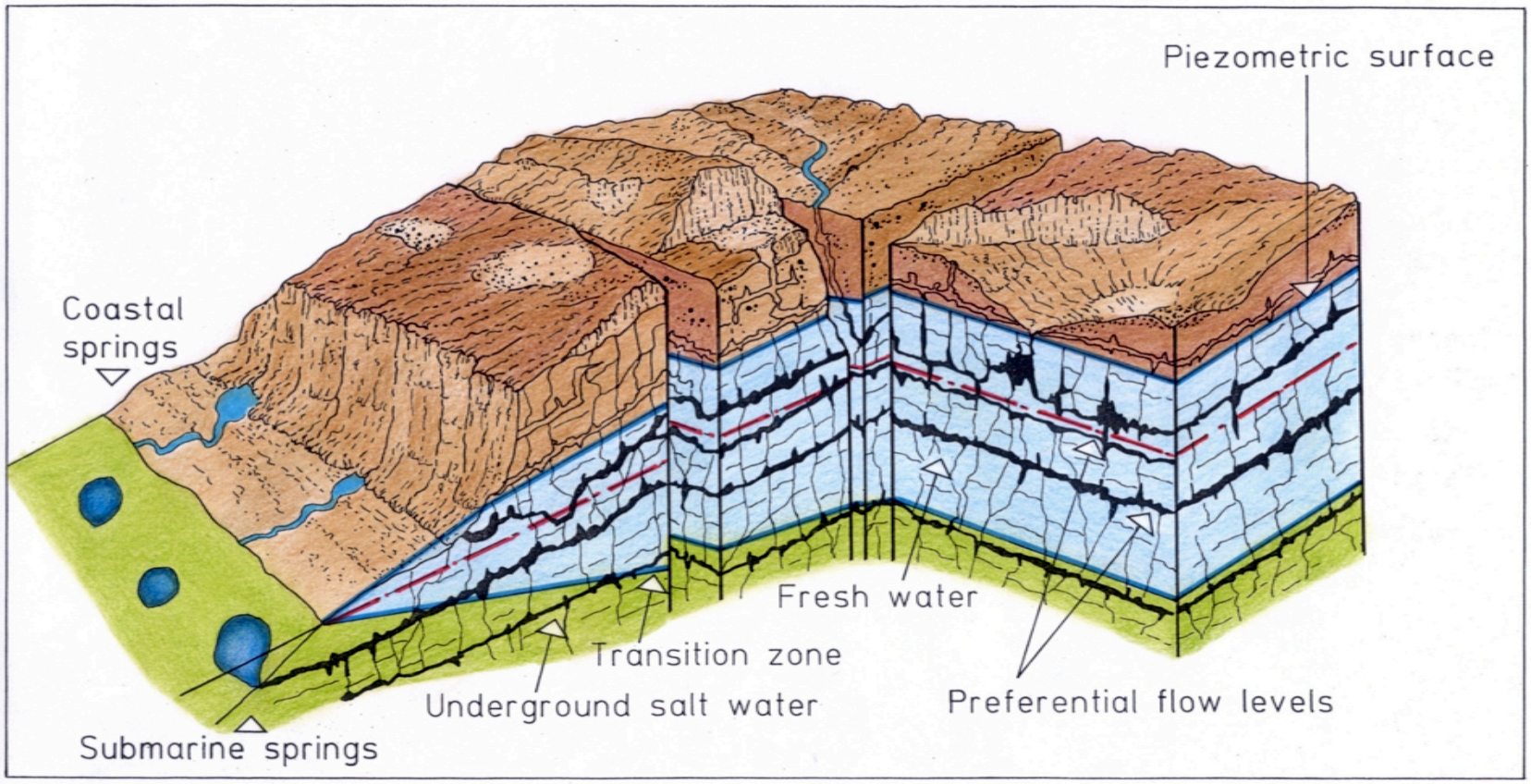
- Coastal aquifers: study of groundwater salinization
  - Conceptual modelling

- Looking for groundwater dynamics and source of salts
  - Temperature and Electrical Conductivity logs
  - Hydraulic measures
  - Geochemical approach

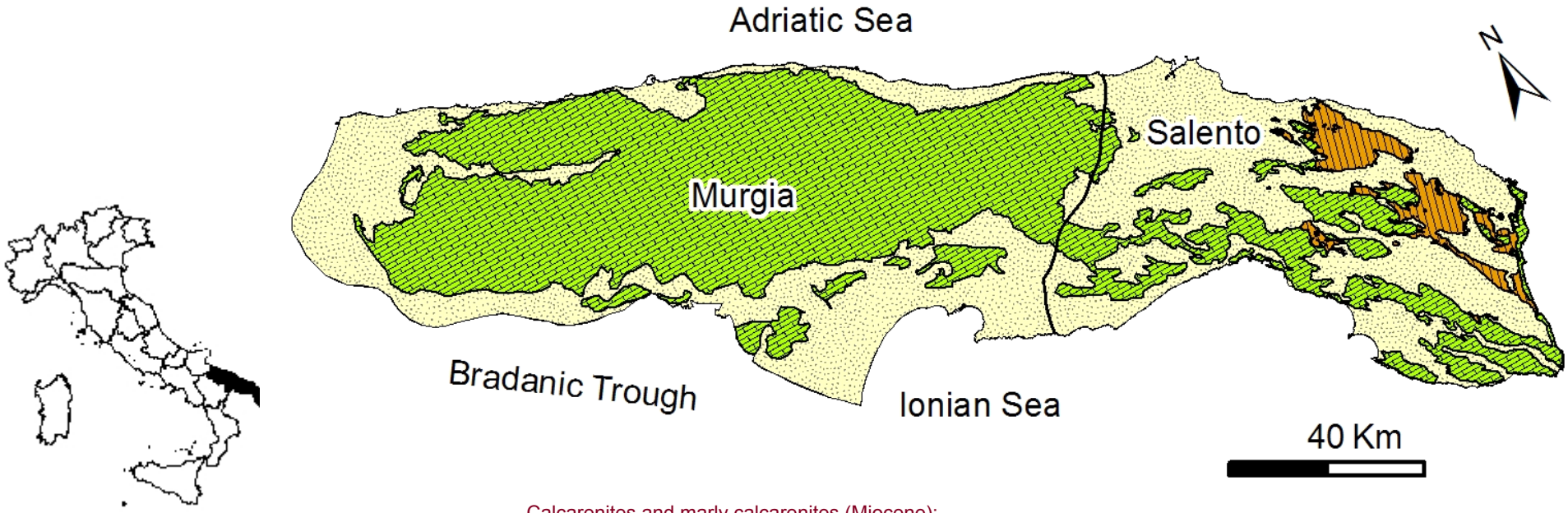
Selecting the suitable conceptual model .....



Coastal karst aquifer



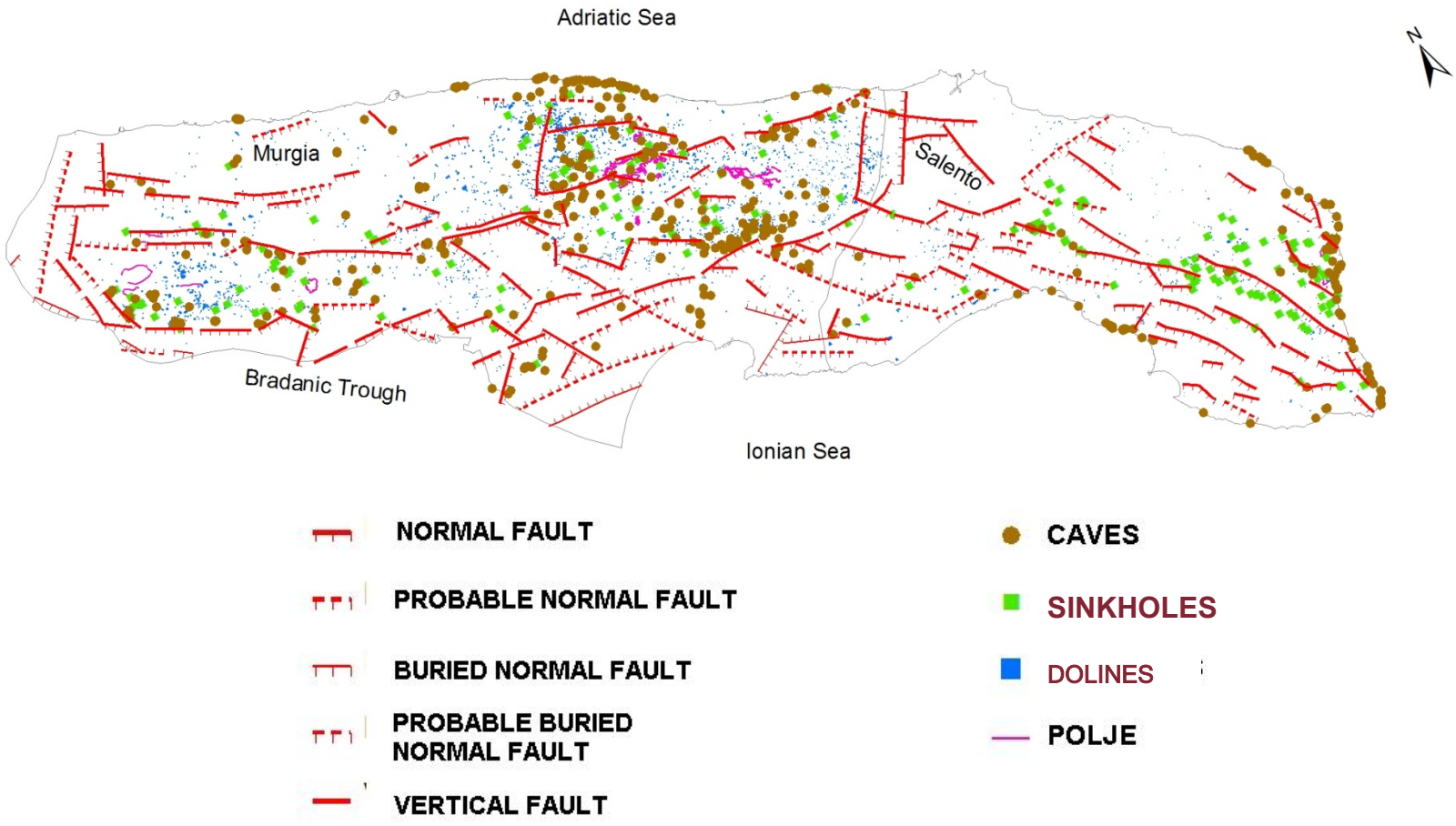
Murge and Salento karstic coastal aquifers
Schematic geological map



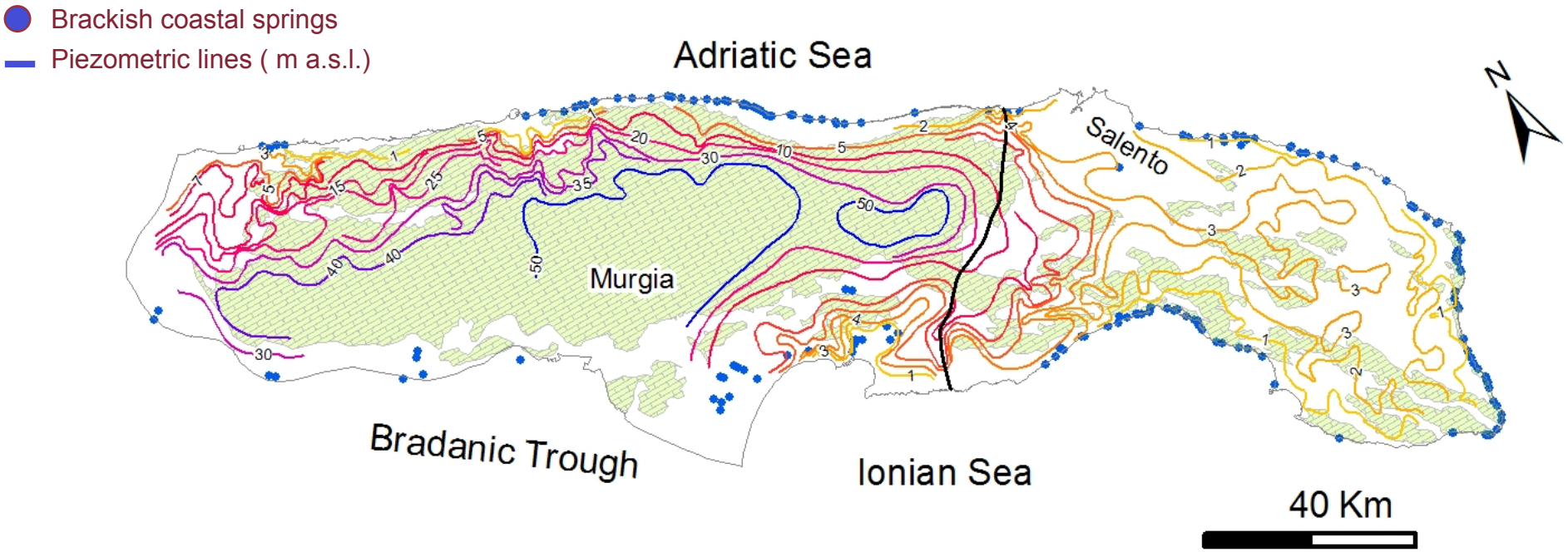
Calcarenites and marly calcarenites (Miocene);

Limestones and dolomitic limestones (Cretaceous)

Murgia and Salento karstic coastal aquifers
Structural features



Murgia and Salento carbonate karstic coastal aquifers: piezometric map (m a.msl)



Murgia

Mean recharge rate → 47 m^3/s

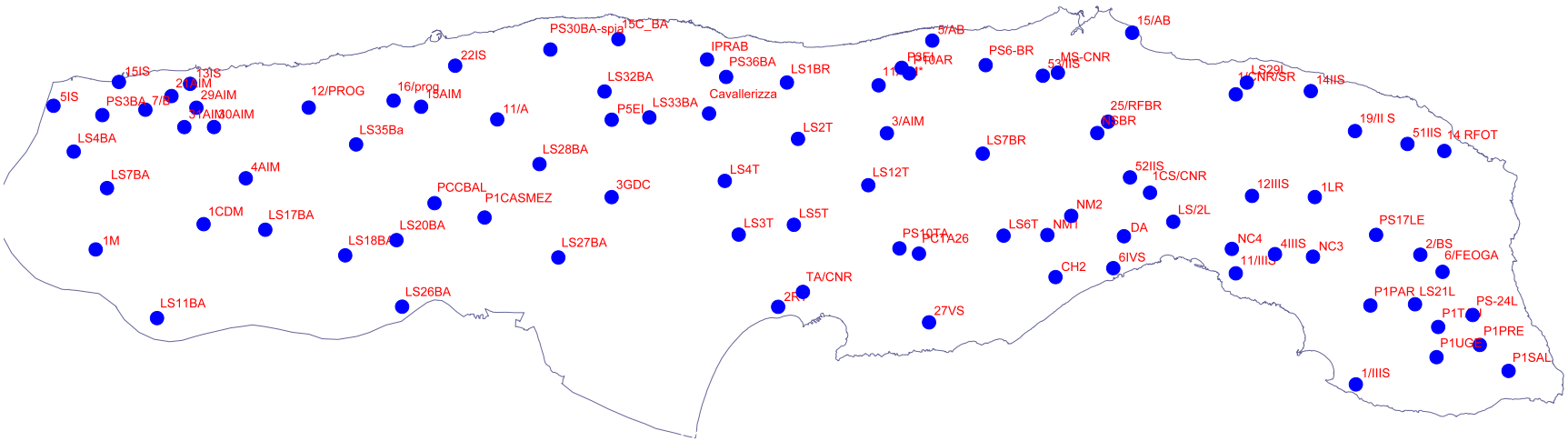
Hydraulic gradient → 0.2 $^0/_{00}$

Salento

Mean recharge rate → 28 m^3/s

Hydraulic gradient → 0.2 $^0/_{00}$

Monitoring net (1st Level)

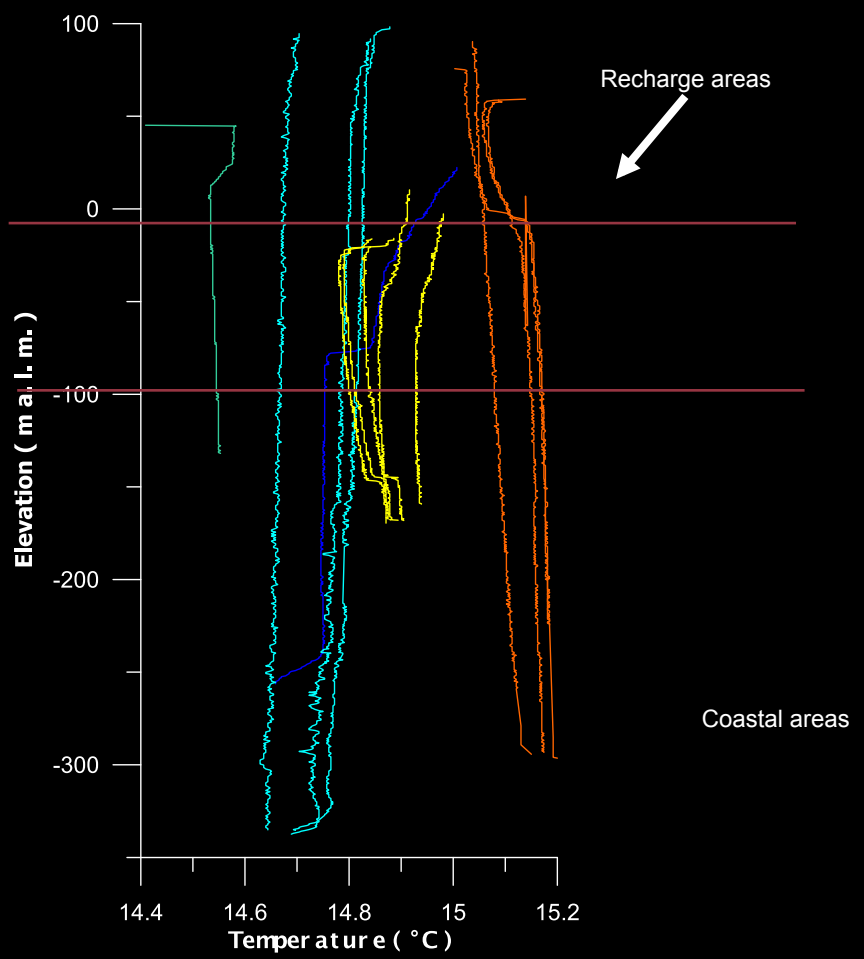


MONITORING WELLS

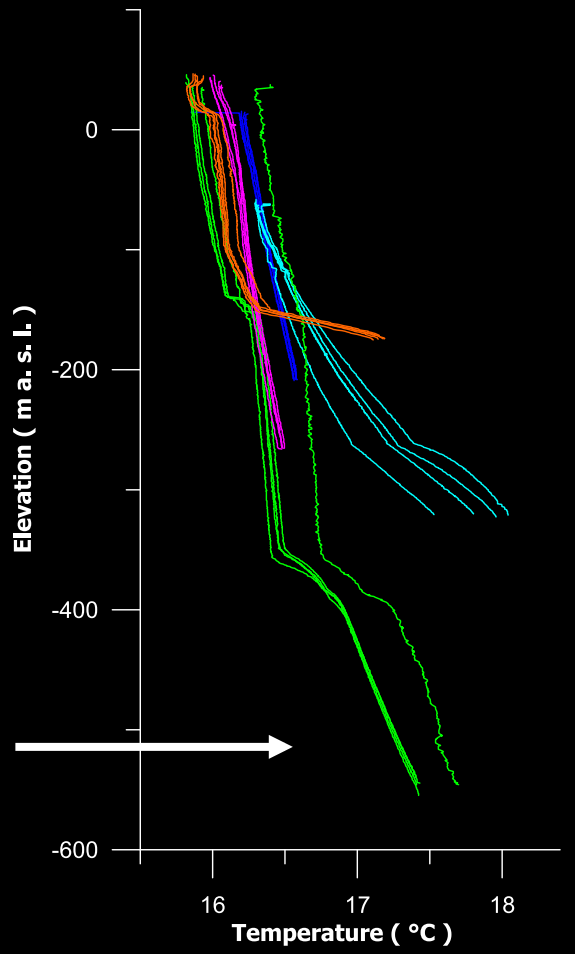
Monitoring periods: I) 1995-1996; 2) winter 2007 → end 2010

Dataset 1995-1996: no. 428 temperature (and EC, pH, Eh and O_2) profiles (107 wells x 4 profiles)

Selected time horizon for geostatistical study: 107 profiles of winter 1995



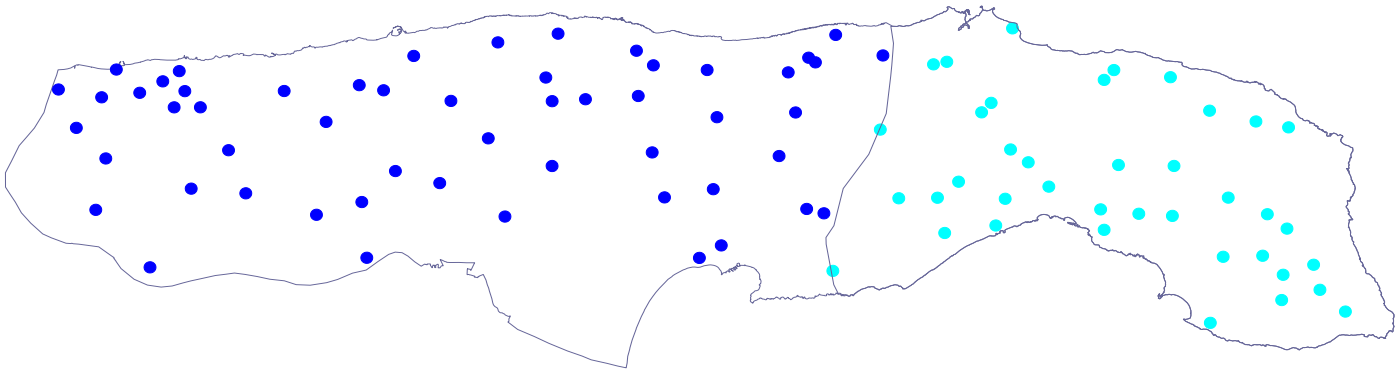
Coastal areas



CLUSTER ANALYSIS

The temperatures measured respectively at -5, -20, -30, -50, -70, -85, and -100 m AMSL, constitute no. 7 datasets.

