Monitoring and management of coastal karstic aquifers

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Our general purpose

- To study complex phenomena on risks for groundwater resources of quality and quantity degradation offering:
  - Synthetic view on ongoing trends
  - As simple as possible tools to quantify degradation effects
  - Solutions to improve the groundwater quality and promoting durable sustainability of groundwater resource utilisation

Quantity and quality degradation of Groundwater Resources (GR)

GR OVEREXPLOITATION → **QUANTITY DEGRADATION**

SHORTAGE OF WATER RESOURCES
- **DROUGHT AND CLIMATE CHANGE**
- **INCREASING WATER DEMAND**

AQUIFER VULNERABILITY AND WIDESPREAD POLLUTION → **QUALITY DEGRADATION**

SALT POLLUTION BY SEAWATER INTRUSION (SAPSI) → **QUALITY DEGRADATION**

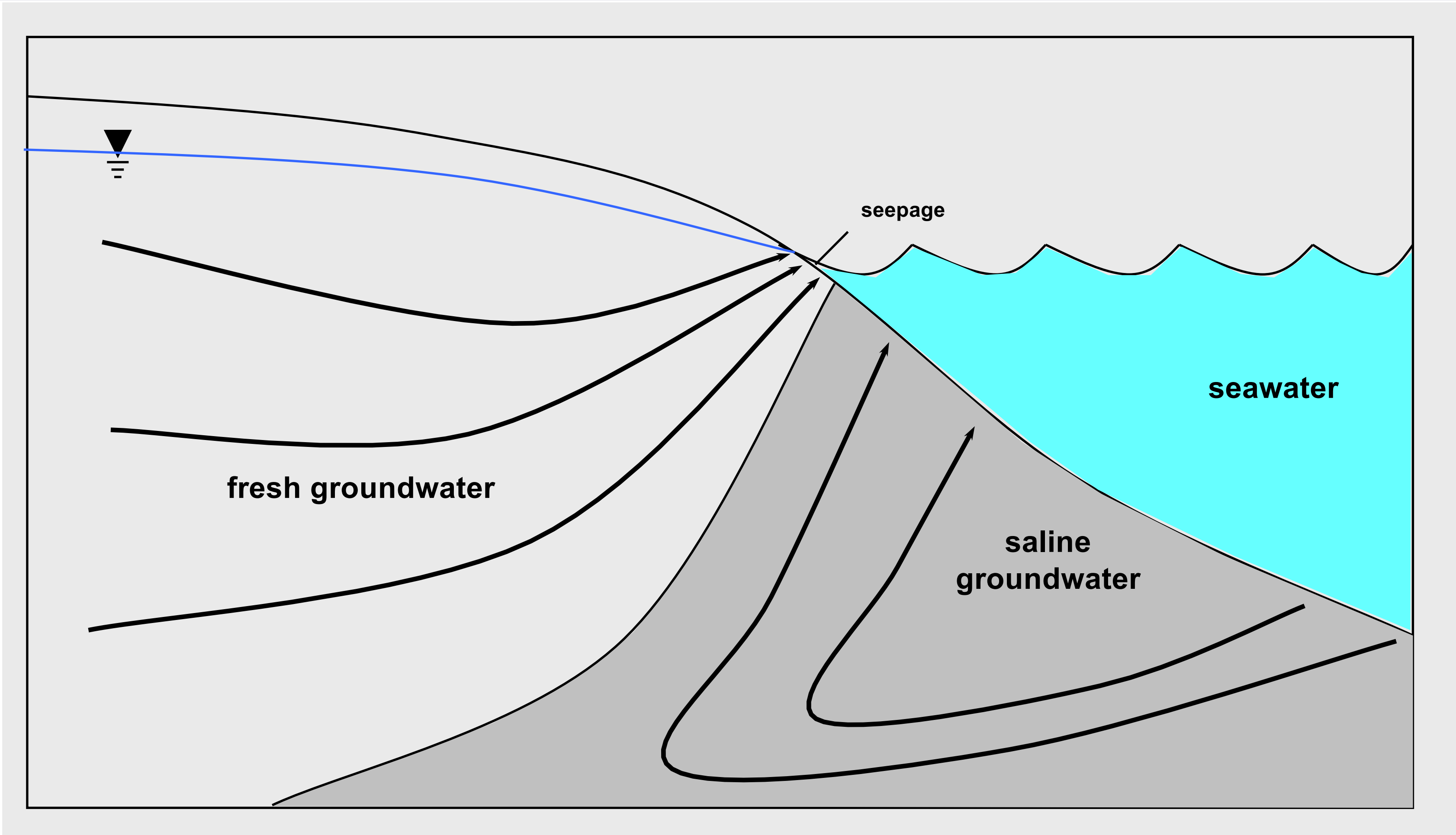
Polemio, 2016, Monitoring and Management of Karstic Coastal Groundwater in a Changing Environment (Southern Italy): A Review of a Regional Experience: Water, v. 8, no. 4, p. 1-16.

Polemio, M., Casarano, D., and Limoni, P. P., 2009, Karstic aquifer vulnerability assessment methods and results at a test site (Apulia, southern Italy): Natural Hazards and Earth System Sciences, v. 9, no. 4, p. 1461-1470.

Main Mediterranean coastal groundwater affected by quality degradation due to seawater intrusion and/or anthropogenic contamination

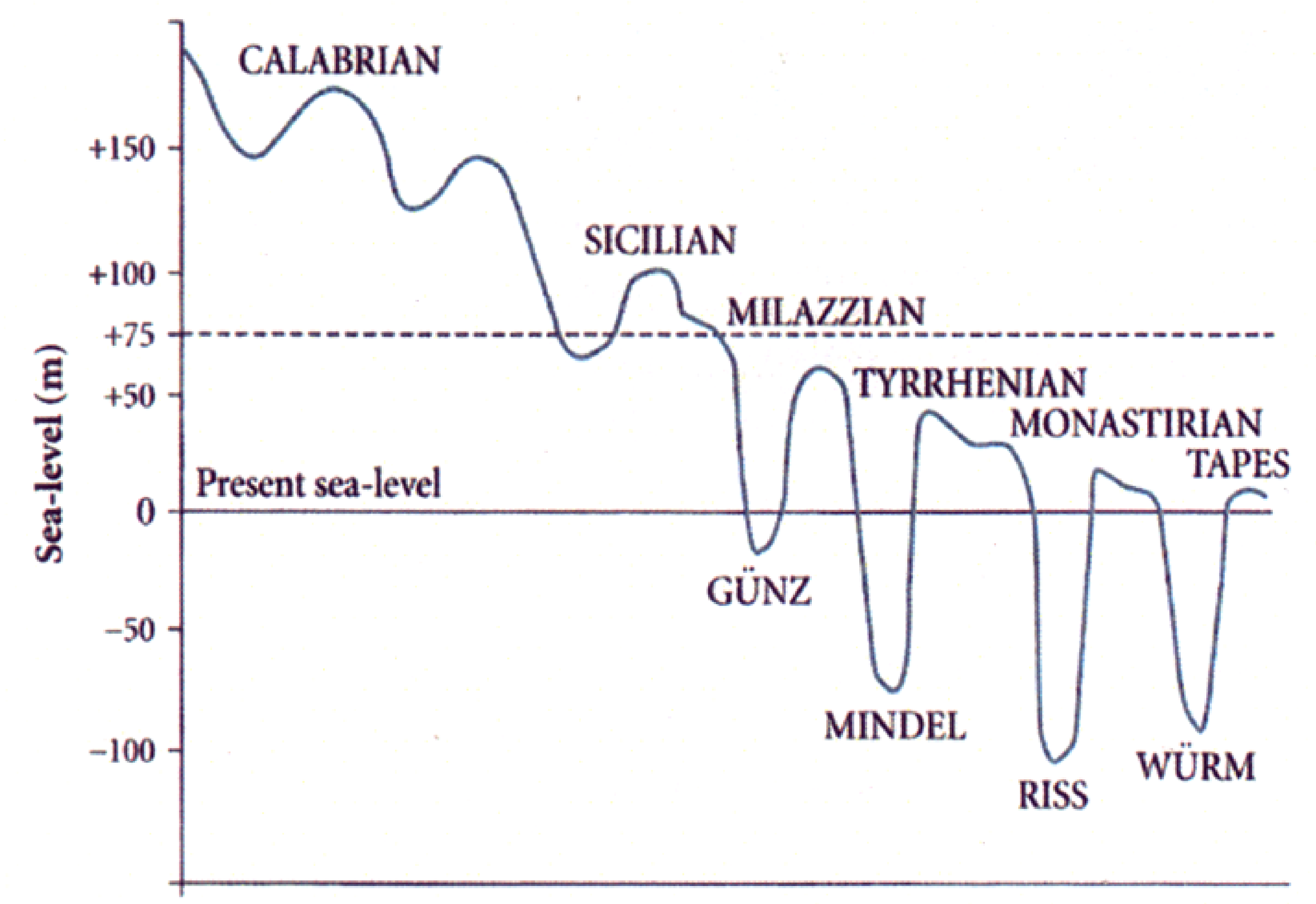
Polemio, 2016, Monitoring and Management of Karstic Coastal Groundwater in a Changing Environment (Southern Italy): A Review of a Regional Experience: Water, v. 8, no. 4, p. 1-16.