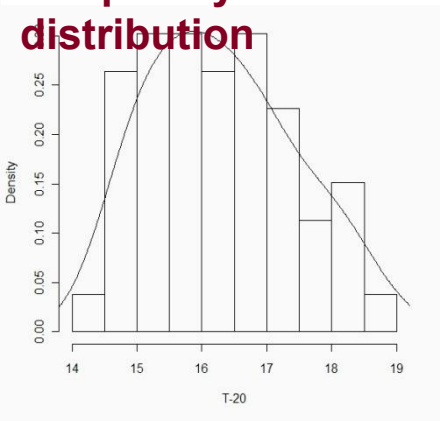
The basic statistical analysis of each sub-set showed frequency distributions of bimodal type of the variable Temperature, indicating the presence of at least two distinct groups.



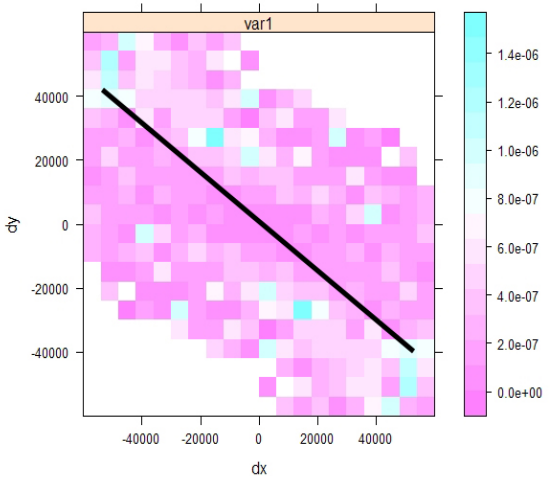
Cluster analysis, based on EC and T, allowed recognizing two main data populations, corresponding to the two contiguous aquifers.

VARIOGRAMS

Frequency distribution

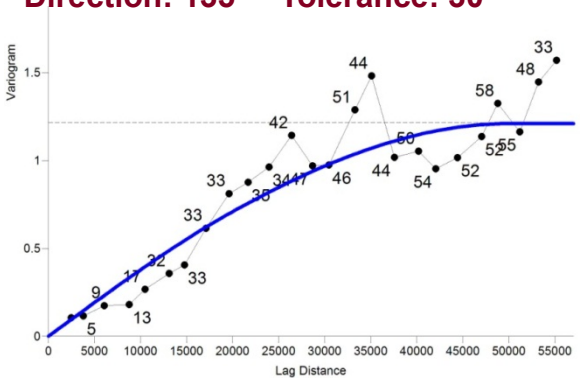


Variogram map



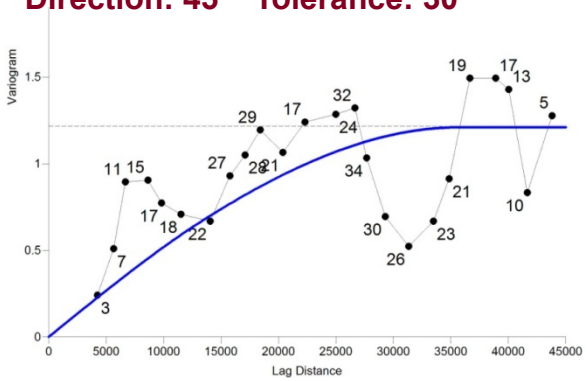
MURGE -20 m a.s.l

Direction: 135 Tolerance: 30

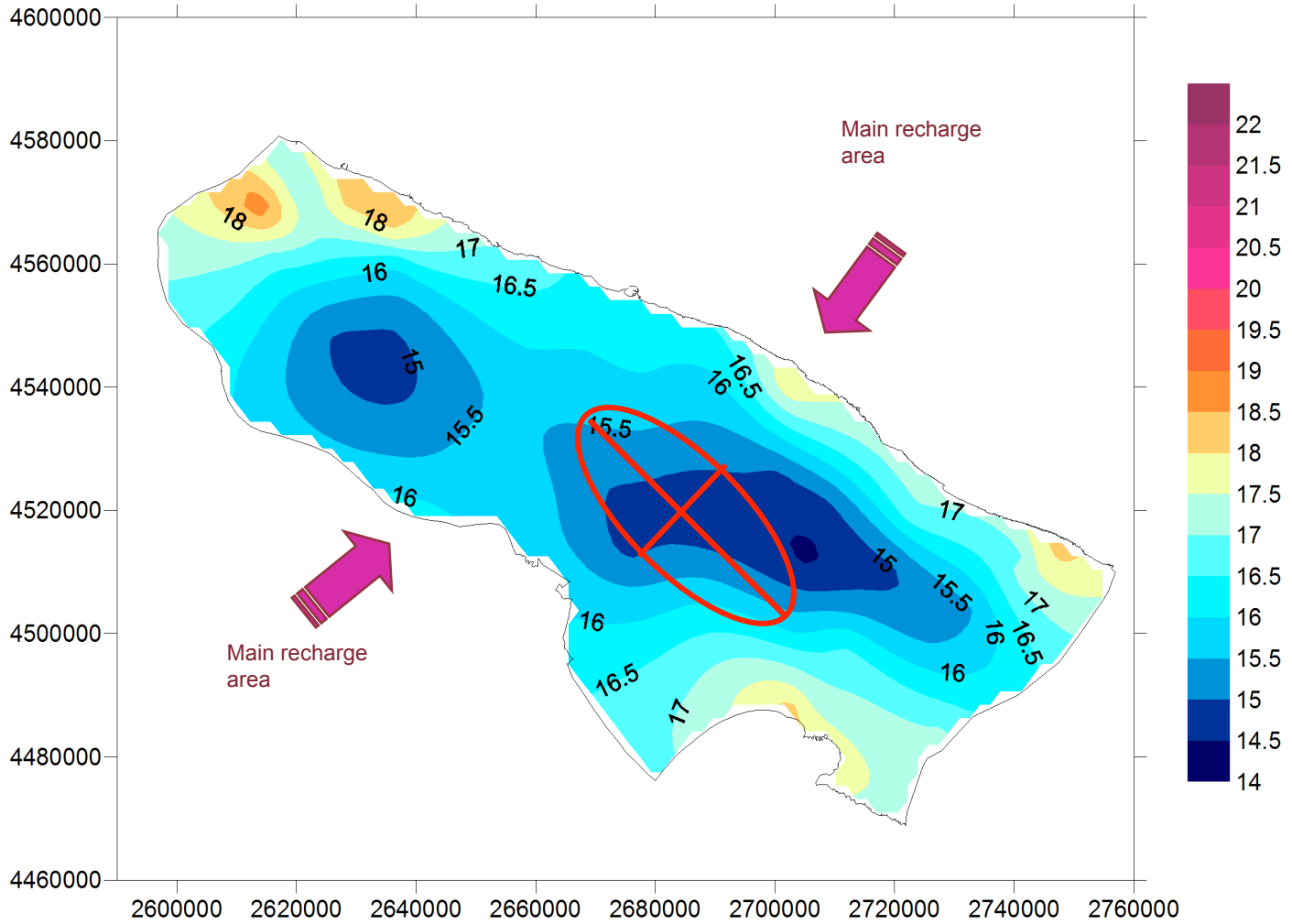


MURGE -20 m a.s.l

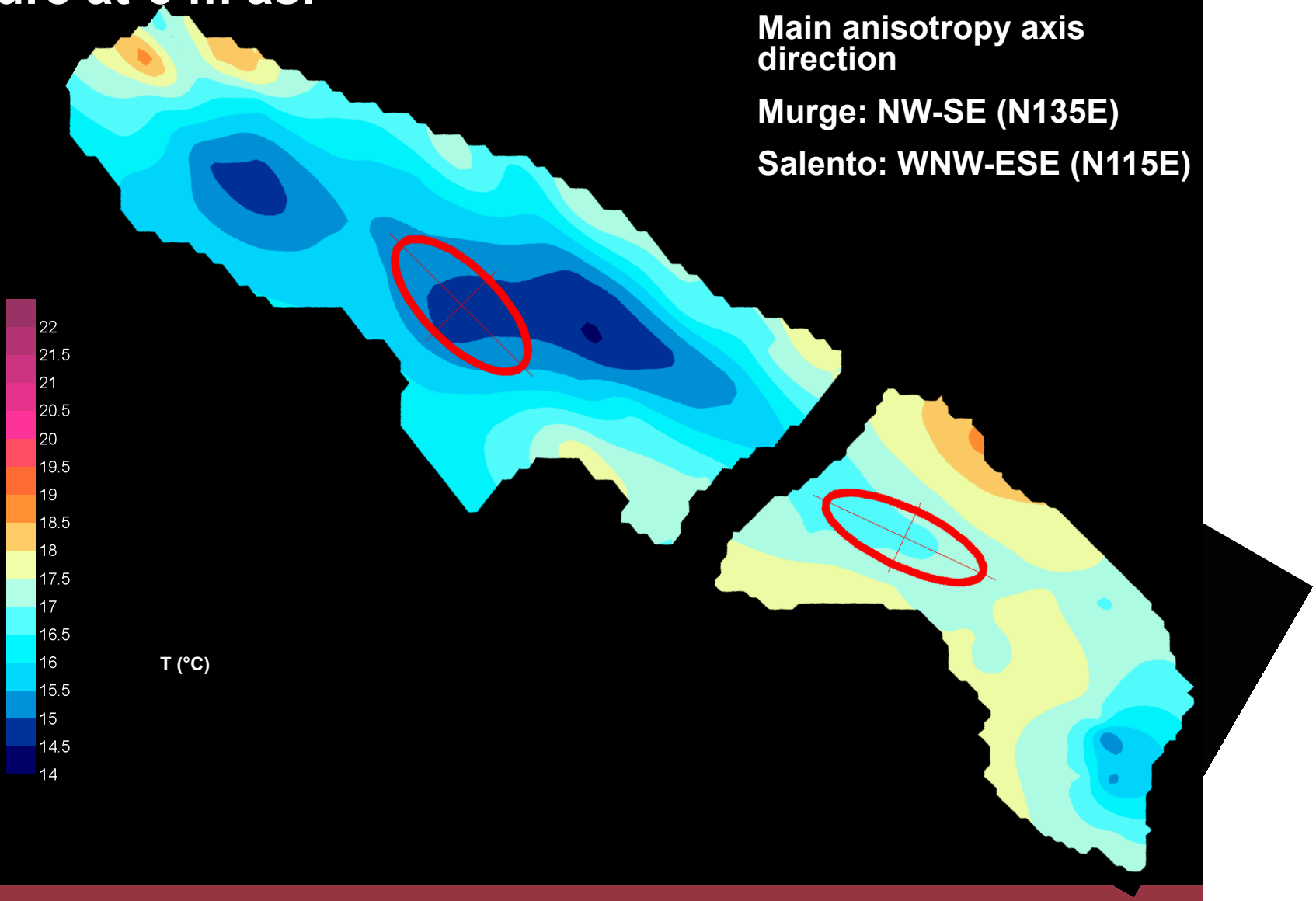
Direction: 45 Tolerance: 30



Horizontal temperature section at -5 m a msl



Temperature at-5 m asl

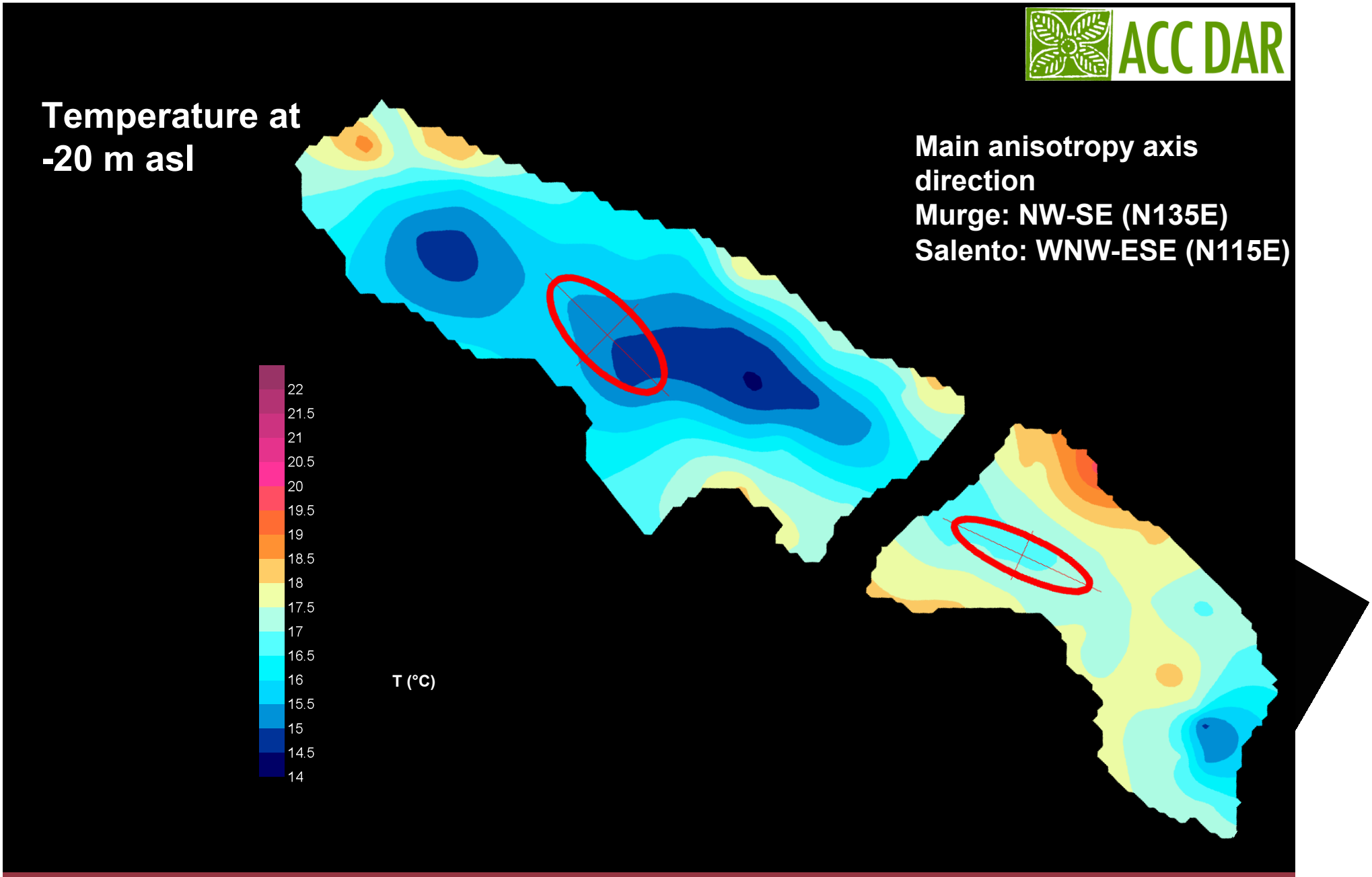


Main anisotropy axis direction

Murge: NW-SE (N135E)

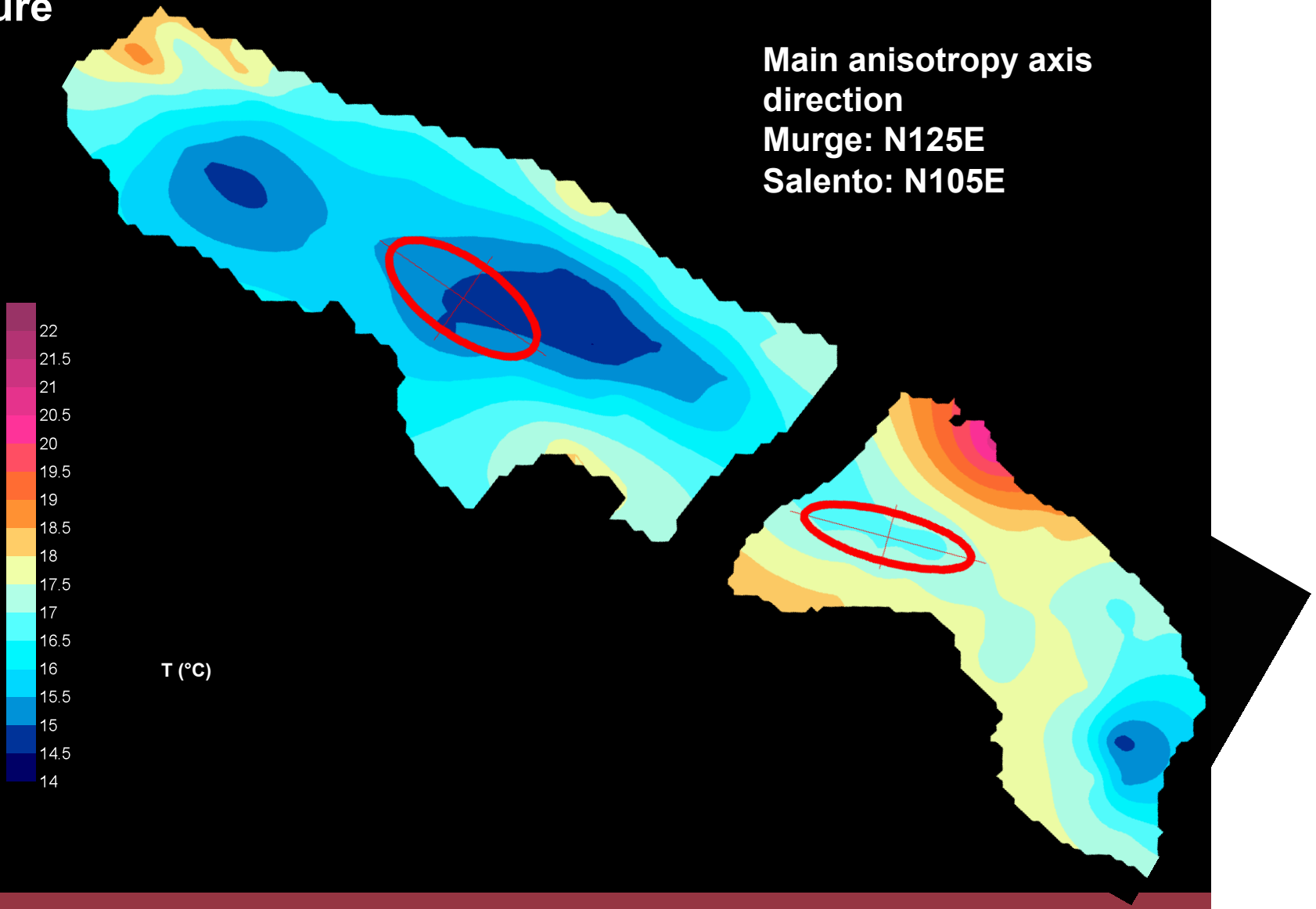
Salento: WNW-ESE (N115E)