A simple coastal aquifer



Polemio, M., Dragone, V., and Limoni, P. P., 2009, Monitoring and methods to analyse the groundwater quality degradation risk in coastal karstic aquifers (Apulia, Southern Italy): Environmental Earth Sciences (formerly Environmental Geology), v. 58, no. 2, p. 299-312.

Downward trend of Pleistocene sea-level sequence



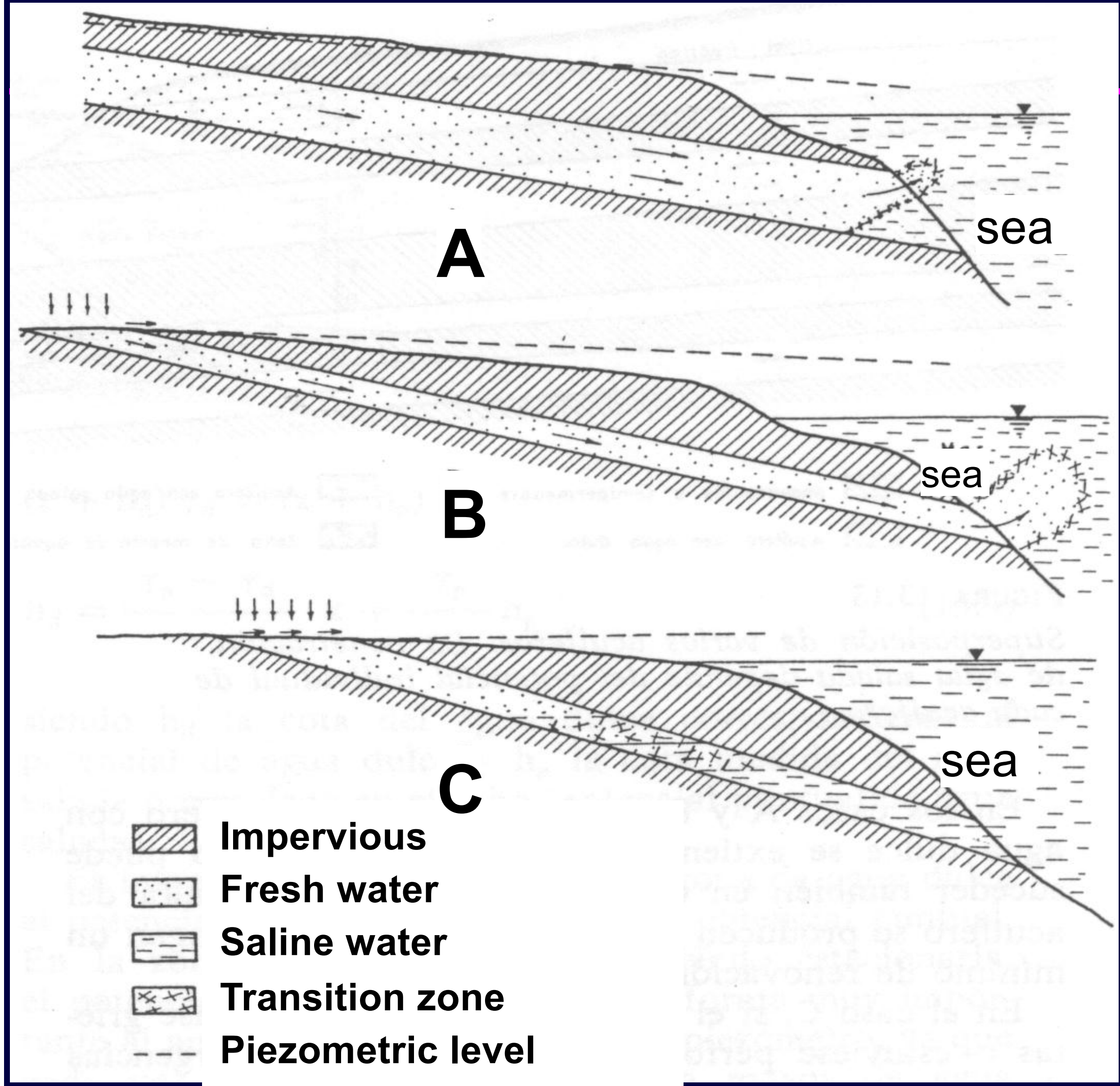
Frenzel, 1973

Coastline during previous glacial maximum (22 ka BP)

On the basis of Italian geomorphological map (Climex maps, Vai & Cantelli, 2004), it can be seen **the sea level was -149 m** during last glacial maximum (LGM, about 22 thousands year before present).

The mean temperature was about 4÷5 °C lower than today.

Relationship freshwater – saltwater: the effect of variable recharge or fresh groundwater flow (confined aquifer)

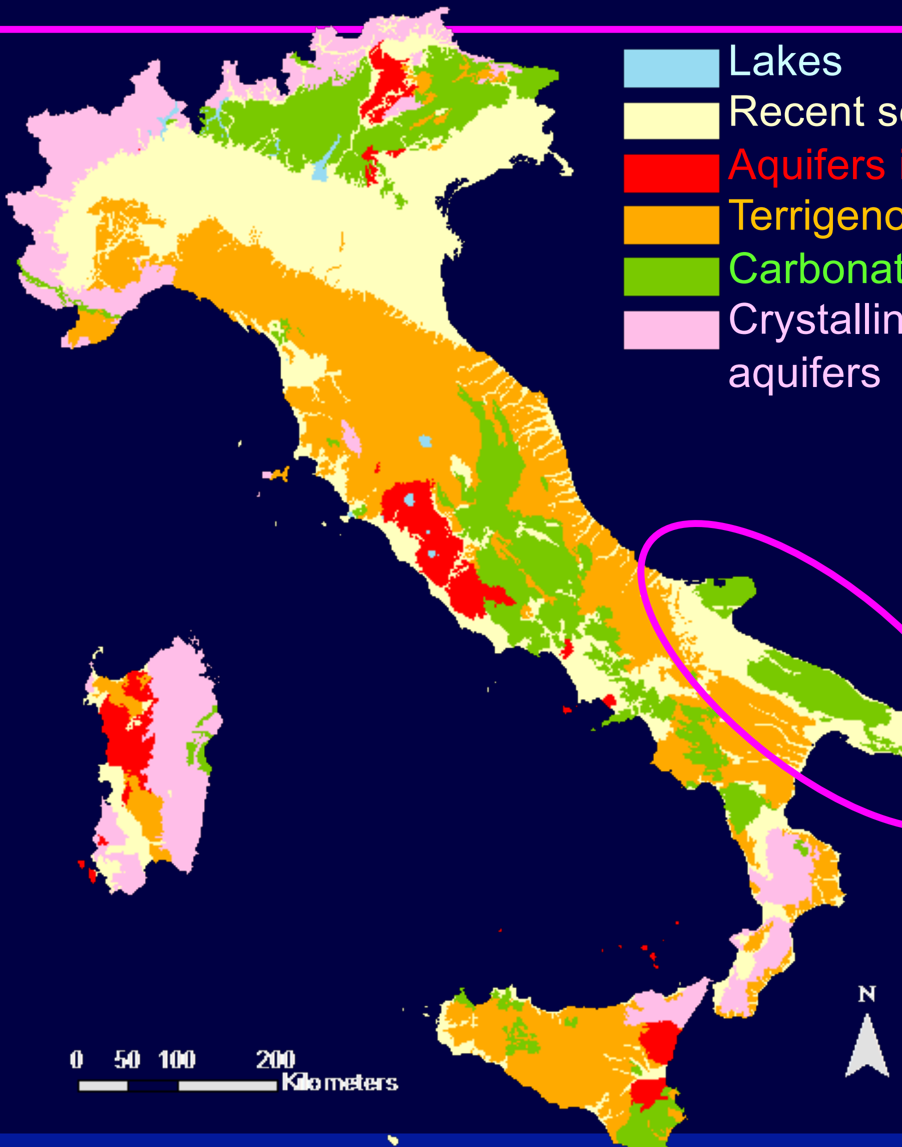


A) The freshwater flow is enougth to allow the sea discharge. A saline wedge is obsvered below fresh groundwater

B) The freshwater potential is very high and the saltwater wedge does not exists

C) The freshwater pressure is low and not enough to be discarged to the sea (again the saltwater wedge does not exists)

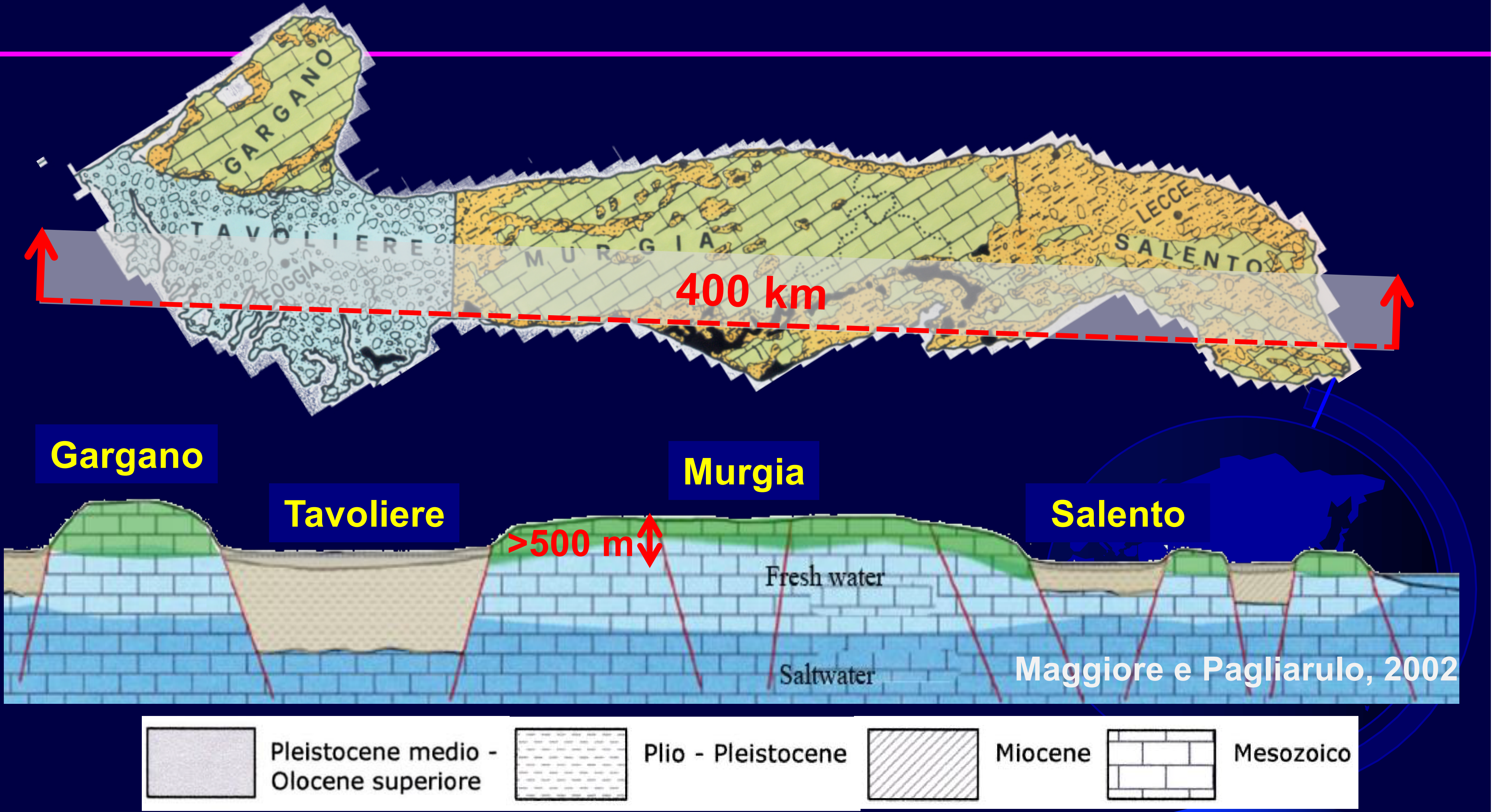
Schematic Italian hydrogeological map and coastal karstic aquifers