Temperature at -20 m asl



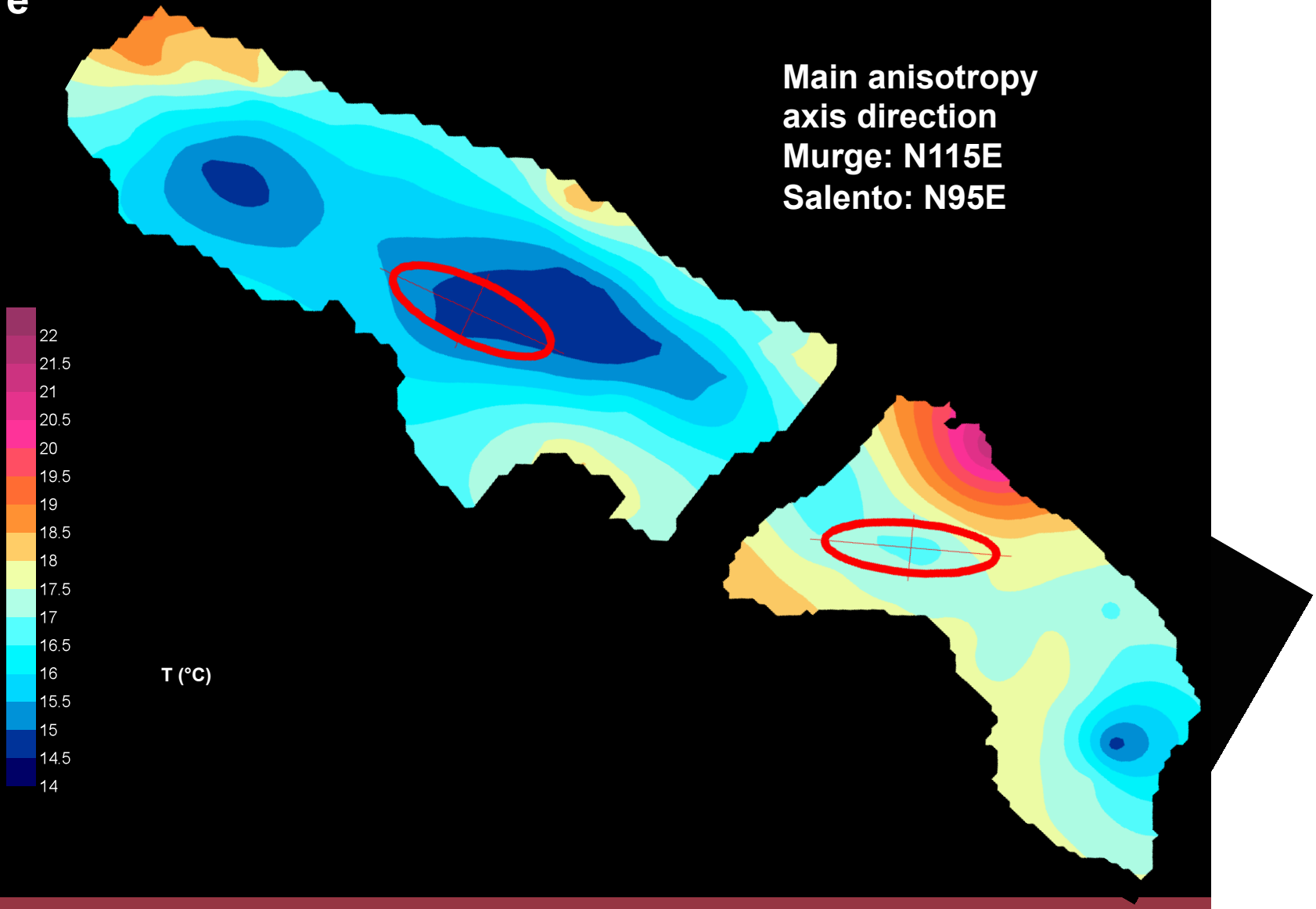
Main anisotropy axis direction
Murge: NW-SE (N135E)
Salento: WNW-ESE (N115E)

Temperature -35 m asl

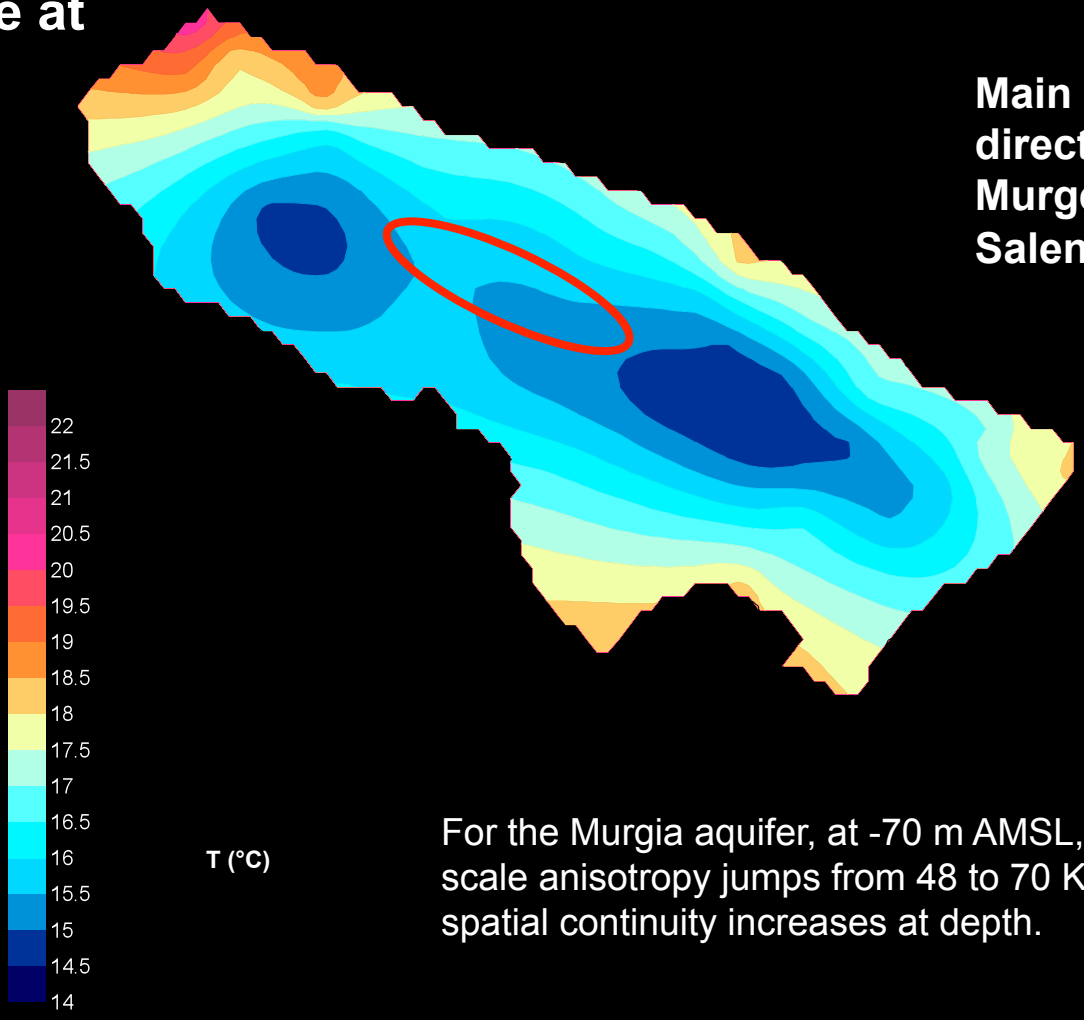


Main anisotropy axis direction
Murge: N125E
Salento: N105E

Temperature -50 m asl



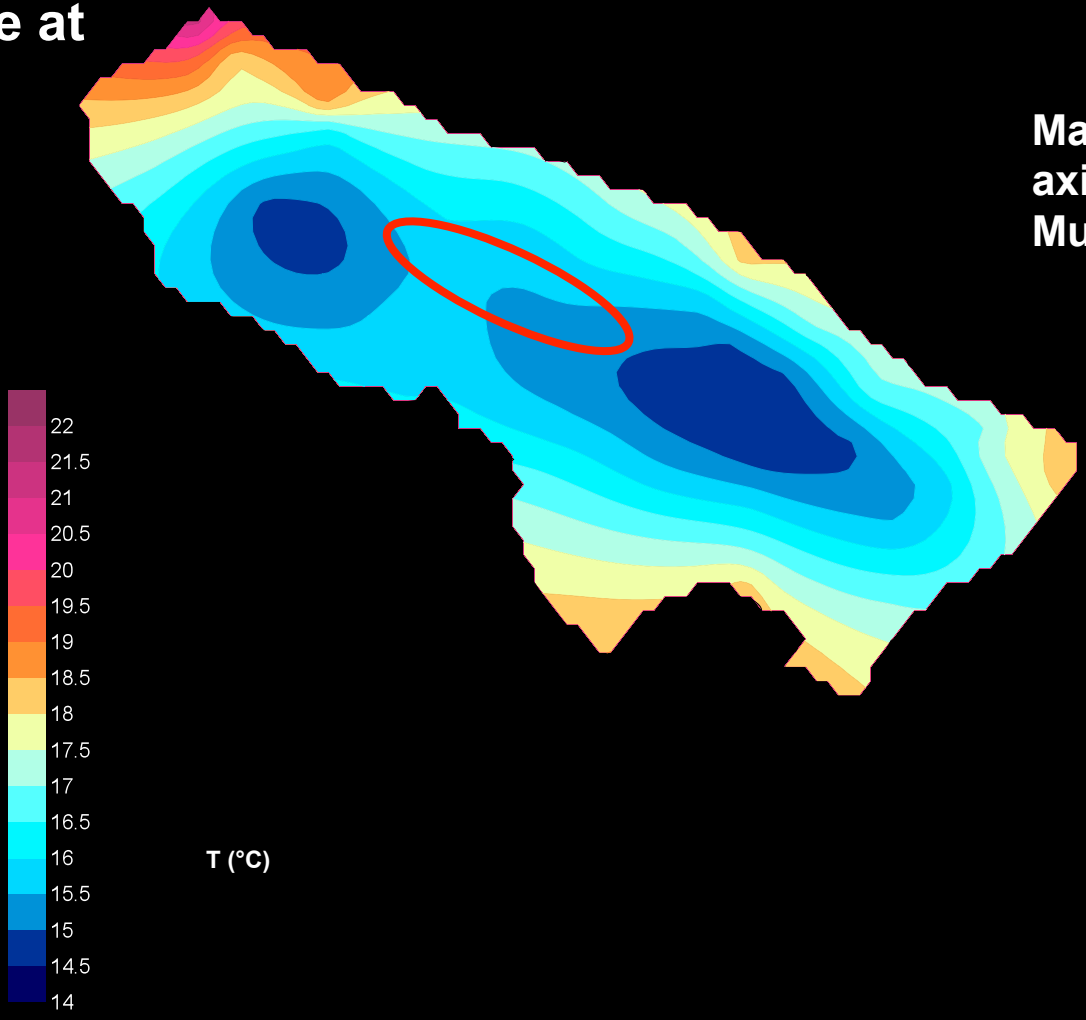
Temperature at -70 m asl



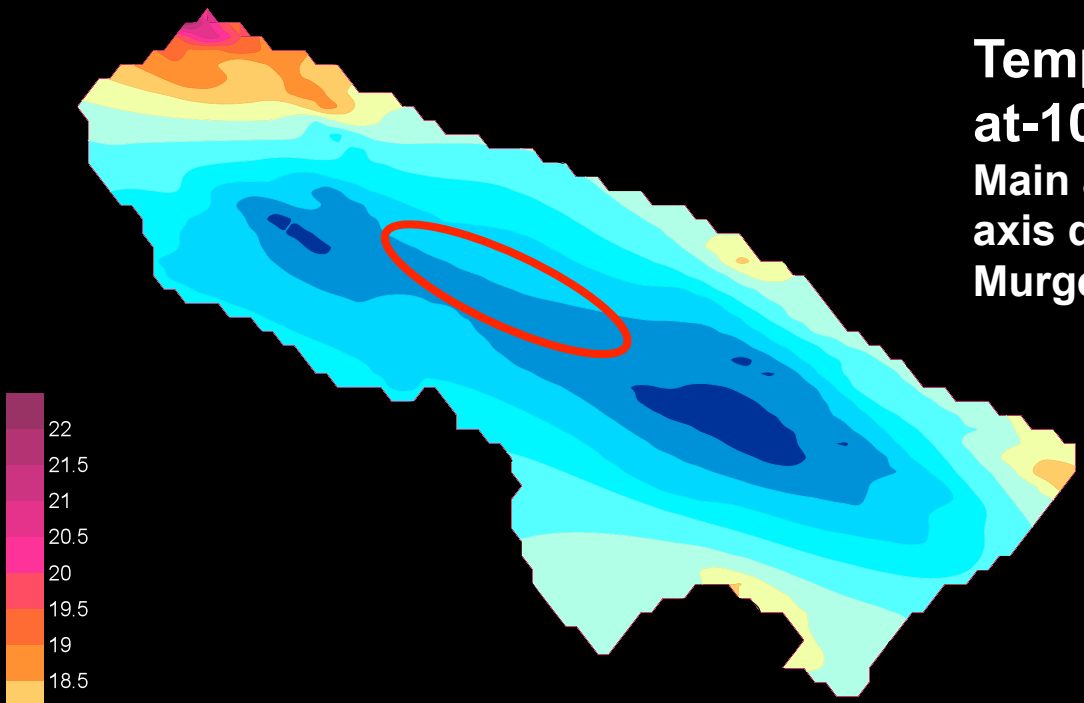
Main anisotropy axis direction
Murge: N115E
Salento: isotropic?

For the Murgia aquifer, at -70 m AMSL, the range of the regional scale anisotropy jumps from 48 to 70 Km, indicating that the spatial continuity increases at depth.

Temperature at -85 m asl

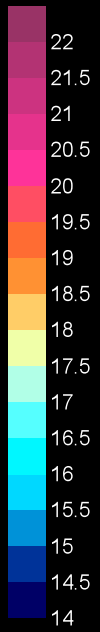


Main anisotropy axis direction Murge: N115E



Temperature at-100 m a.s.l

Main anisotropy axis direction Murge: N115E

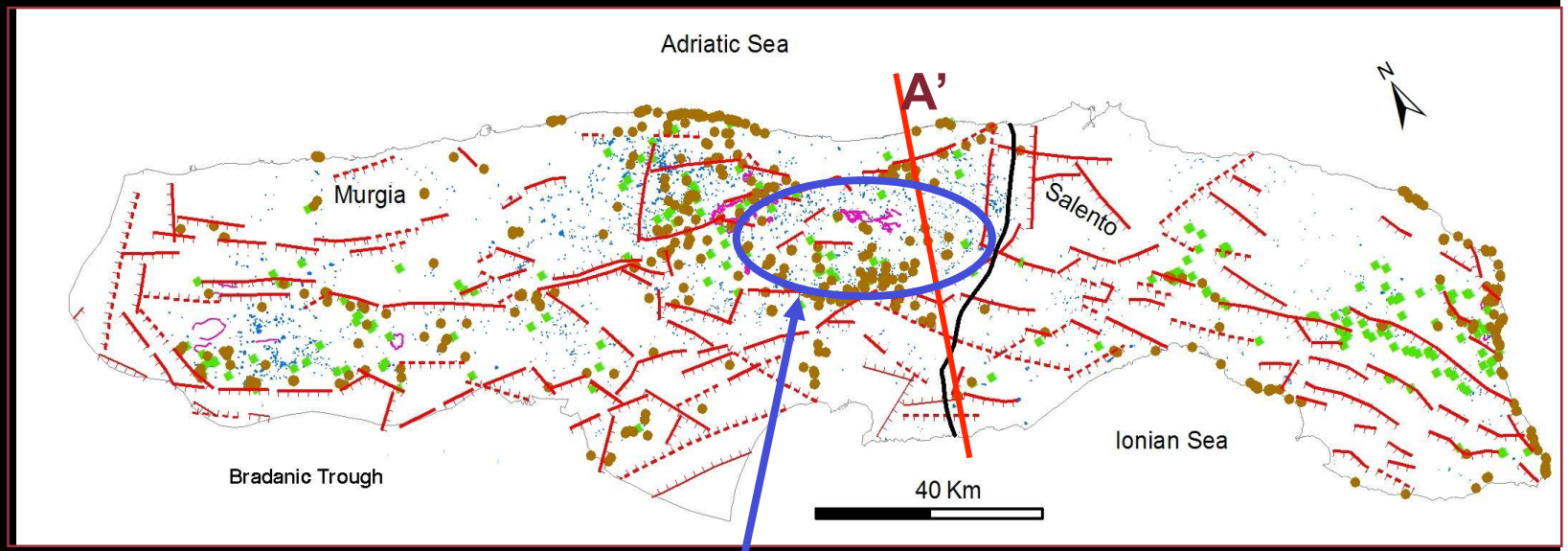


T (°C)

At the increase of the depth, the range of the **local scale anisotropy** decreases

Considering the contemporaneous increase of the regional anisotropy, this indicates an increase of anisotropy

Vertical temperature sections



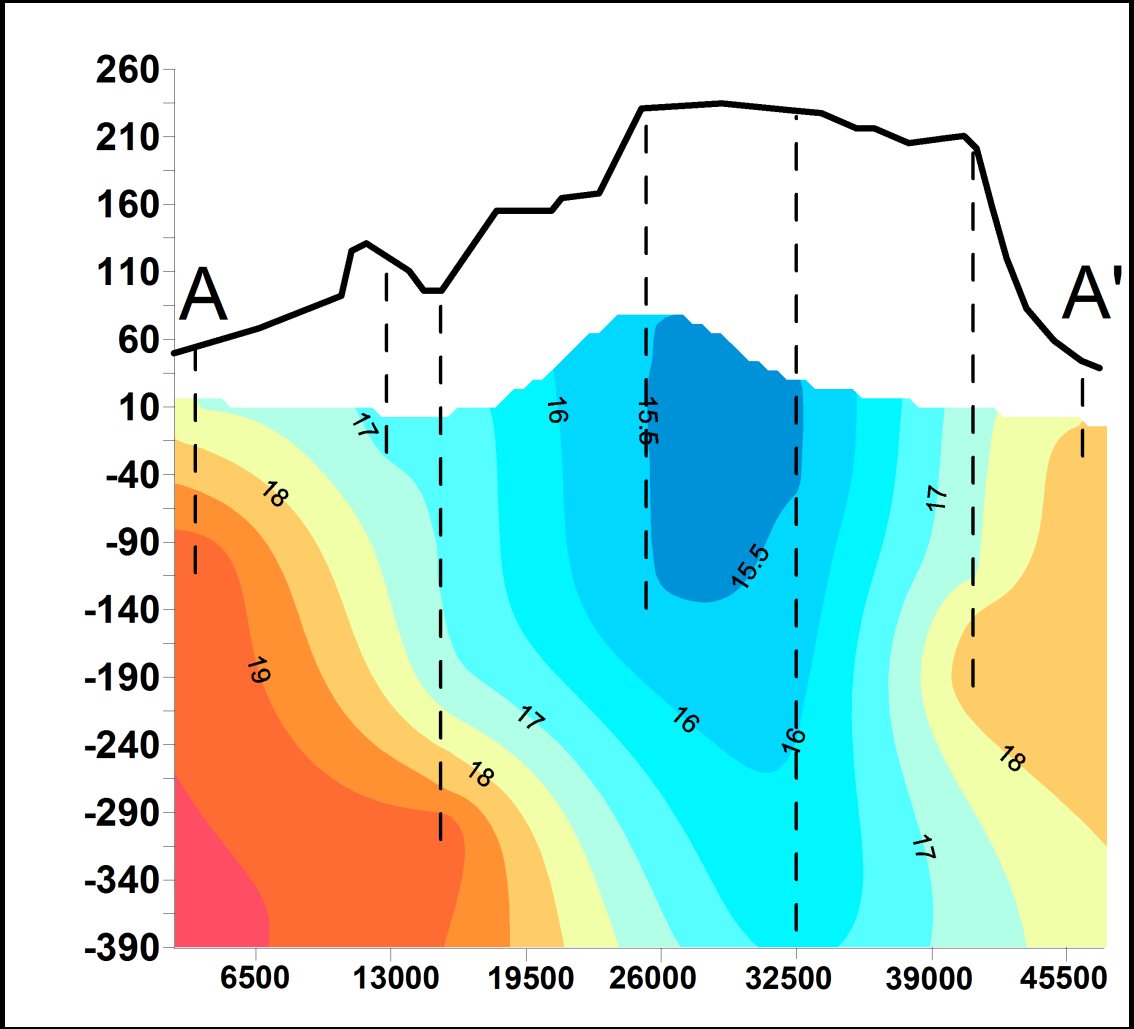
Main recharge area

. Thermal vertical section obtained by OK of data from profiles and horizontal OK grids.

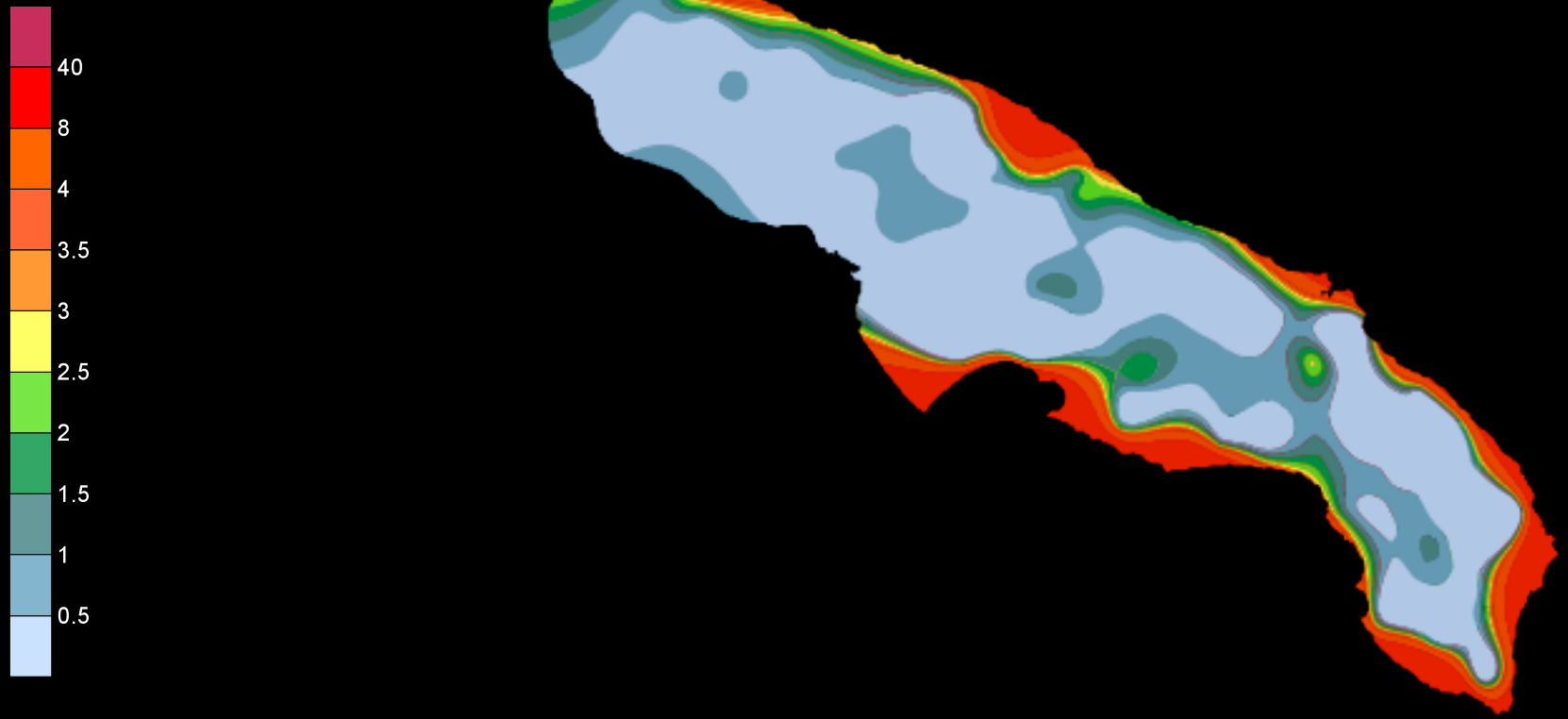
The main vertical anisotropy axis has an inclination of 85°.

Groundwater flows horizontally through nearly vertical structures, which allow hydraulic connection between Murge and Salento.

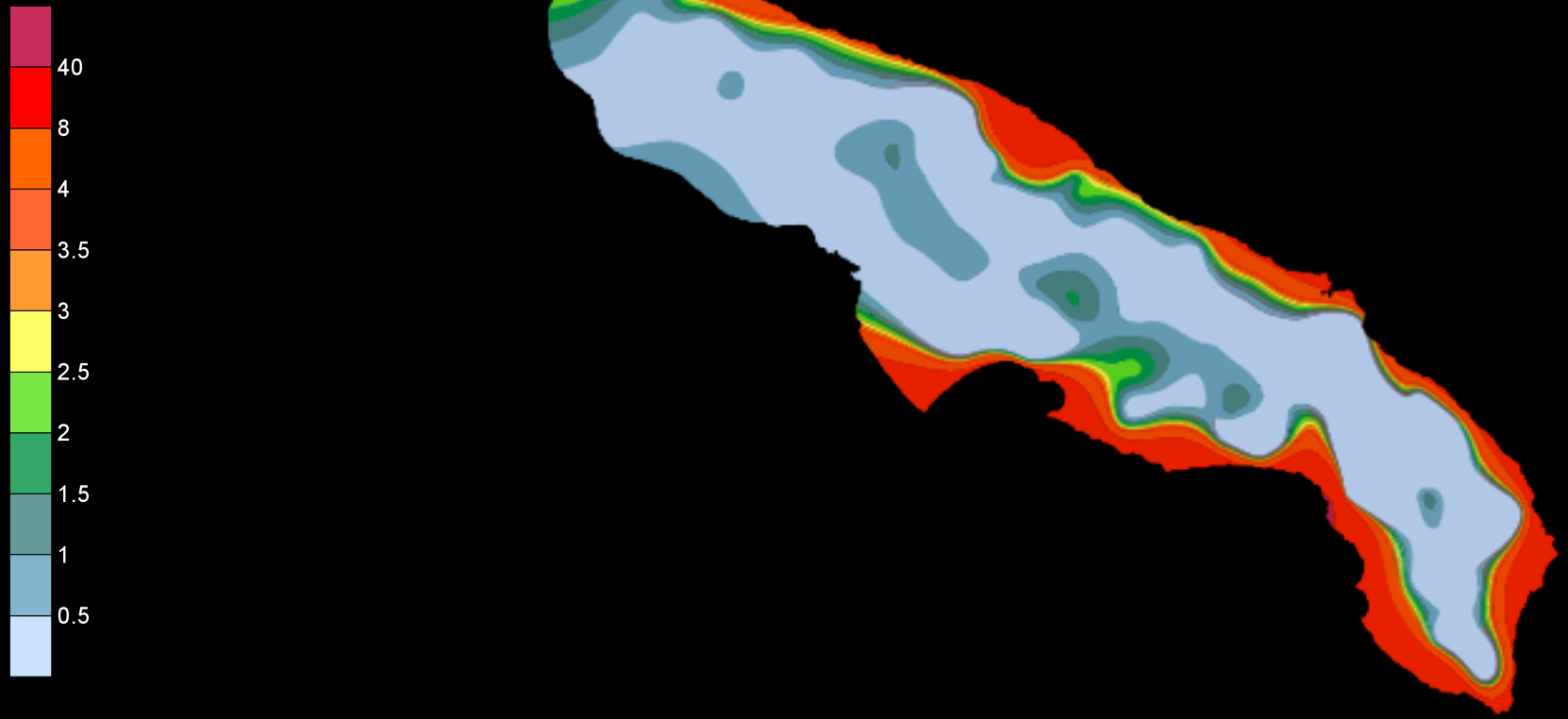
Water balance studies indicate that Murgia aquifer recharges laterally the aquifer Salento with about 10 m^3/s.



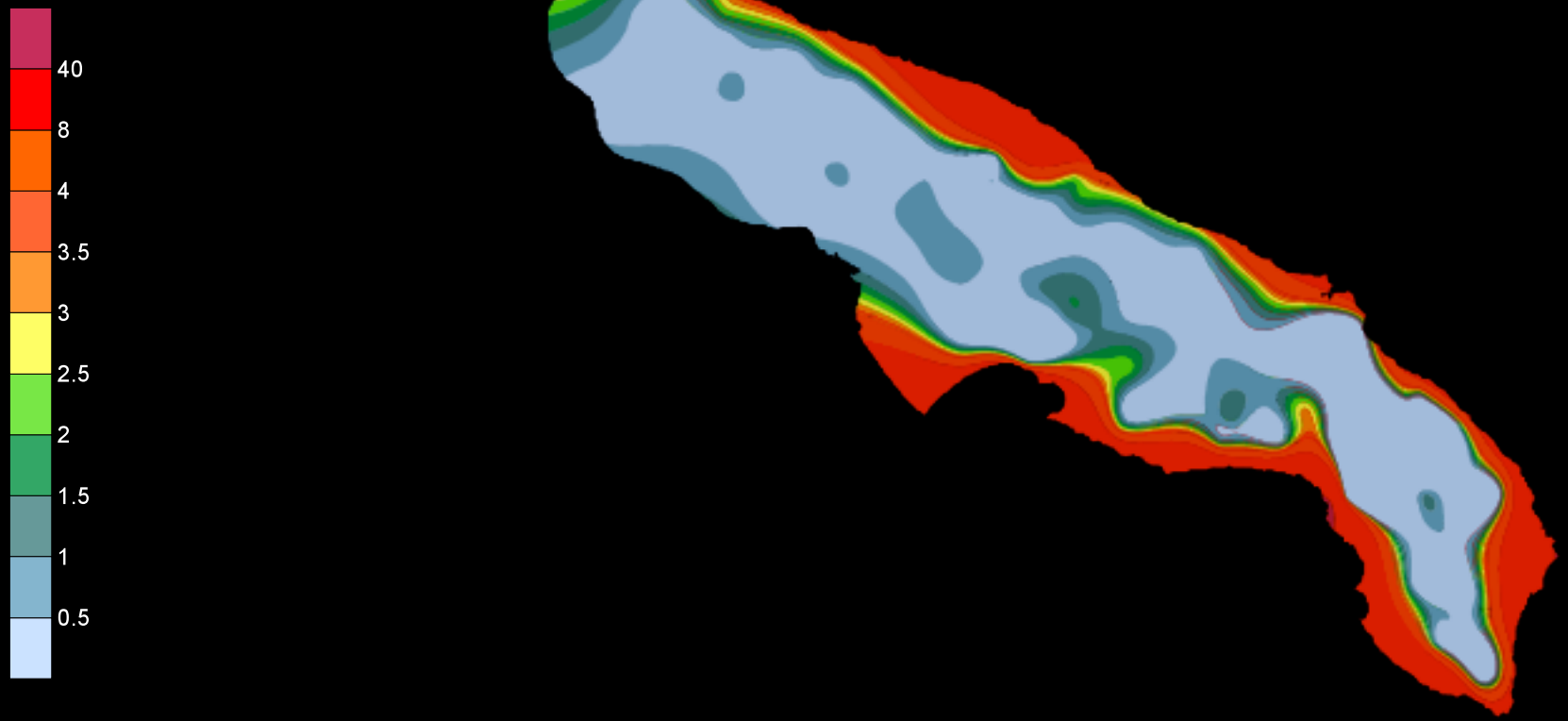
TDS (g/l) -5 m s.l.m.



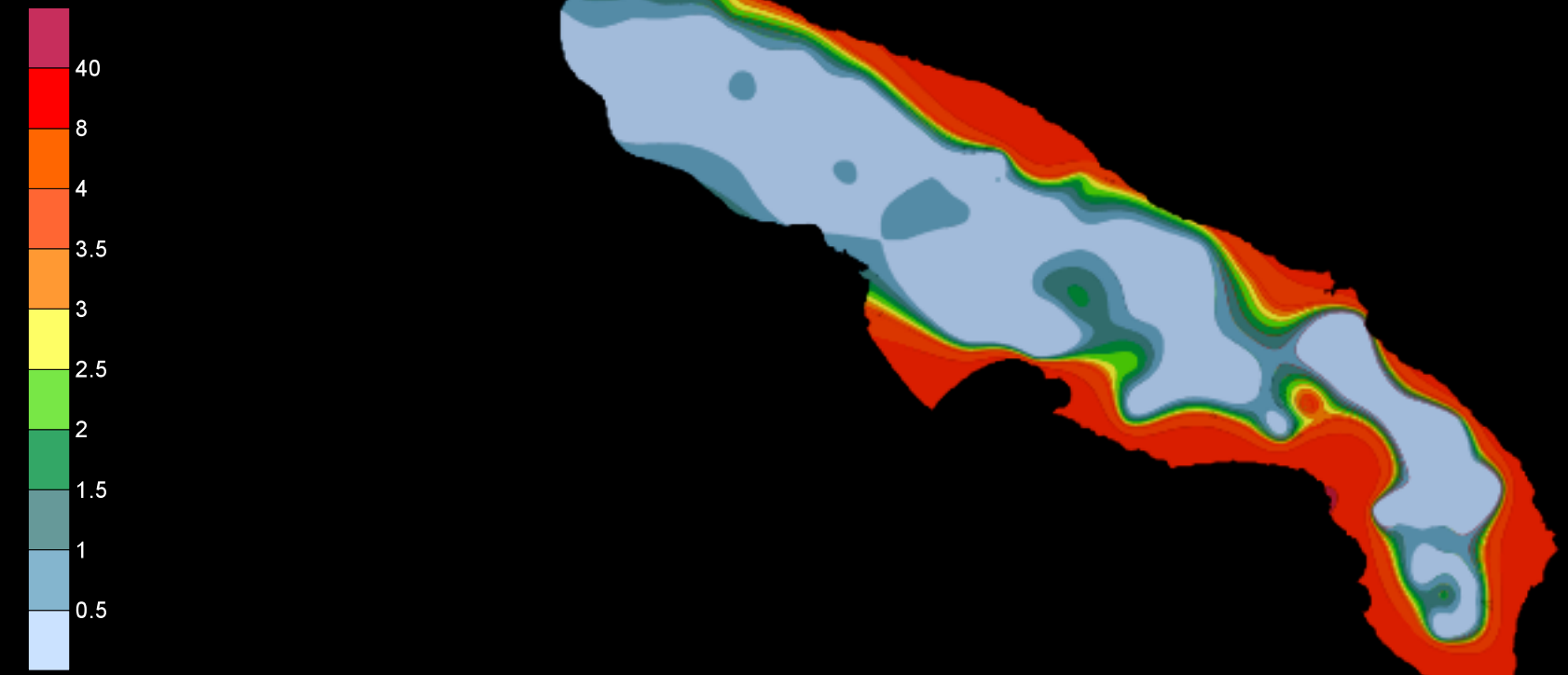
TDS (g/l) -20 m s.l.m.



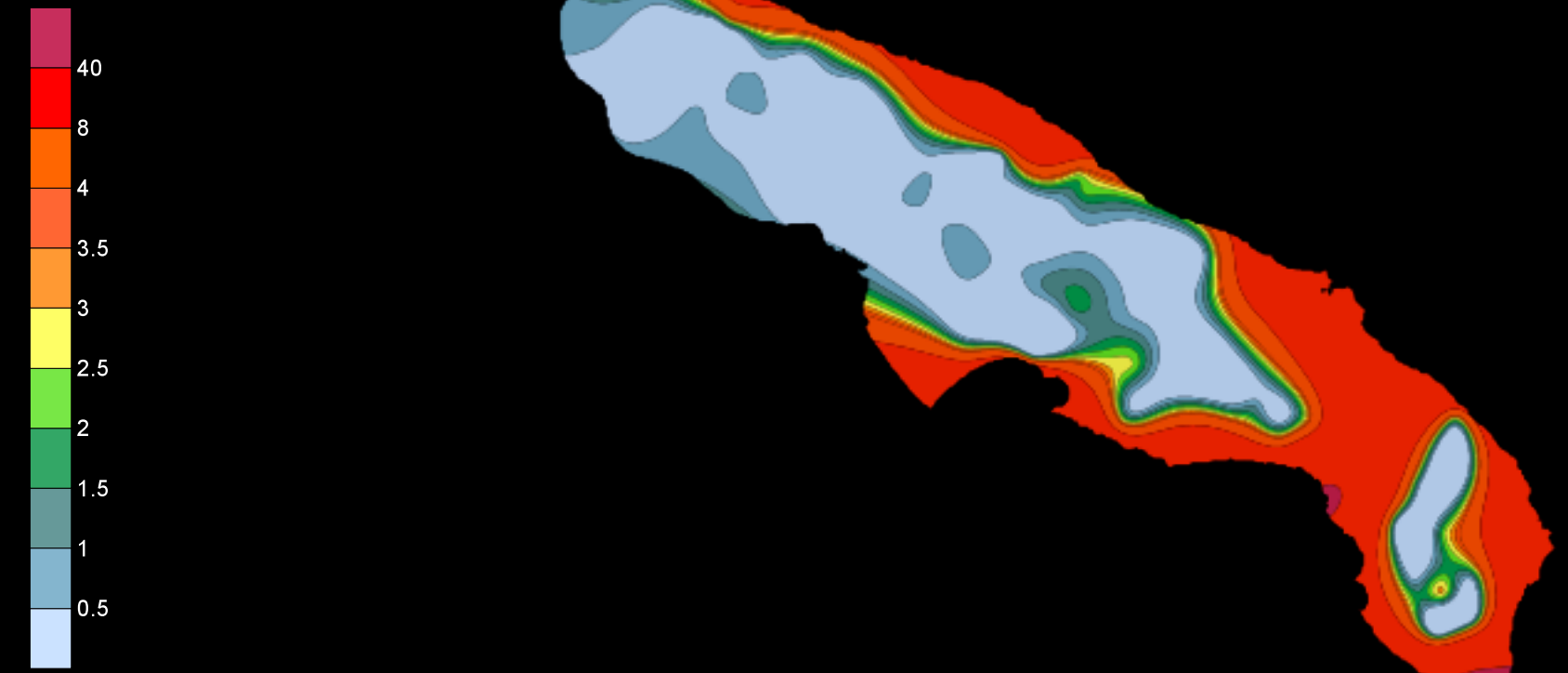
TDS (g/l) -35 m s.l.m.