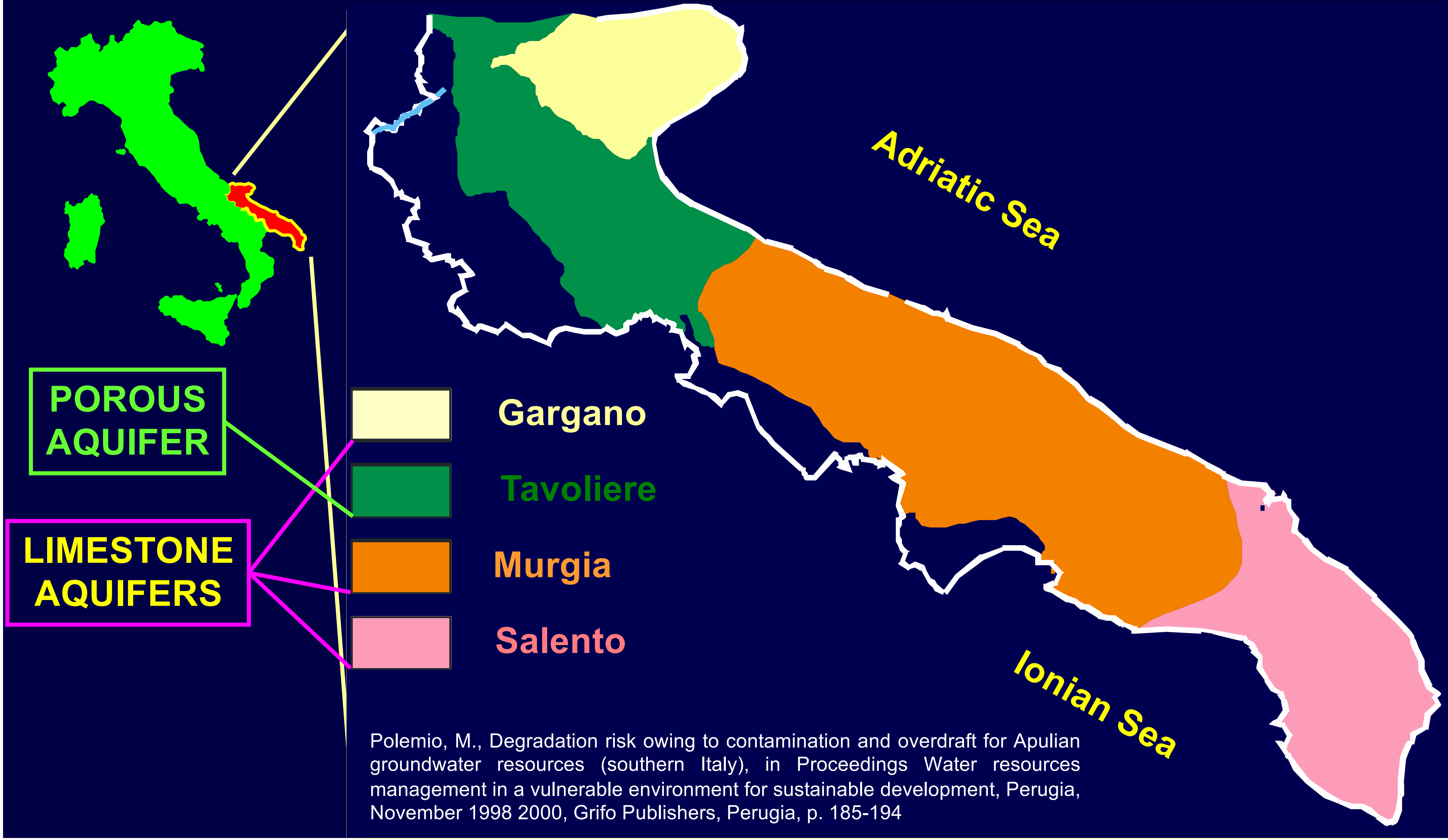
- Lakes
- Recent sedimentary successions-stratified aquifers of coastal/alluvial plains
- Aquifers in volcanic or pyroclastic successions
- Terrigenous Cenozoic successions - Mainly low permeability
- Carbonate aquifers – mainly karstic aquifers
- Crystalline or metamorphic successions – low permeability and shallow aquifers

More coastal karstic aquifers (Sardinia, Sicily, Friuli and Apulia): the largest one's are in Apulia

The schematic hydrogeological map and section



The schematic map of Hydrogeological Structures (HSs)



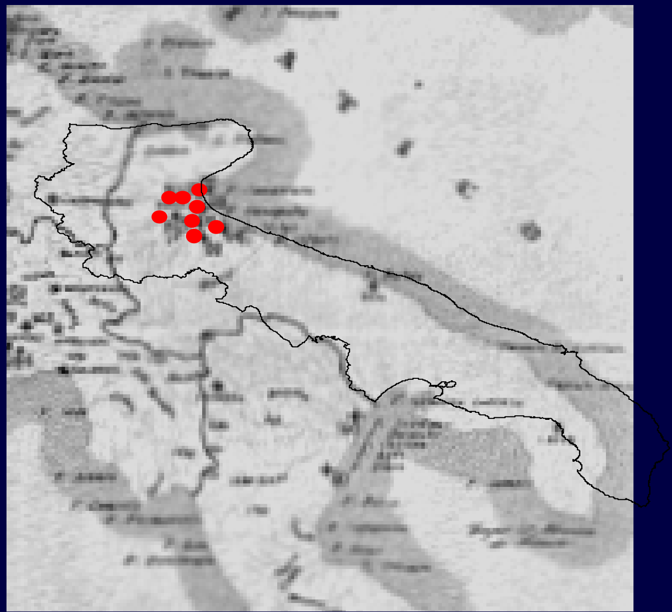
Polemio, M., Degradation risk owing to contamination and overdraft for Apulian groundwater resources (southern Italy), in Proceedings Water resources management in a vulnerable environment for sustainable development, Perugia, November 1998 2000, Grifo Publishers, Perugia, p. 185-194

General purpose

Reducing the risk of **G**roundwater quality **D**egradation due to the **S**eawater **I**ntrusion (GDSI) with

- the management of the resource and the control of GDSI effects using tools as simple as possible to be utilized by each kind of public institutions
  - **spatial and multi-temporal analyses of usual chemical and physical data (threshold approach)**
  - **Definition of management criteria**

Apulia groundwater utilisation over time



- Pallucchini summarised the Italian situation during thirties. About Apulia:
  - 87 monitoring wells (unused wells) of shallow (nowadays secondary) aquifers (Tavoliere and Salento)
  - very few deep or bored wells, all in the porous Tavoliere aquifer
- The level of Apulian karstic groundwater utilisation was null inland and almost low near the coast, due to low depth to water, until the end of the Second World War.
- A continuous increasing trend of groundwater discharge started about from the second half of fifties; this trend is still observed.

Apulia groundwater utilisation and regulation

- From fifties groundwater discharge is increasing as an effect of social and economical improvements, population increase and availability of new boring technologies to realize very deep wells.
- The current number of wells is not well known due to high percentage of abusive wells; in any case, the number should be measured as many tens of thousands.

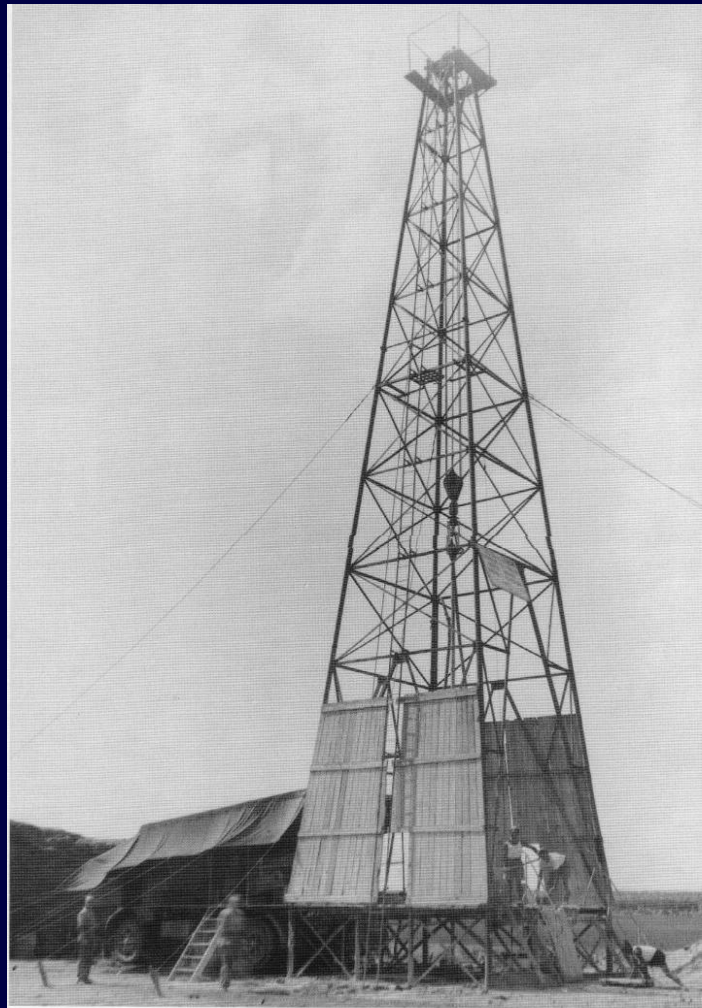


Fig. 77 - Impianto a rotazione a circolazione diretta di acqua per pozzi a carotaggio continuo tavoliere di Puglia