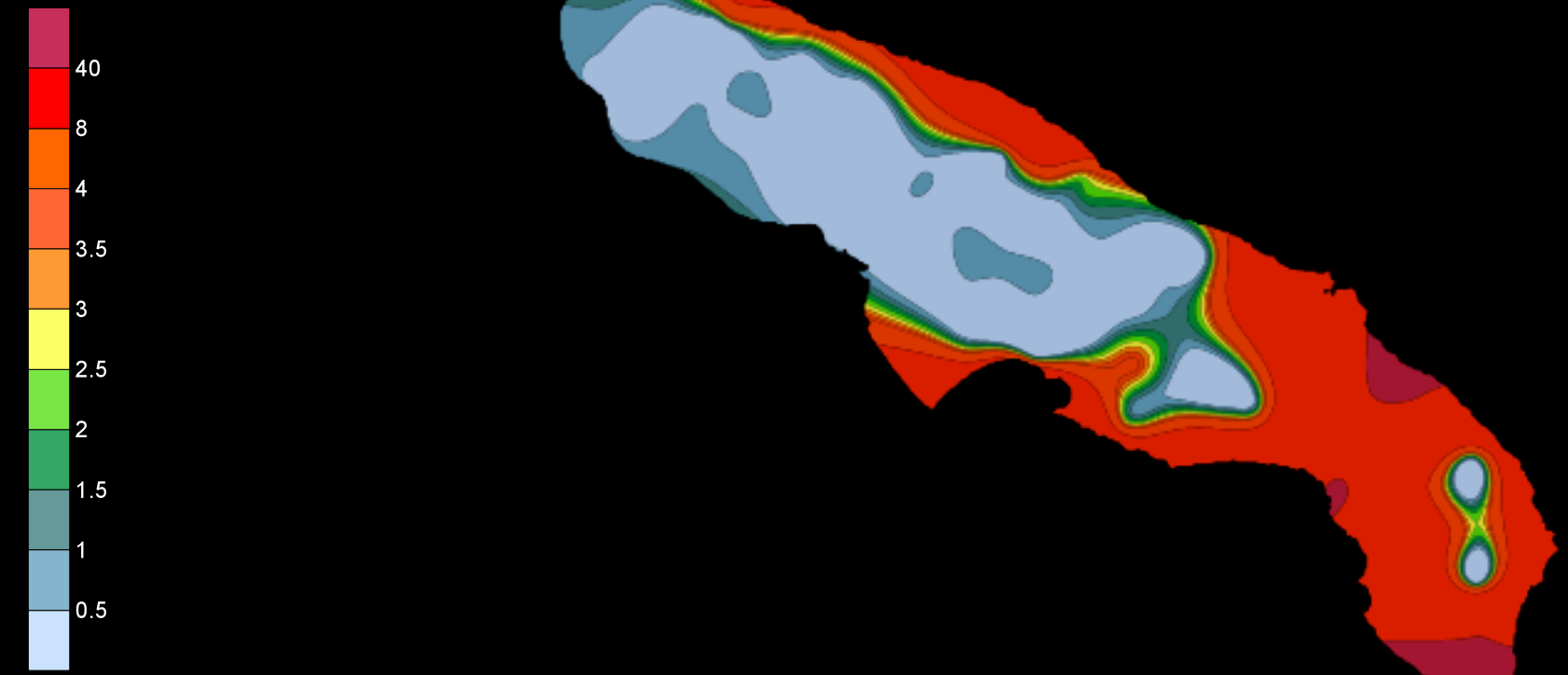
TDS (g/l) -50 m s.l.m



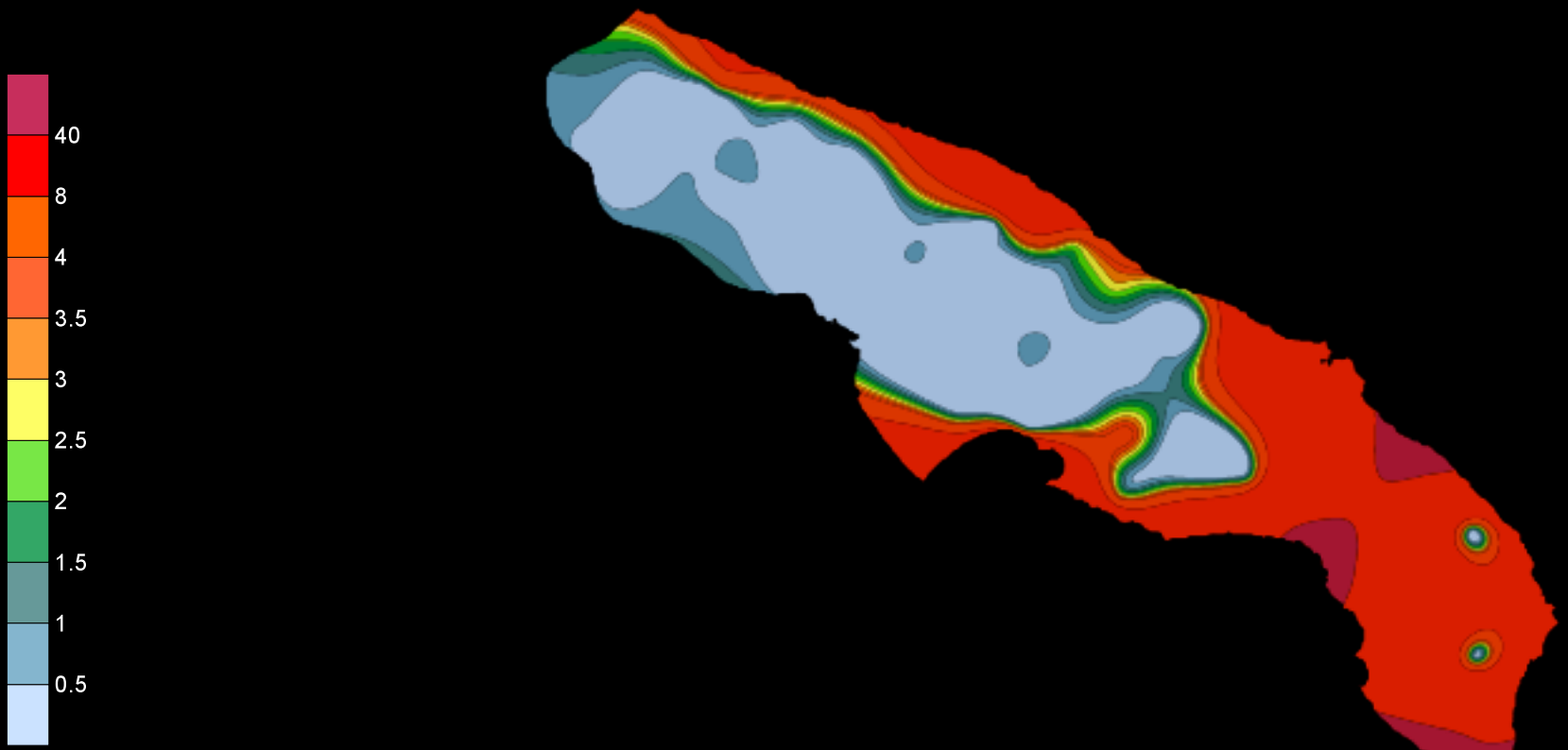
TDS (g/l) -70 m s.l.m



TDS (g/l) -85 m s.l.m



TDS (g/l) -100 m s.l.m.

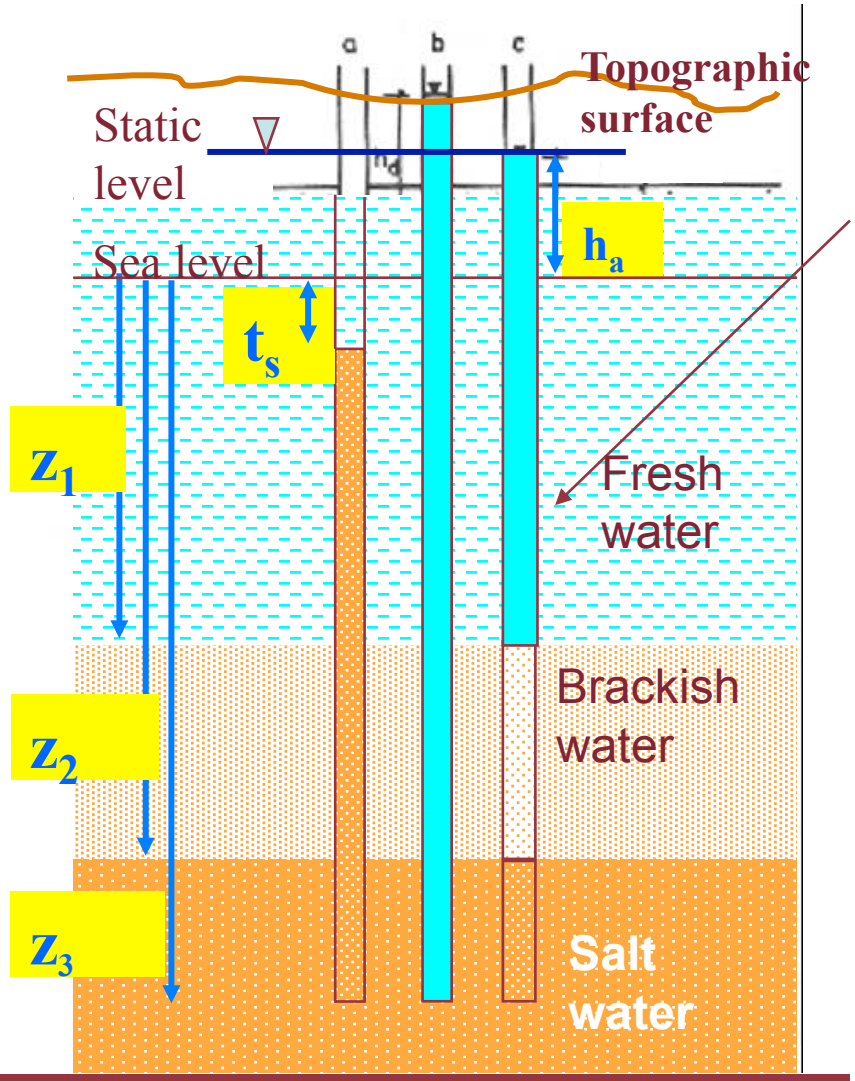


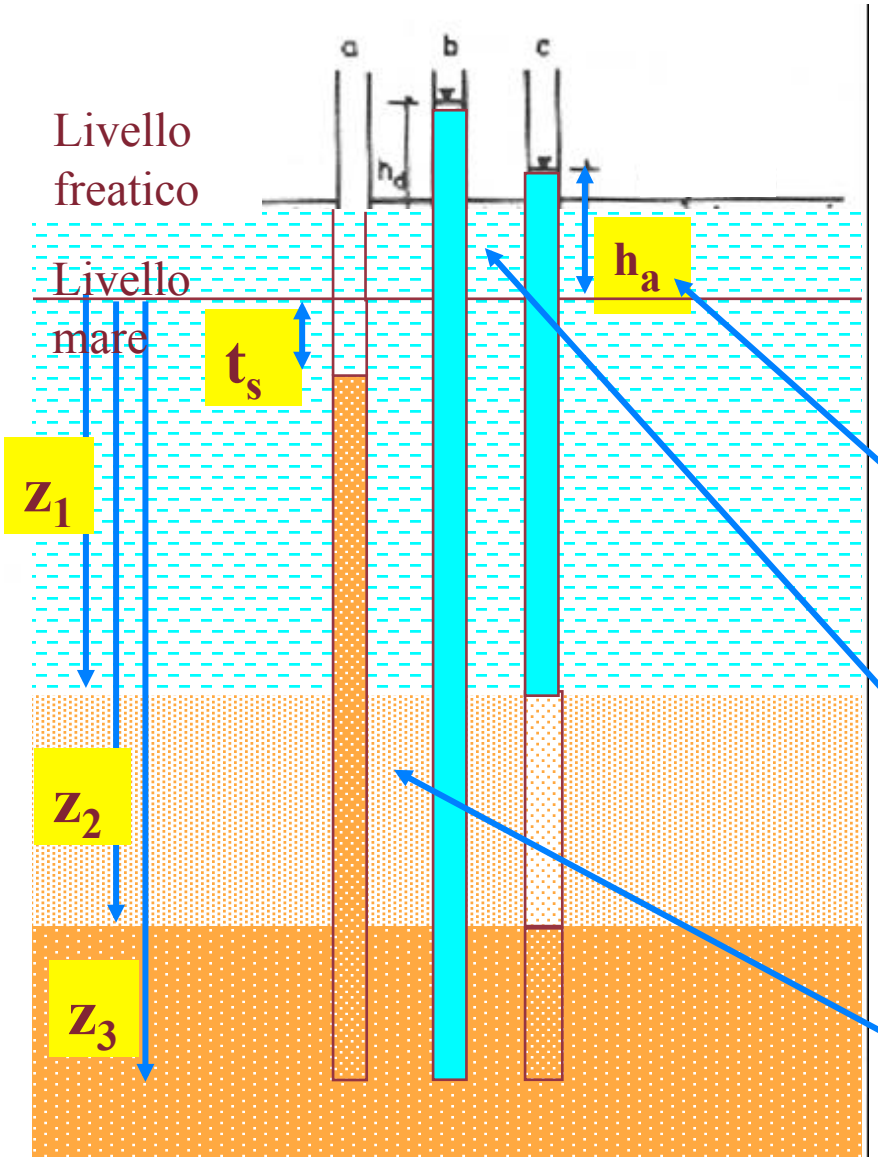
Observation wells (Lago Rosso e Surbo) in Salento Peninsula

Environmental head

In a well completely screened in a phreatic groundwater, the distribution of water in depth mirrors the distribution of the groundwater in the aquifer.

The hydraulic head that can be measured in such conditions coincides with the *Environmental Head* or local Head h_a defined by Lusczynski





Lusczynski - Equilibrium in presence of water with variable density

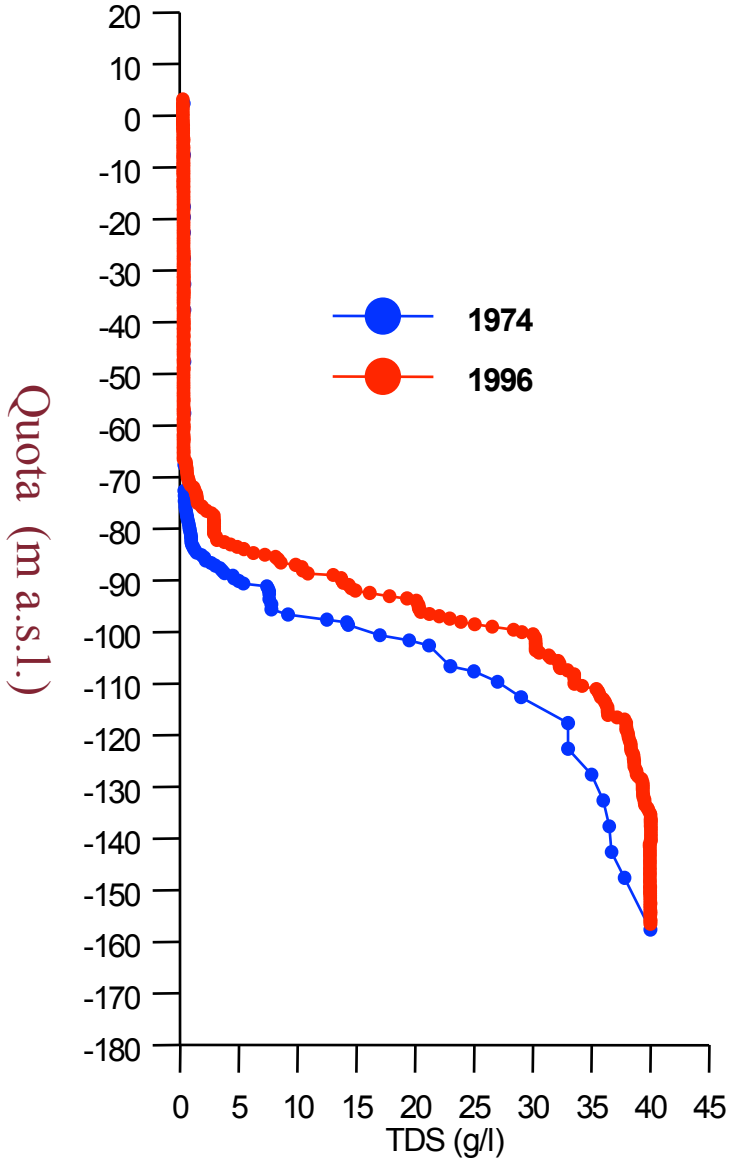
Environmental head

Hydraulic Head (h_d) expressed in fresh water **equivalent to t_s**

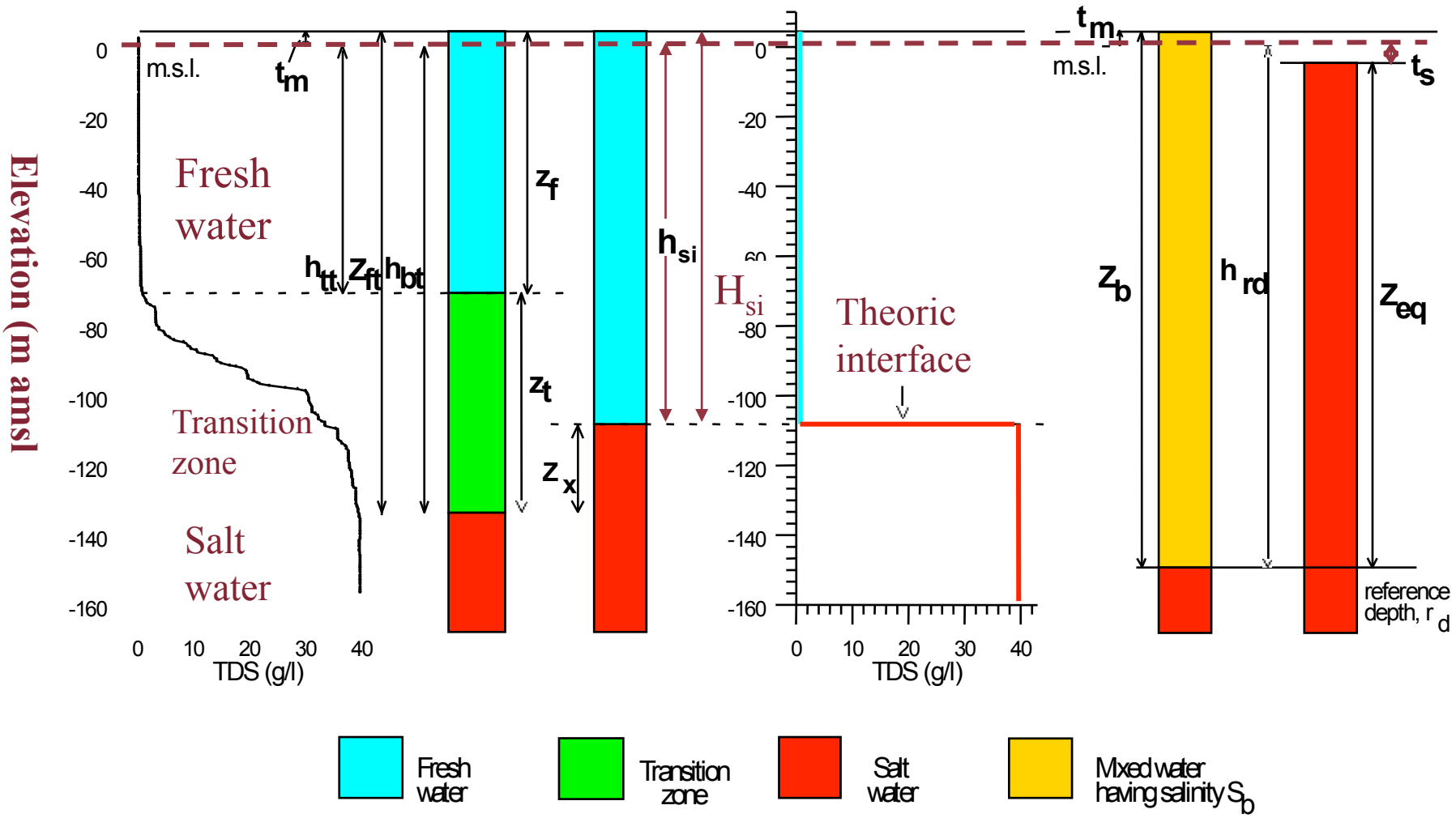
Piezometer open in salt water

$$(t_s + z_3)\delta_s = (h_a + z_1)\,\delta_d + \int_{z_1}^{z_2} \delta(l)dl + (z_3 - z_2)\delta_s$$

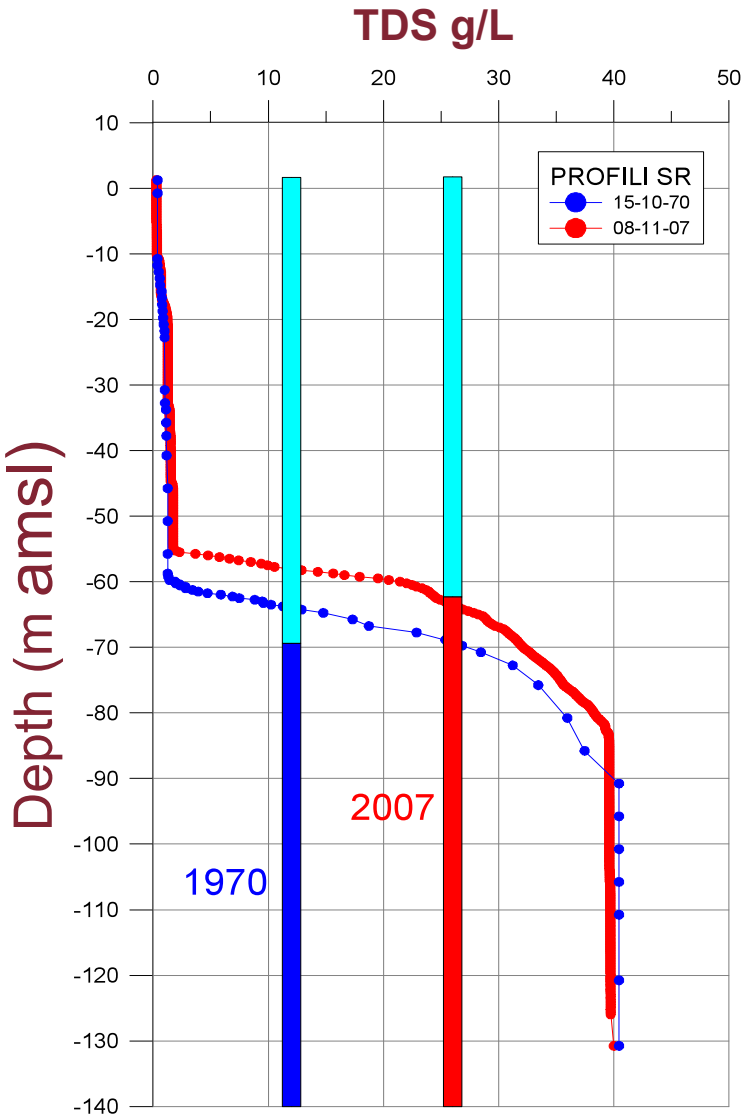
Observation well LR
TDS profiles
1974 and 1996

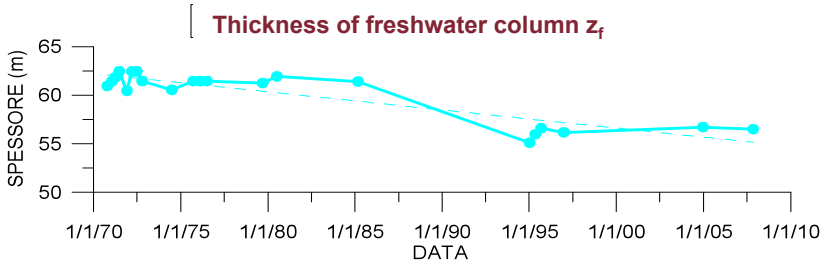


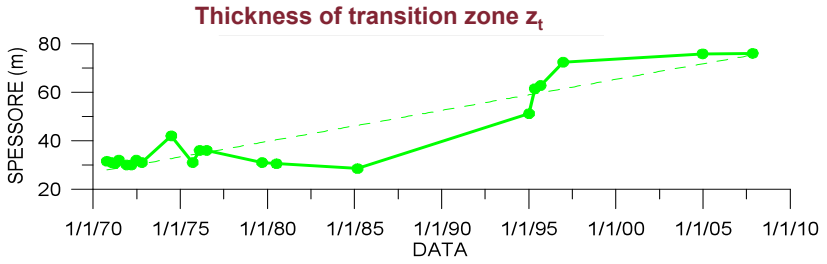
Scheme of parameters, which can be obtained by an EC profile

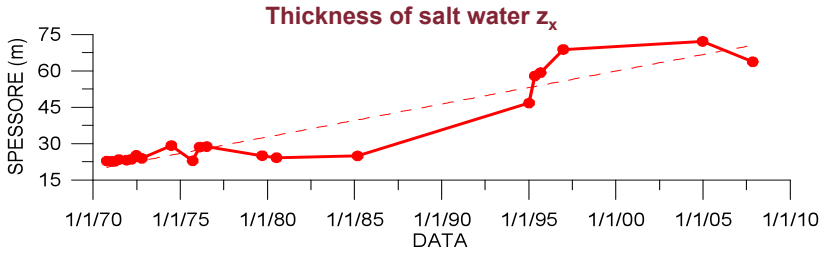


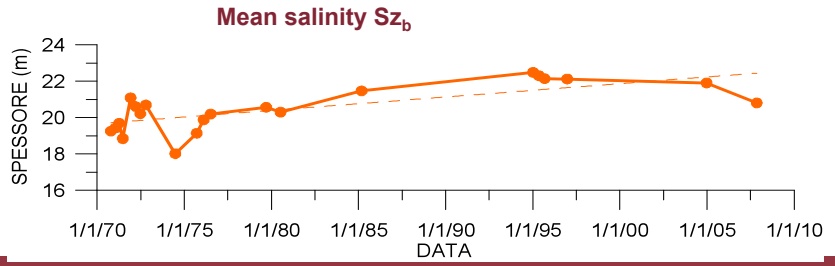
OW SR


TDS g/L
0
10
20
30
40
50
Depth (m amsl)
PROFILI SR
15-10-70
08-11-07
1970
2007

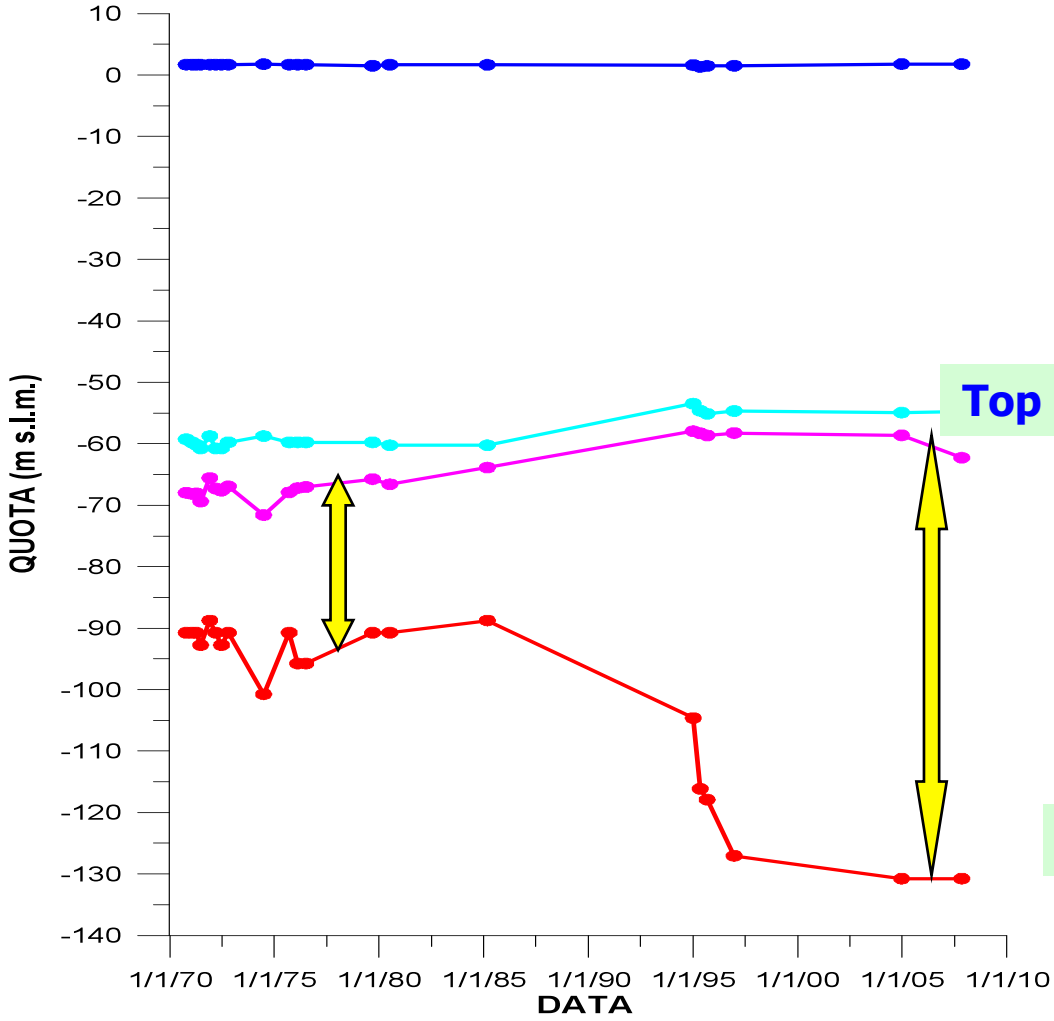

Thickness of freshwater column z_f
SPESSORE (m)
DATA
1/1/70
1/1/75
1/1/80
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10


Thickness of transition zone z_t
SPESSORE (m)
DATA
1/1/70
1/1/75
1/1/80
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10


Thickness of salt water z_x
SPESSORE (m)
DATA
1/1/70
1/1/75
1/1/80
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10


Mean salinity Sz_b
SPESSORE (m)
DATA
1/1/70
1/1/75
1/1/80
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10