Apulia groundwater utilisation and regulation

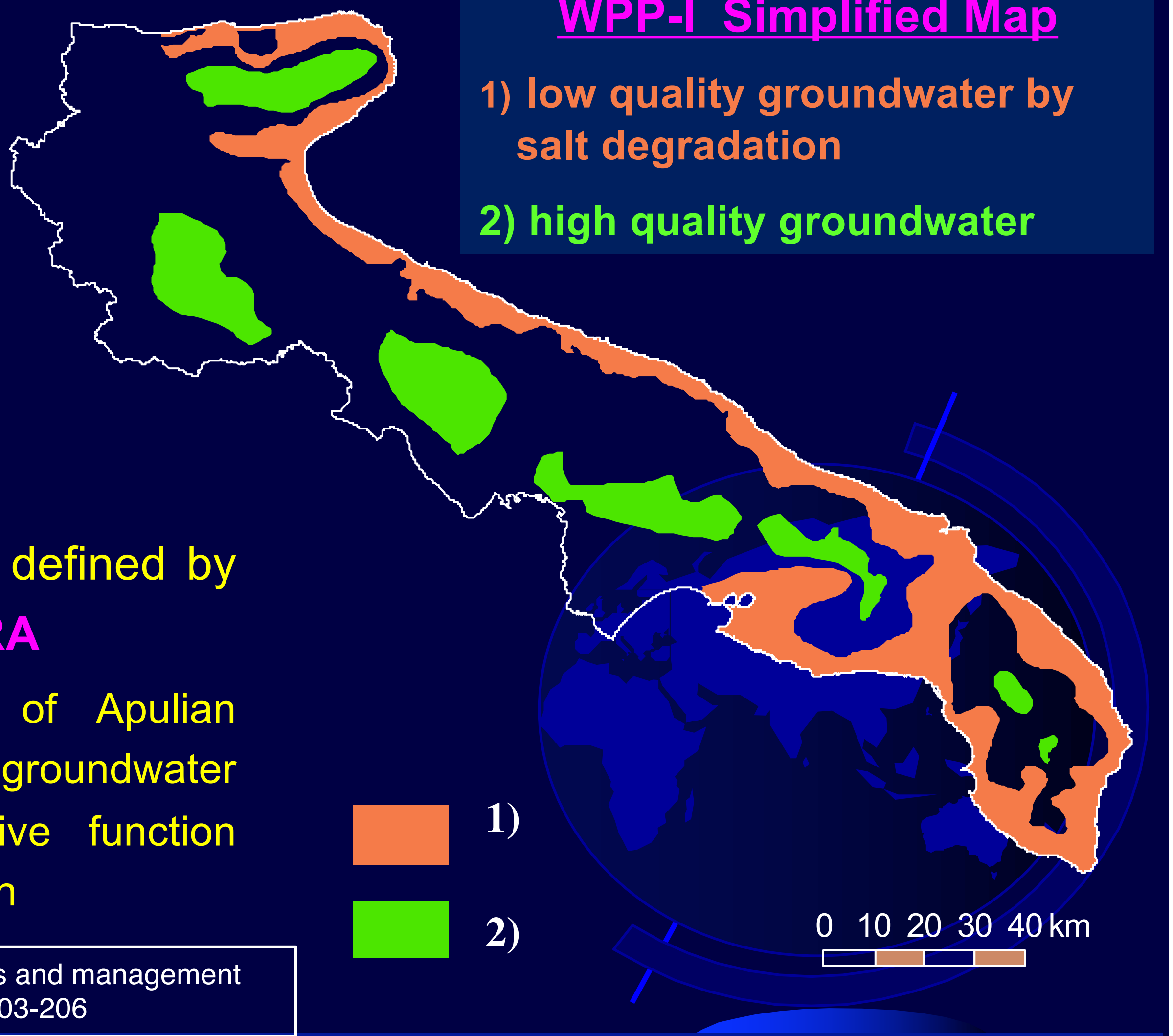
Water Protection Plan I (WPP-I or PRA, 1984)

- The groundwater discharge in Apulia (and roughly in Italy) was regulated by law only from an administrative point of view until 1984
- The effects of seawater intrusion and the application of hydrogeological management criteria were completely neglected until 1984
- In the **1984**, Apulia Regional authorities defined by law the **Water Protection Plan**, called **PRA**
  - determining the quality zonation of Apulian groundwater and the regulation of groundwater and aquifer utilisations as a qualitative function of the risk of groundwater degradation

WPP-I Simplified Map

1) low quality groundwater by salt degradation

2) high quality groundwater

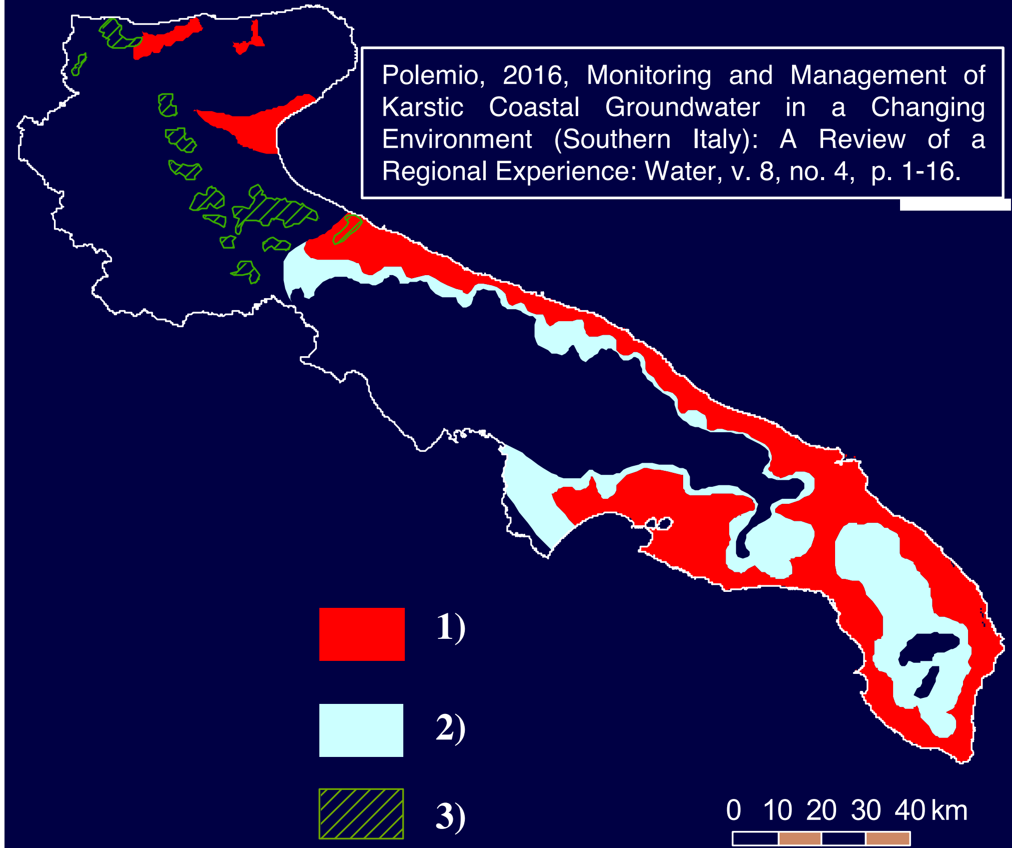


Polemio, M., Casarano, D., and Limoni, P. P., Apulian coastal aquifers and management criteria, *in* Proceedings 21st SWIM, Azores, 21-26/06/2010 2010, p. 203-206

Apulia groundwater utilisation and regulation

Water Protection Plan II (WPP-II or PTA, 2009)

Polemio, 2016, Monitoring and Management of Karstic Coastal Groundwater in a Changing Environment (Southern Italy): A Review of a Regional Experience: Water, v. 8, no. 4, p. 1-16.