Observation Well SR



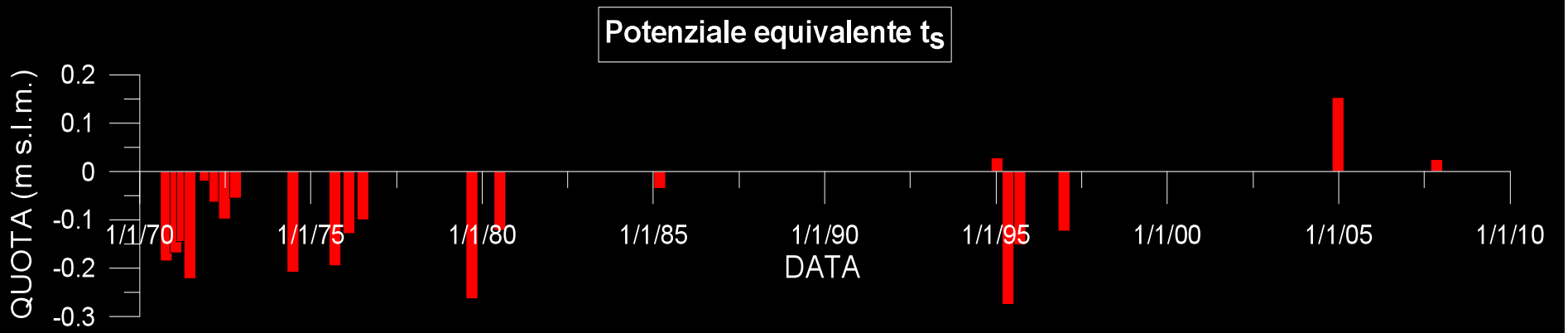
Hydraulic head h_a

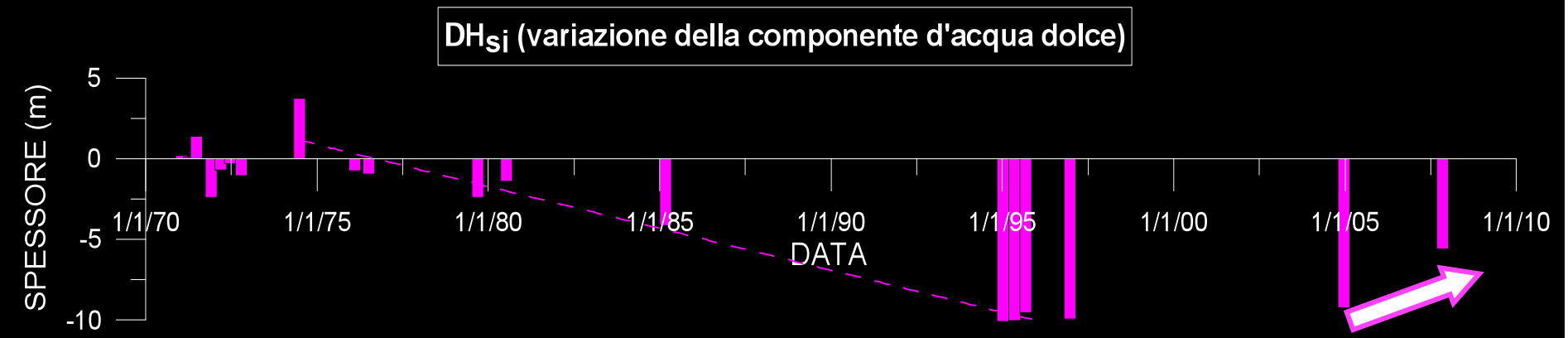
Top of transition zone

Theoric interface

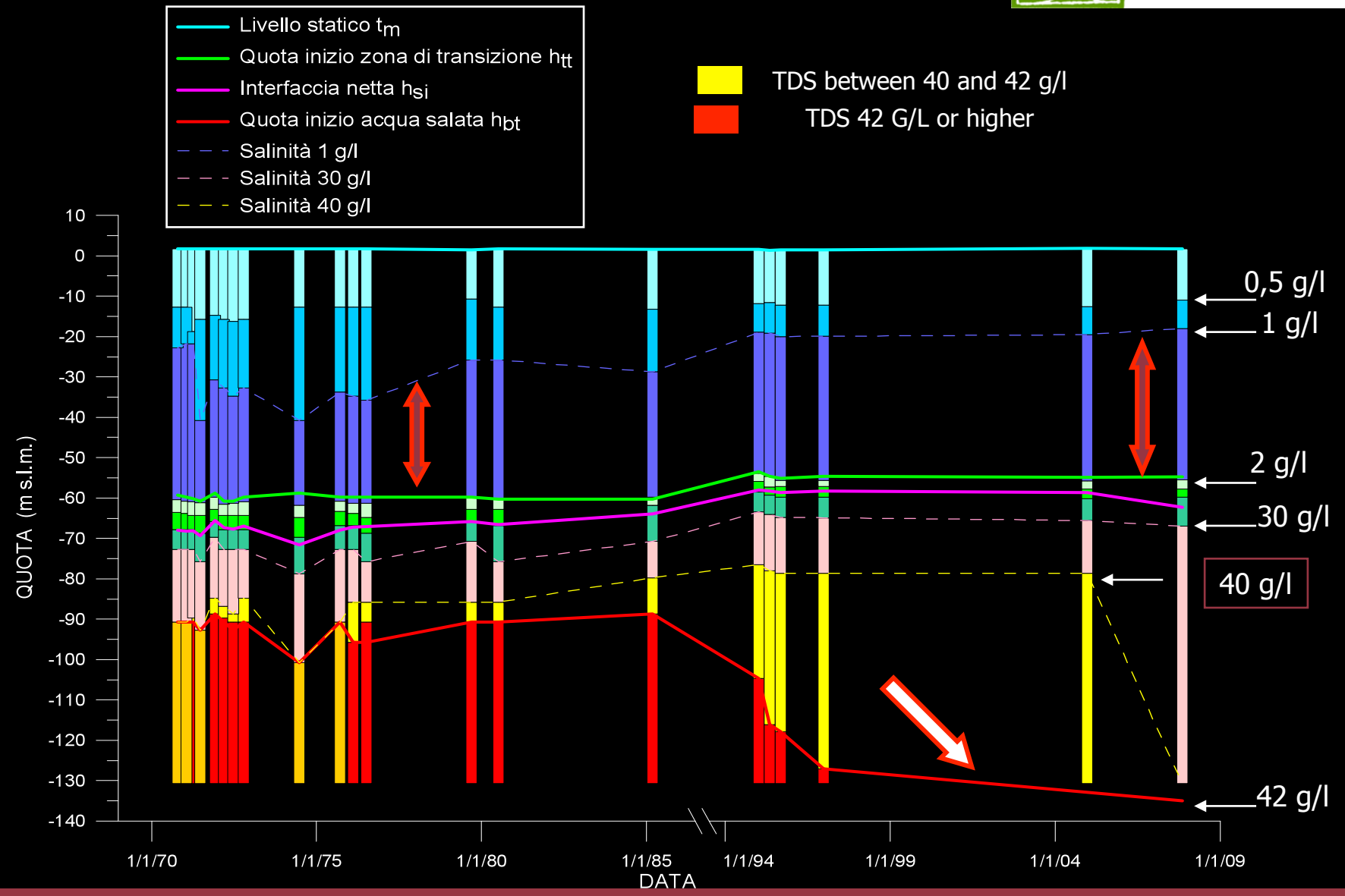
Top of salt water

OW SR– Evolution of t_s (salt water head) and variation of fresh water component





OW SR – Evolution of TDS in 40 years

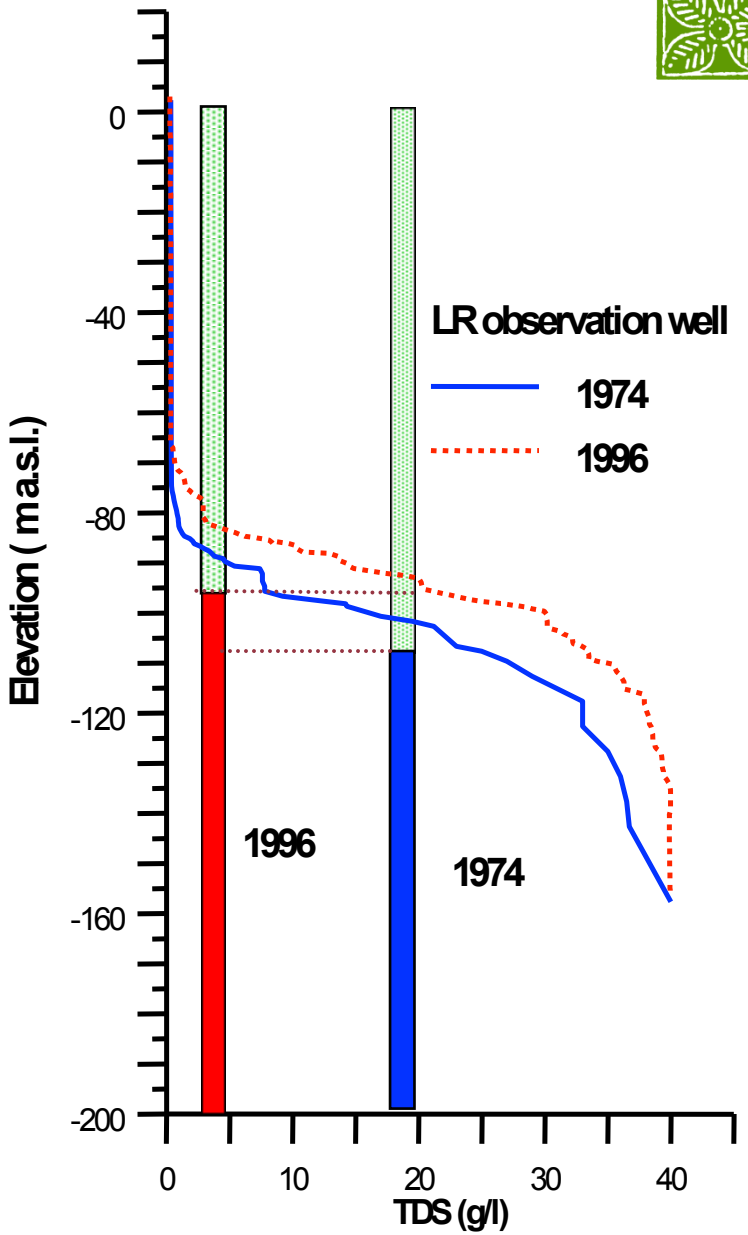


Theoric interface

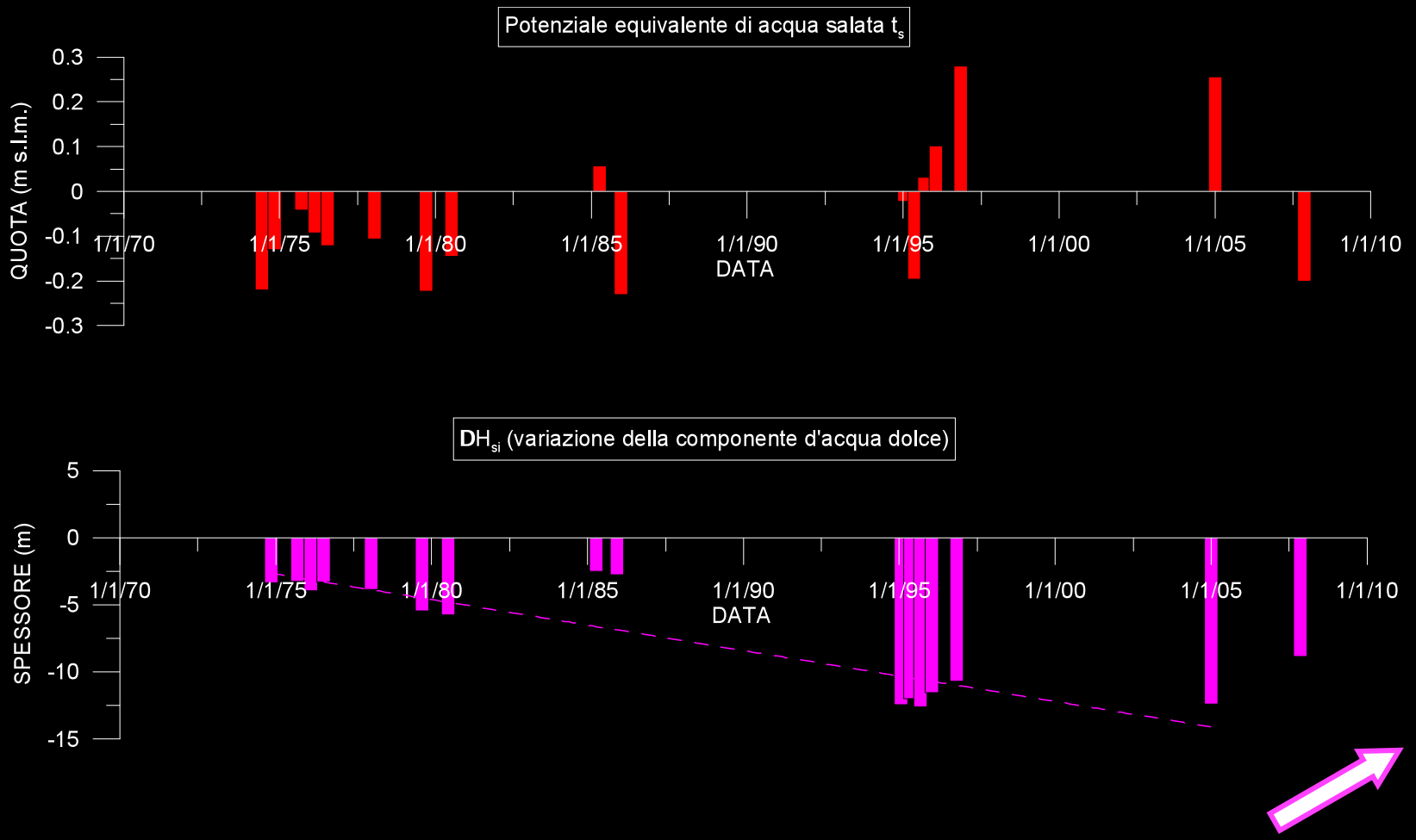
Theoric interface indicates that the aquifer is subject to over-exploitation

Fresh water column and salt water column are virtual:

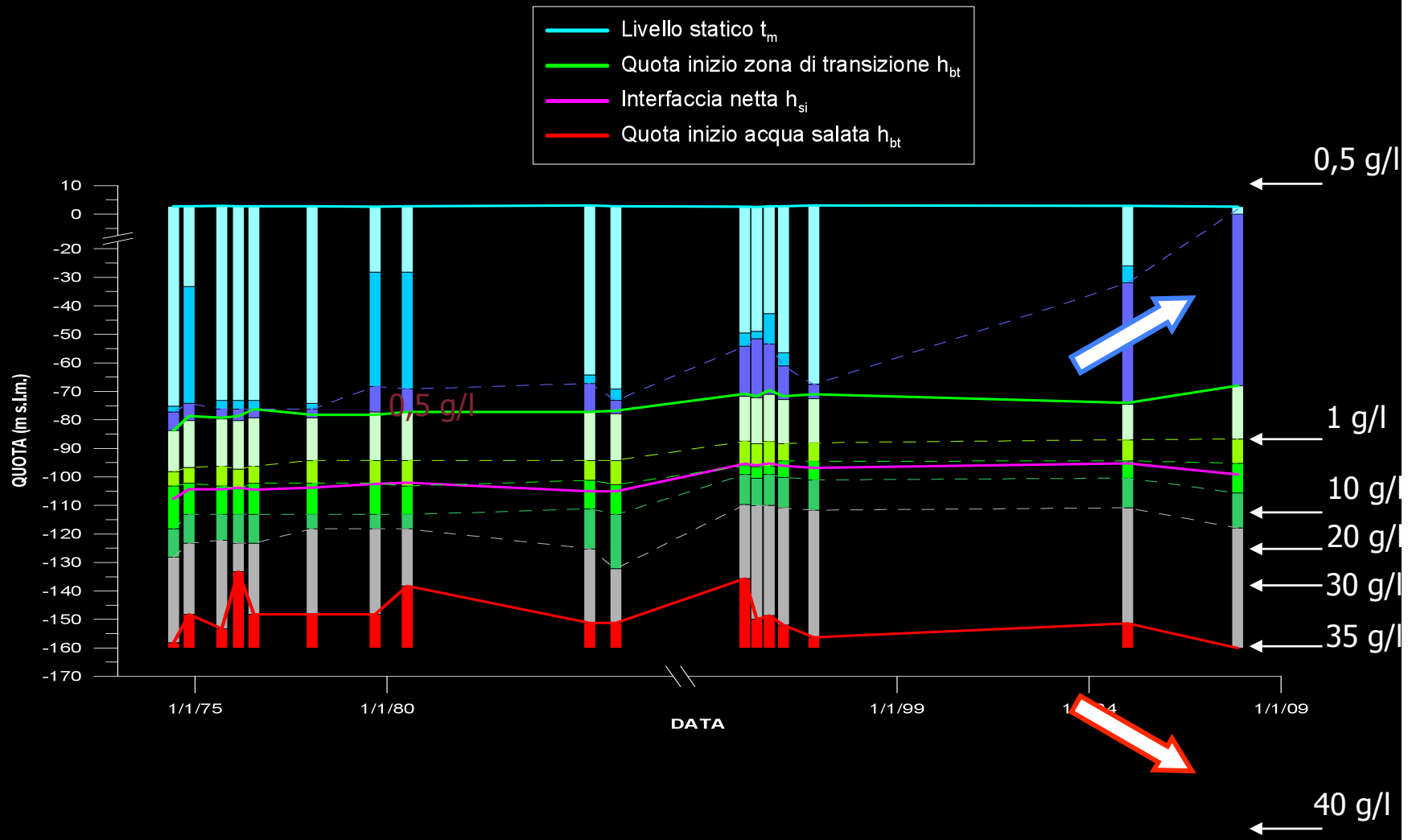
True salinity is shown by profiles



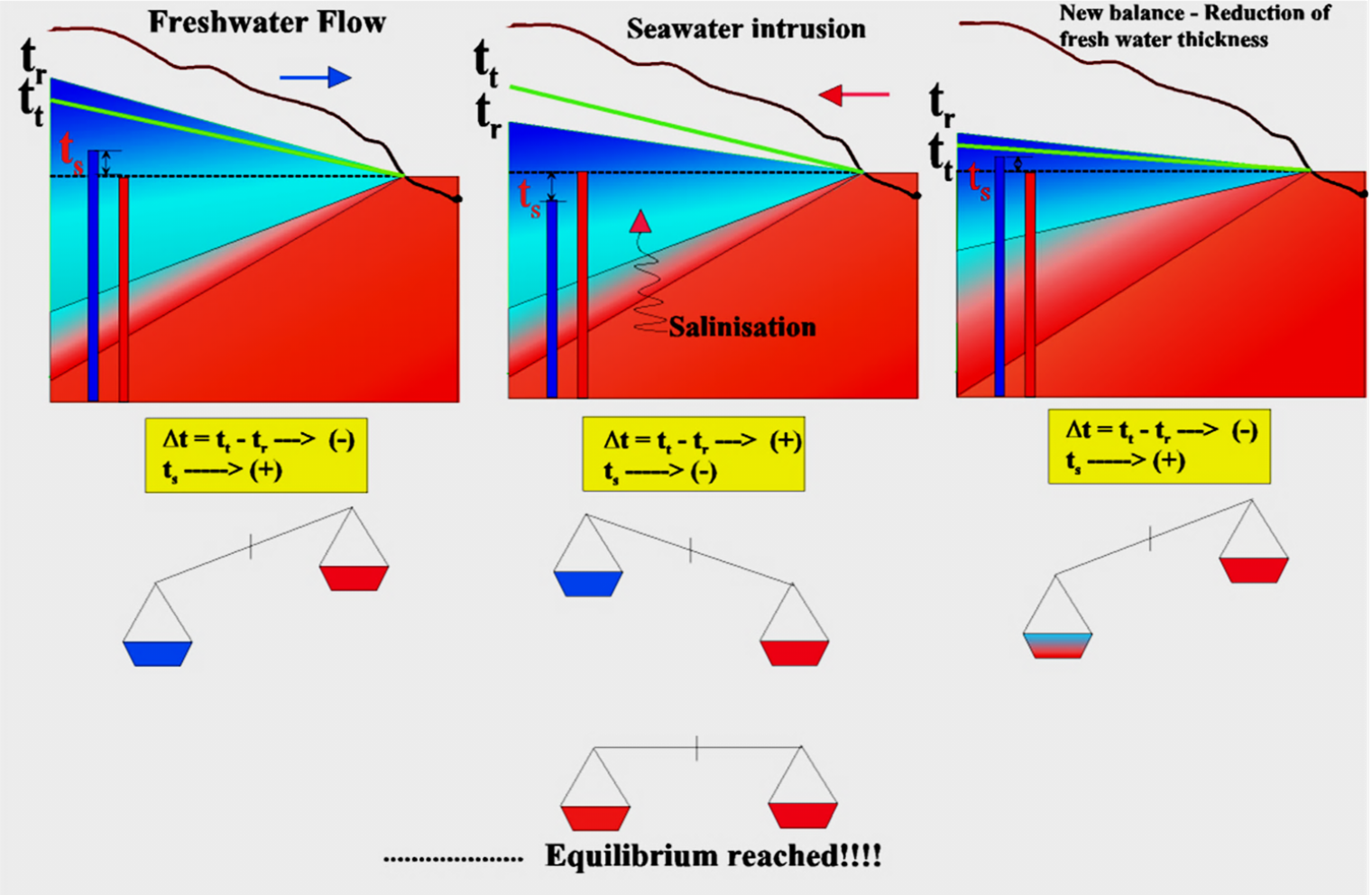
OW LR

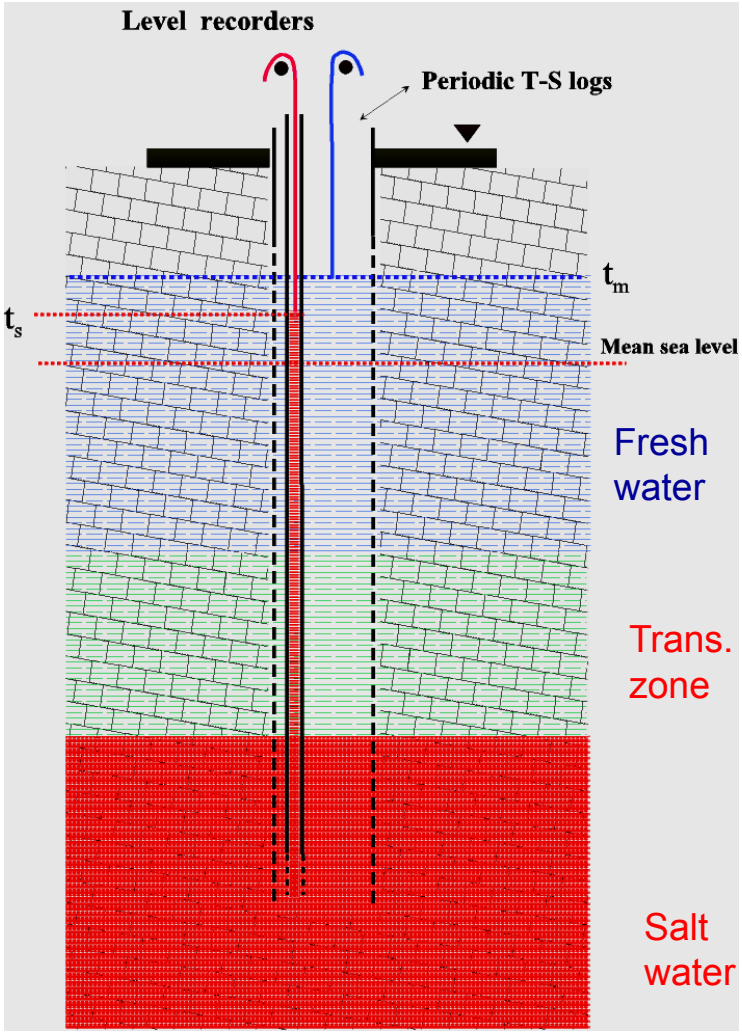

Potenziale equivalente di acqua salata t_s
QUOTA (m s.l.m.)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1/1/70
1/1/75
1/1/80
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
DATA
DH_{si} (variazione della componente d'acqua dolce)
SPESSORE (m)
5
0
-5
-10
-15
1/1/70
1/1/75
1/1/80
1/1/85
1/1/90
1/1/95
1/1/00
1/1/05
1/1/10
DATA

OW LR


Livello statico t_m
Quota inizio zona di transizione h_{bt}
Interfaccia netta h_{si}
Quota inizio acqua salata h_{bt}
QUOTA (m s.l.m.)
10
0
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
0,5 g/l
1/1/75
1/1/80
1/1/99
1/1/09
DATA
0,5 g/l
1 g/l
10 g/l
20 g/l
30 g/l
35 g/l
40 g/l

Mechanism of salinization induced by overexploitation





Scheme of an observation well for the monitoring of freshwater-seawater equilibrium

ORIGIN OF SALINIZATION

Groundwater salinisation may derive, beside from seawater intrusion, either from *other natural salt sources* or from *human impact.*

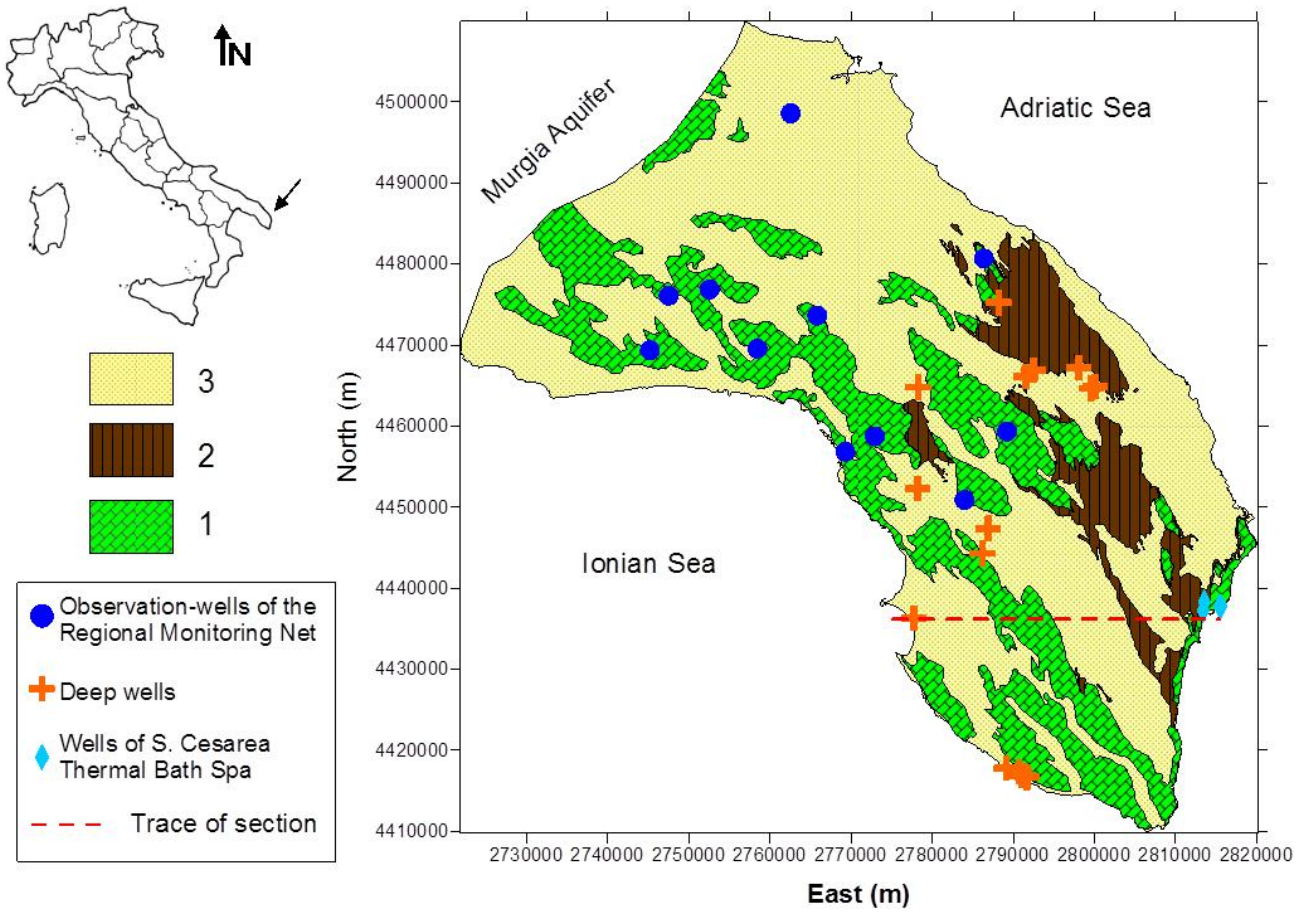
Human impact

- Irrigation practices and land use
- Infiltration of polluted or saline surface waters (rivers, ponds, lagunes, salt works)
- Infiltration from landfills or injection of municipal wastewaters…….