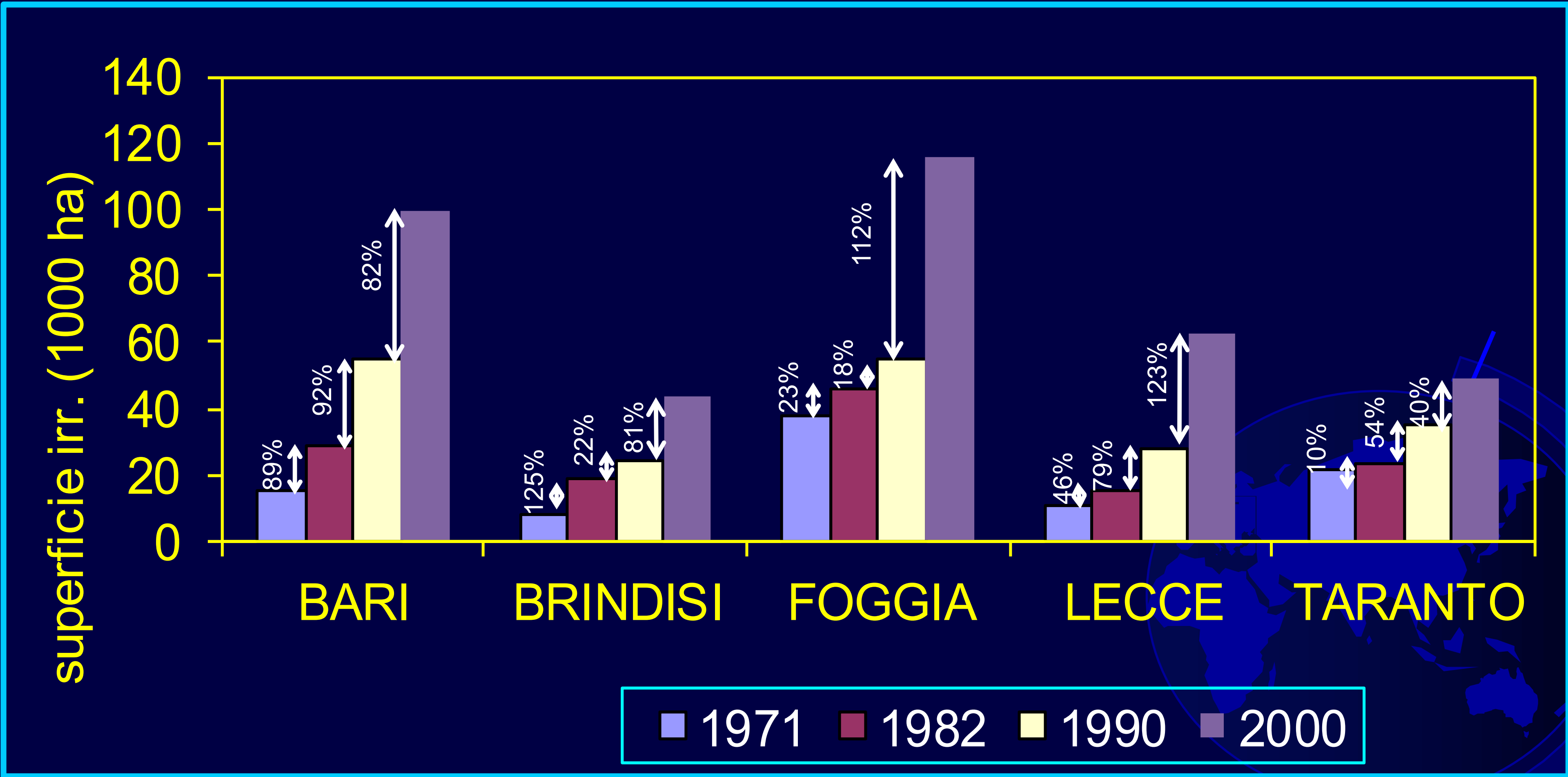
NOD	**Authorization extension (existing well):** • well bottom (-m asl) less than 20-30 piez. head (m asl) • drawdown (m) of max discharge yield less than 30-50% piez. head (m asl)
QQP	**New wells are possible if:** • If unconfined, well bottom (-m asl) less than 20-25 piez. head (m asl) • drawdown (m) of max discharge yield less than 30-60% piez. head (m asl), TDS<1 g/l, CC<500 mg/l

1)low quality groundwater by salt degradation (new fresh discharge permission not provided, NOD zone)

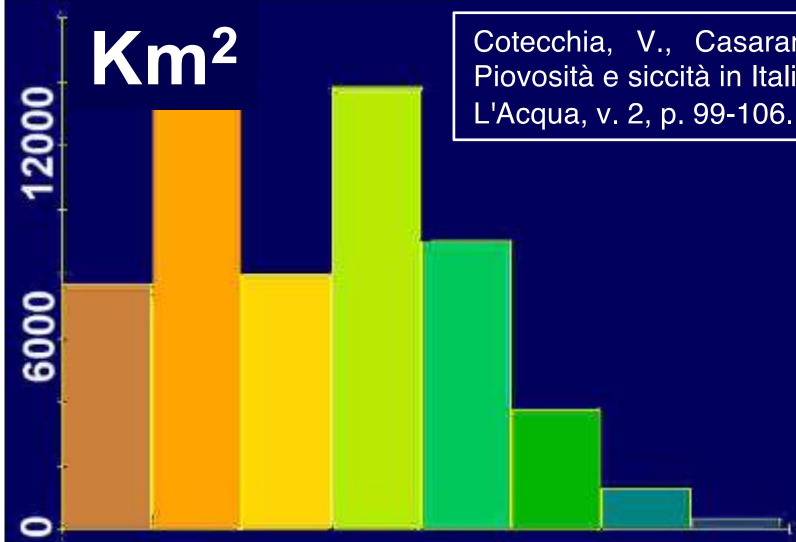
2)qualitative and quantitative protection zone (QQP zone, regulated new discharge)

3)quantitative protection zone (QP zone, new discharge permission suspended)