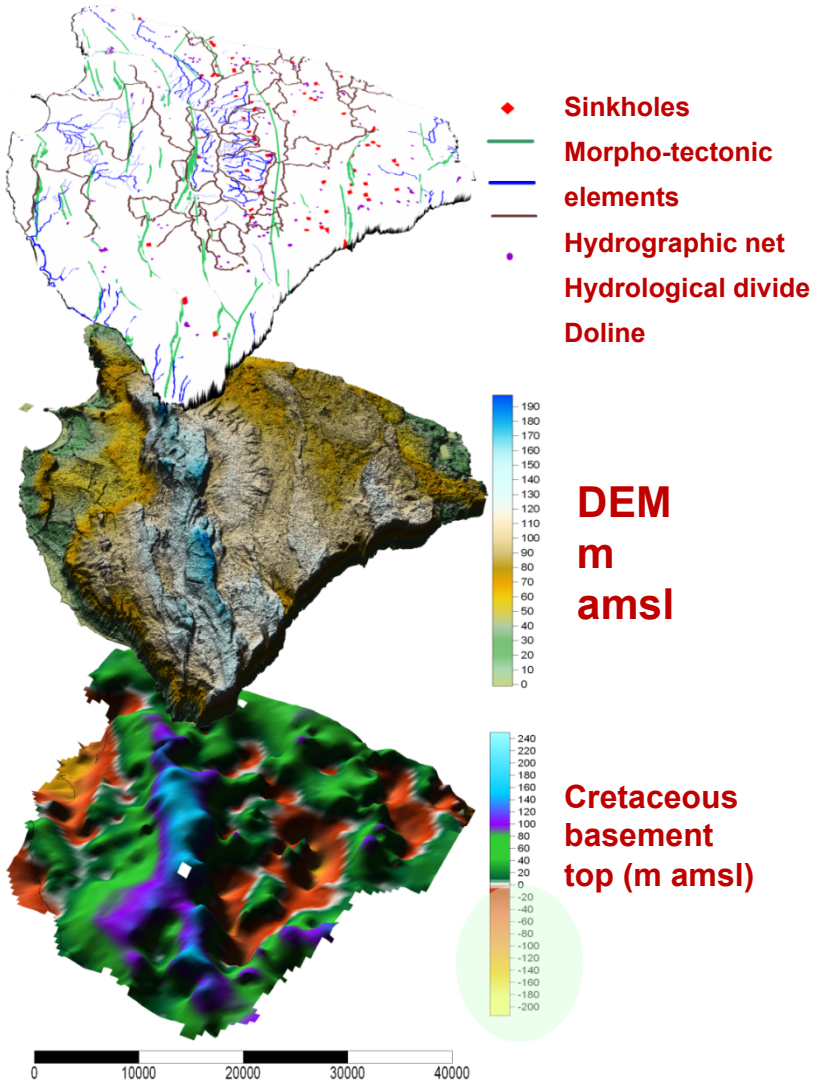
Natural salt sources:

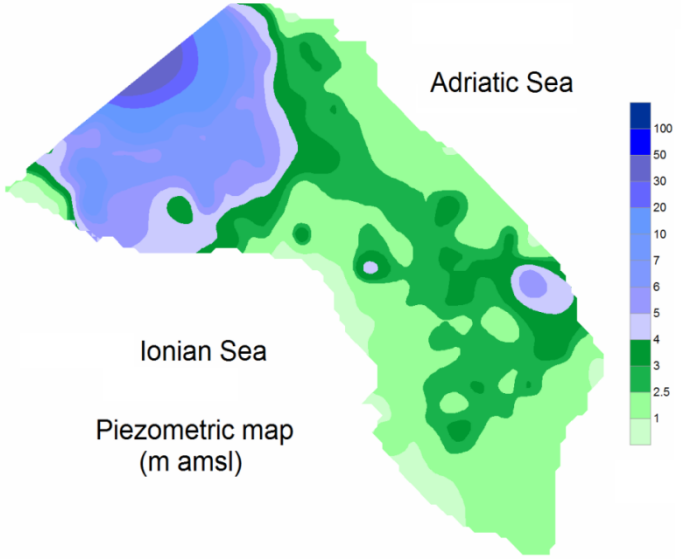
- Present seawater
- Salt waters of marine origin
- Evaporite salts
- Sea spray….

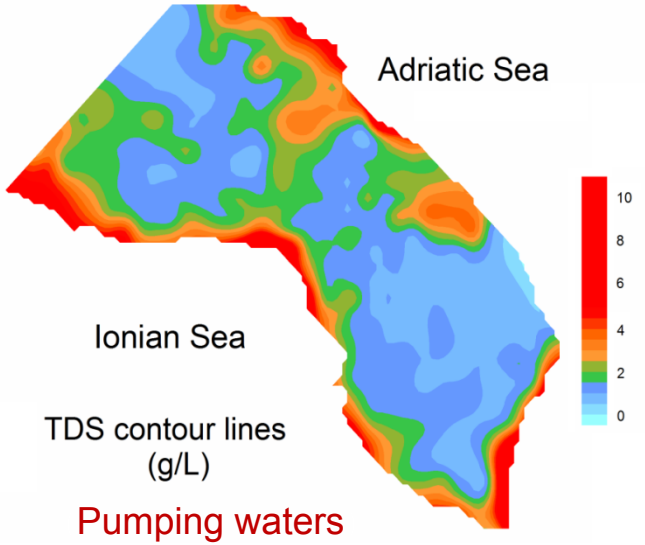
Salt waters …..



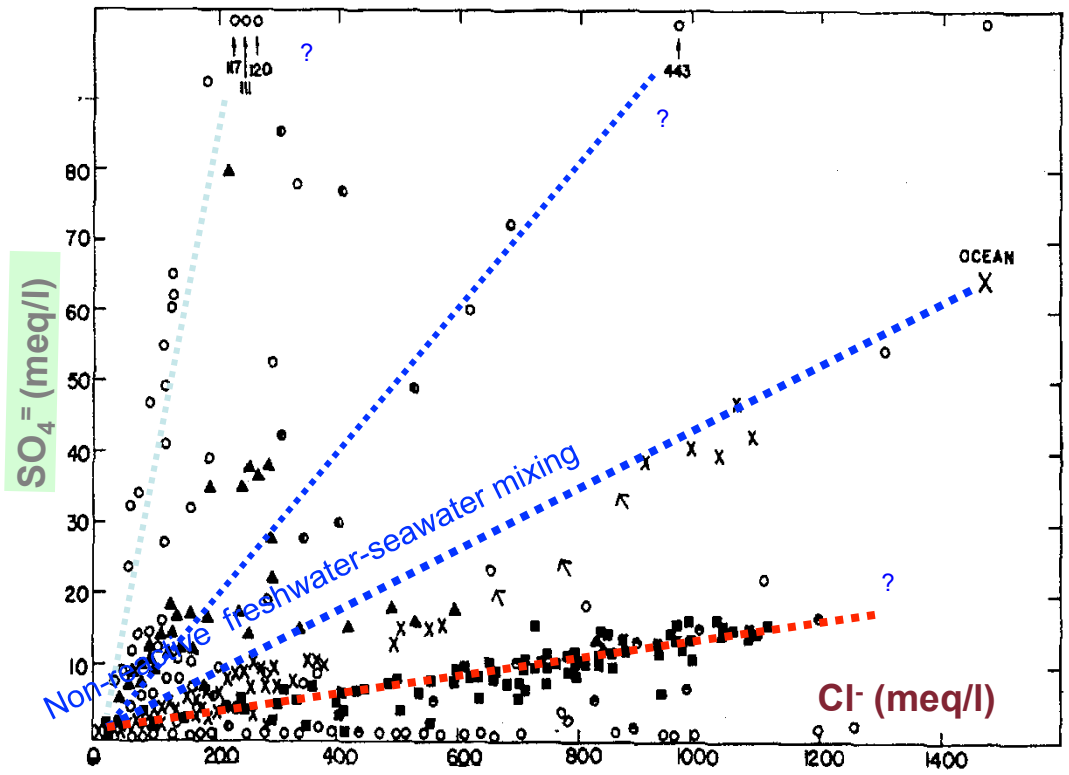
Simplified geological map : 1:Limestone and dolomitic limestones (Cretaceous); 2: Calcarenites and marly calcarenites (Miocene); 3: Calcarenites, sands and clays (Pliocene-Quaternary). Traces of geological section.


Sinkholes
Morpho-tectonic elements
Hydrographic net
Hydrological divide
Doline
DEM m amsl
Cretaceous basement top (m amsl)
0
10000
20000
30000
40000


Adriatic Sea
Ionian Sea
Piezometric map (m amsl)


Adriatic Sea
Ionian Sea
TDS contour lines (g/L)
Pumping waters

How to recognize other sources of salinization?



The deviation from non-reactive mixing (dilution line) can be due either to

- the water-rock interaction processes triggered by mixing process

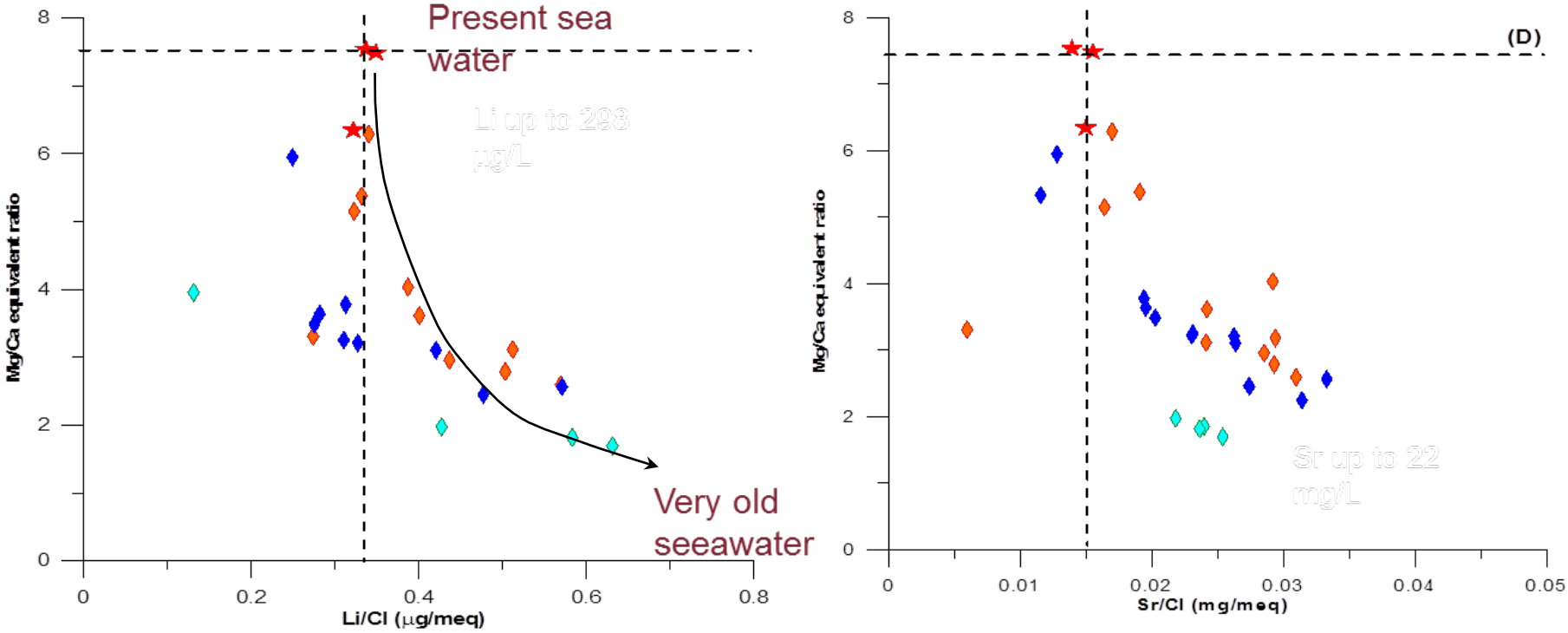
or to

- the intervention of a salt source or a saline fluid of marine origin chemically different from present seawater.

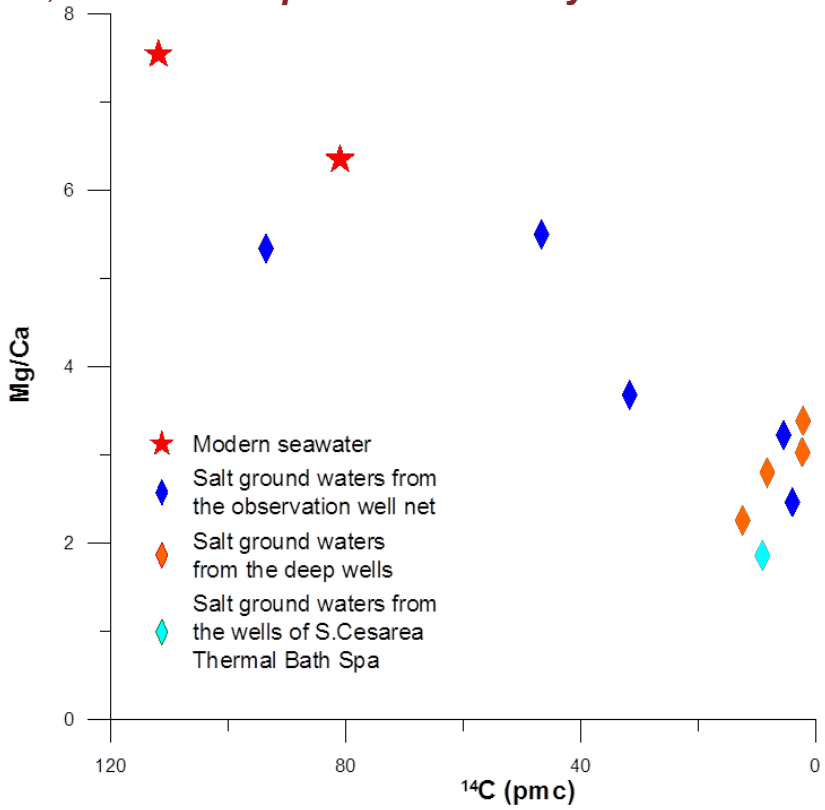
In most cases water-rock interactions overlap the effects of more than one salt source

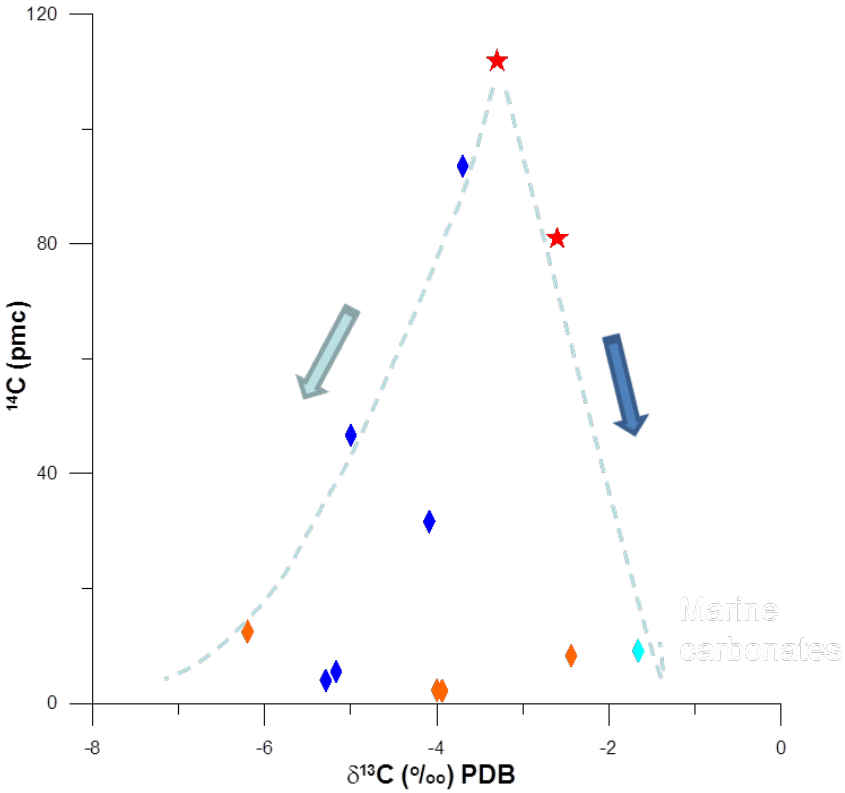
Sr/Cl ratio of saline waters is mostly higher than modern seawater: carbonate rock-water interaction is the main source of Sr, which can be used as relative age tracer.

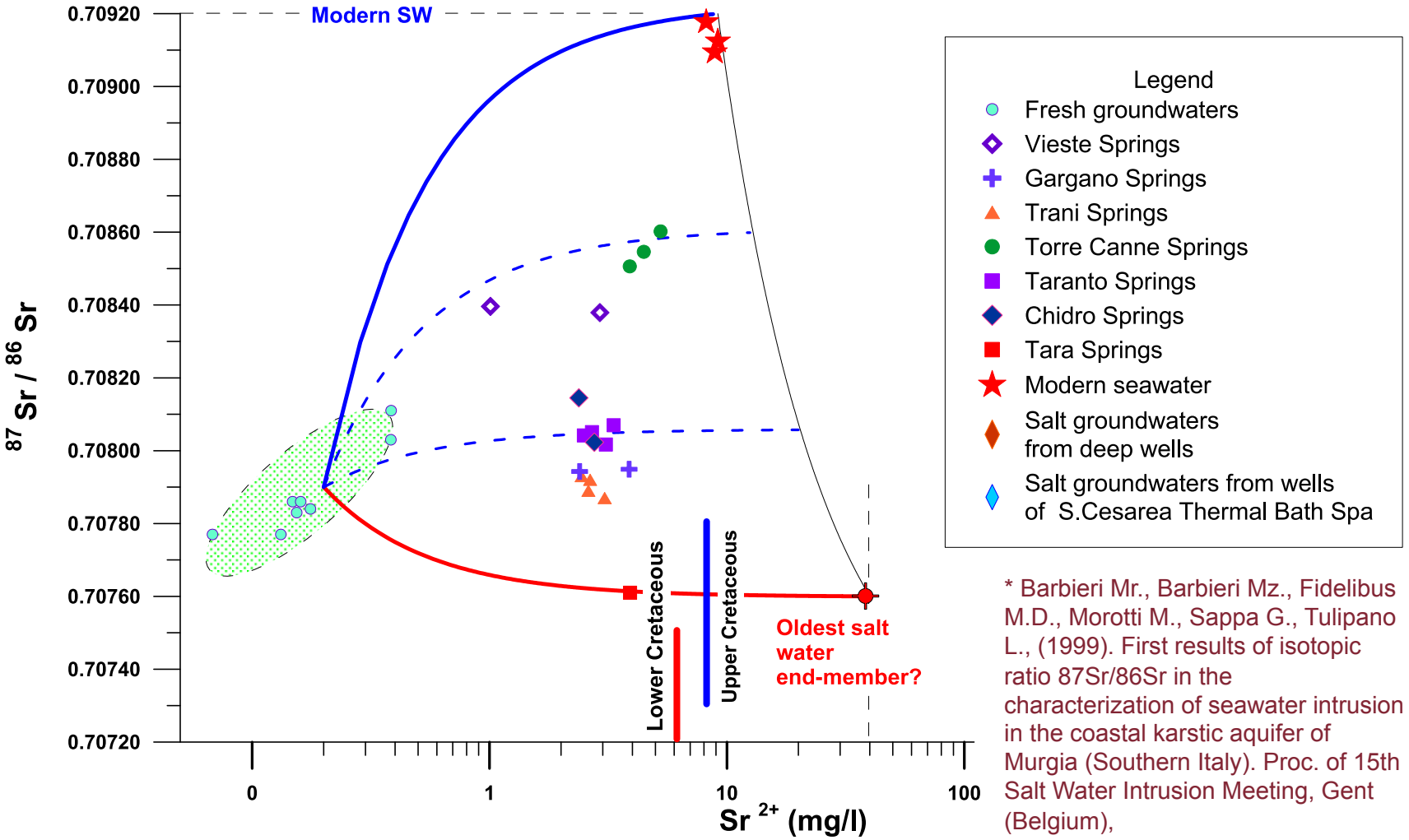
- Li/Cl is highest in thermal waters confirming to be a useful pathfinder for hydrothermal systems



- Saline waters show ^{14}C activities lower than those found in recent seawater. These differences may indicate both ***age variations and chemical interaction with the host rock***.
- Salt waters have $\delta^{13}C$ values either depleted or enriched with respect to recent seawater:, indicating contributions from dissolution of marine carbonates, organic carbon and sulphate reduction.
- Determination of the real age is complicated by several possible sources of carbon that influence the ^{14}C values, ***besides the process of decay***.







* Barbieri Mr., Barbieri Mz., Fidelibus M.D., Morotti M., Sappa G., Tulipano L., (1999). First results of isotopic ratio 87Sr/86Sr in the characterization of seawater intrusion in the coastal karstic aquifer of Murgia (Southern Italy). Proc. of 15th Salt Water Intrusion Meeting, Gent (Belgium),

A never ending process…