Surface watered with grounwater in Apulia region

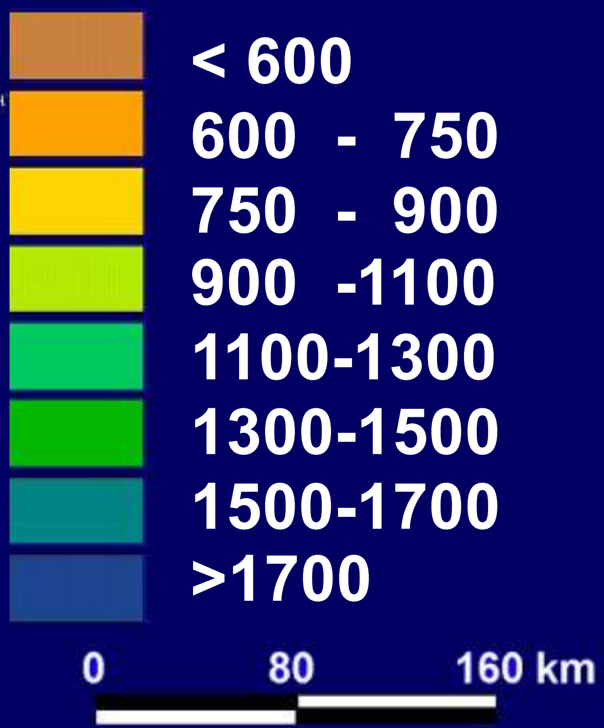


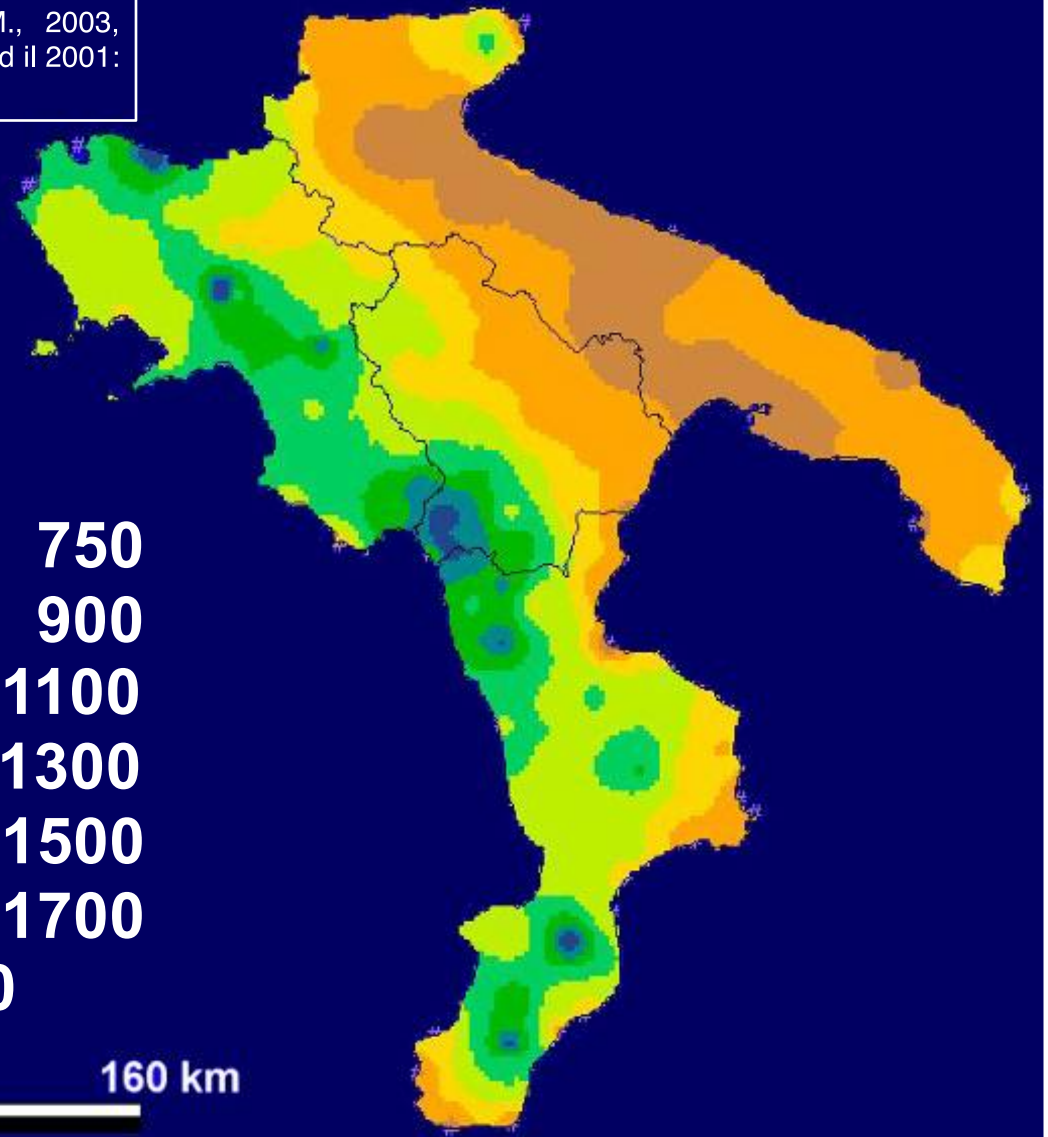
MEAN ANNUAL RAINFALL MAP (PERIOD 1921-2001, mm)



Cotecchia, V., Casarano, D., and Polemio, M., 2003, Piovosità e siccità in Italia meridionale tra il 1821 ed il 2001: L'Acqua, v. 2, p. 99-106.

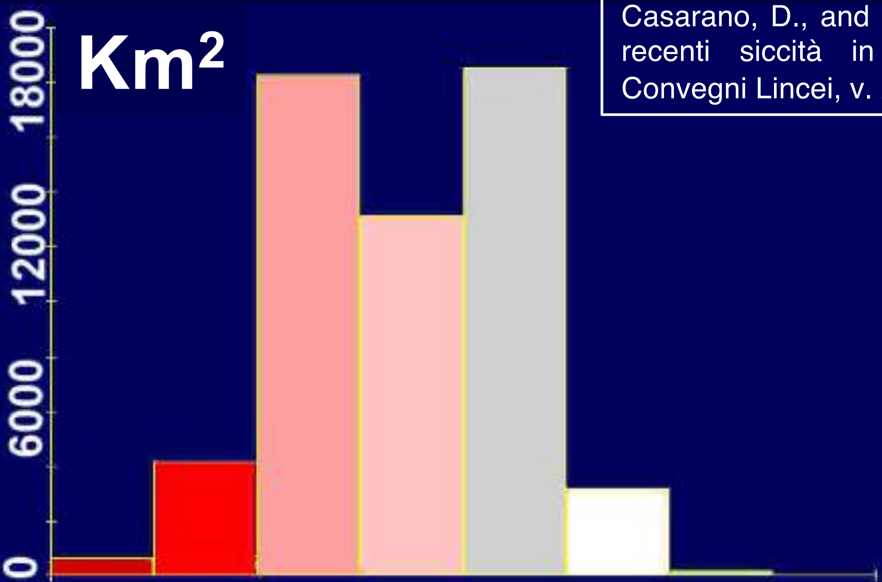
REGION	MEAN ANNUAL RAINFALL	
	mm	Mm^3
APULIA	644	12,500
BASILICATA	893	9,000
CALABRIA	1043	16,000
CAMPANIA	1148	15,000



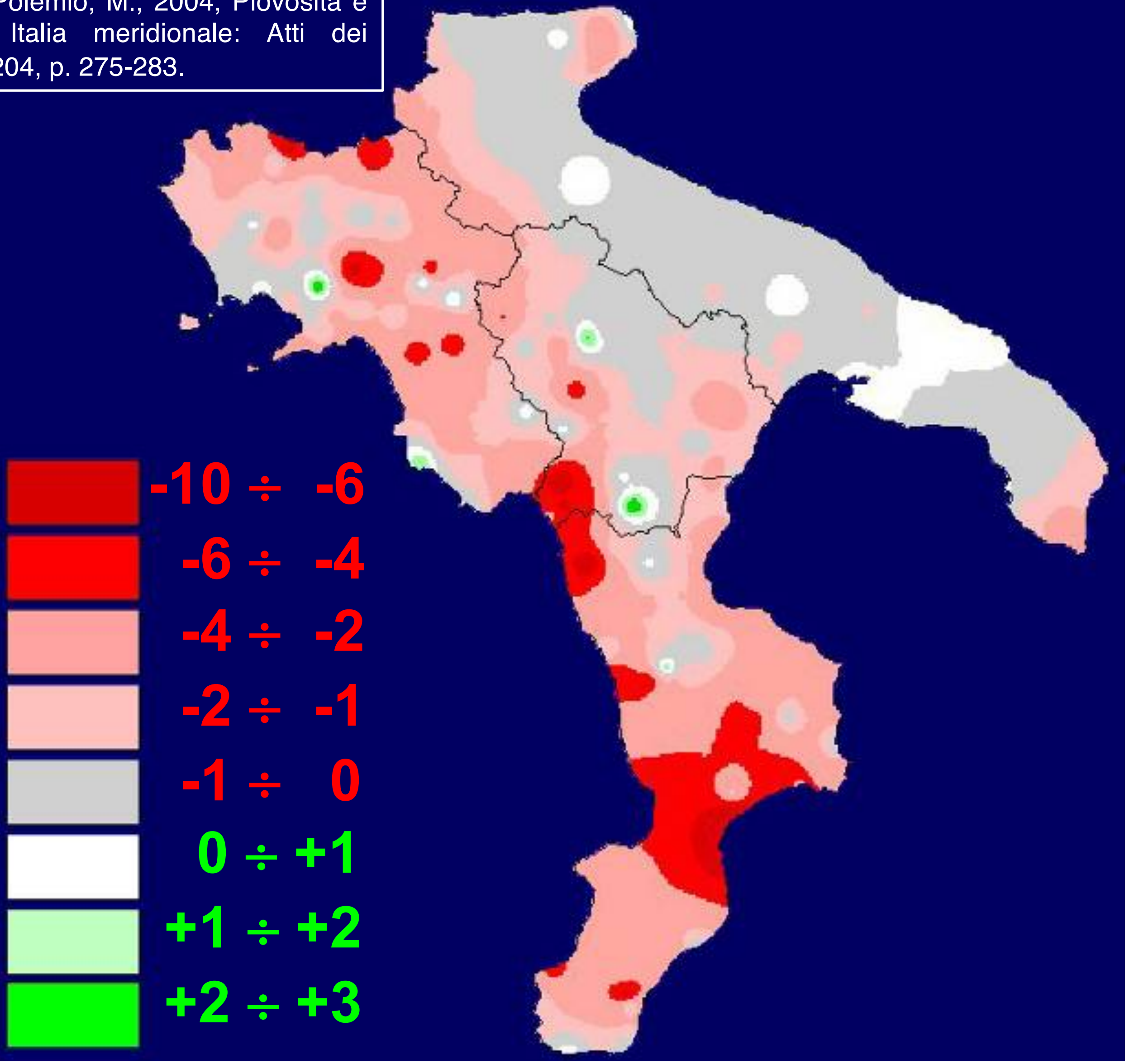


RAINFALL TREND MAP (mm/year)
PERIOD 1921-2001

Casarano, D., and Polemio, M., 2004, Piovosità e recenti siccità in Italia meridionale: Atti dei Convegni Lincei, v. 204, p. 275-283.



REGION	MEAN RAINFALL TREND	
	mm/y	80 YEARS (mm,%)
APULIA	-0.8	-65 (-10%)
BASILICATA	-1.8	-145 (-16%)
CALABRIA	-2.9	-230 (-22%)
CAMPANIA	-2.5	-196 (-18%)



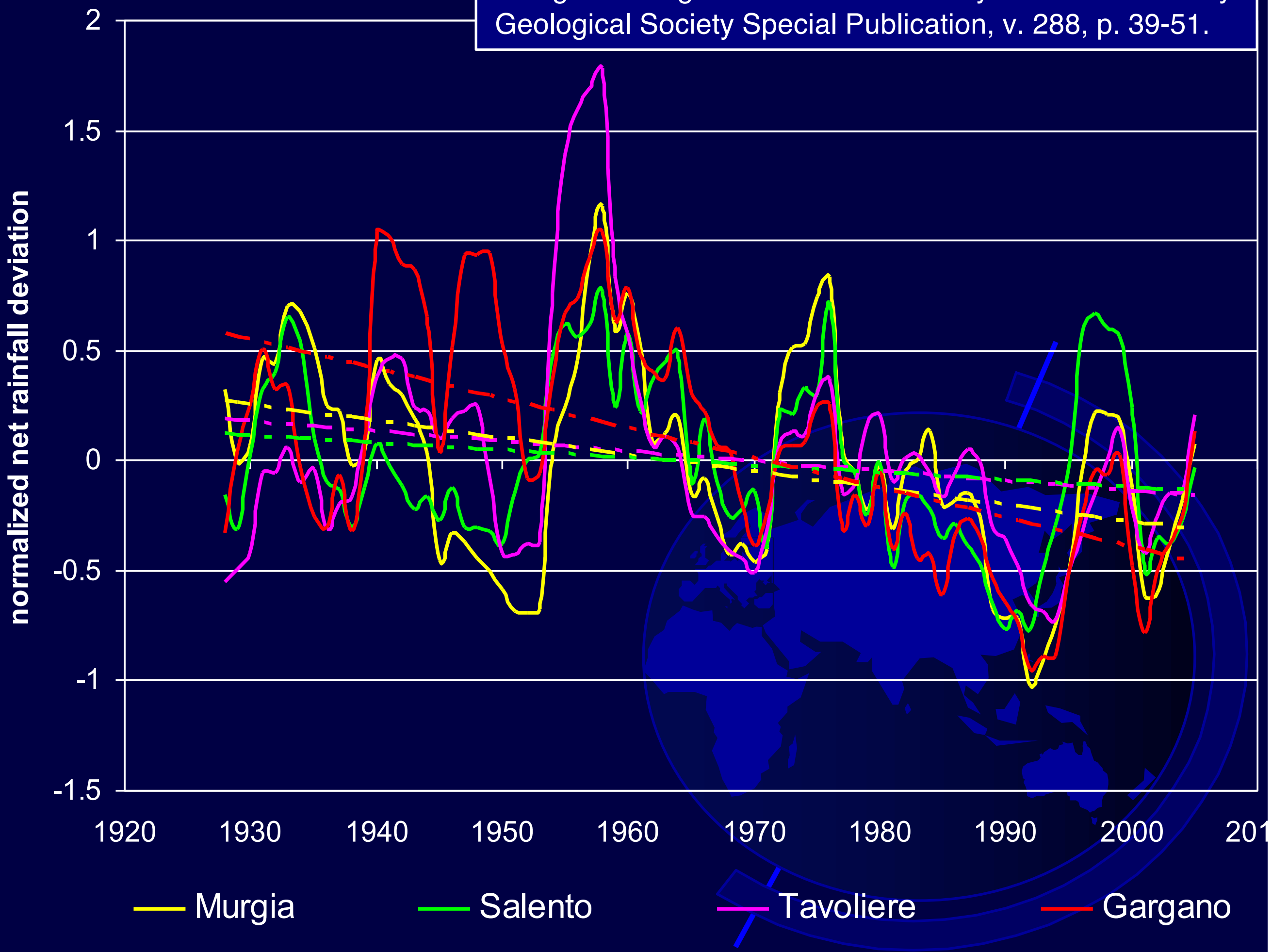
Apulian annual net rainfall and trend

Standardized 5-year moving average [(yr-Mean)/St.Dev]

the annual net rainfall ranged from 52 to 675 mm

- Negative net rainfall trend
  - –ranging from –3.52 to -0.23 mm/yr,
- In the whole period decrease from 22 to 42% of the mean net rainfall
  - – percentage range much higher than similar actual rainfall percentage range

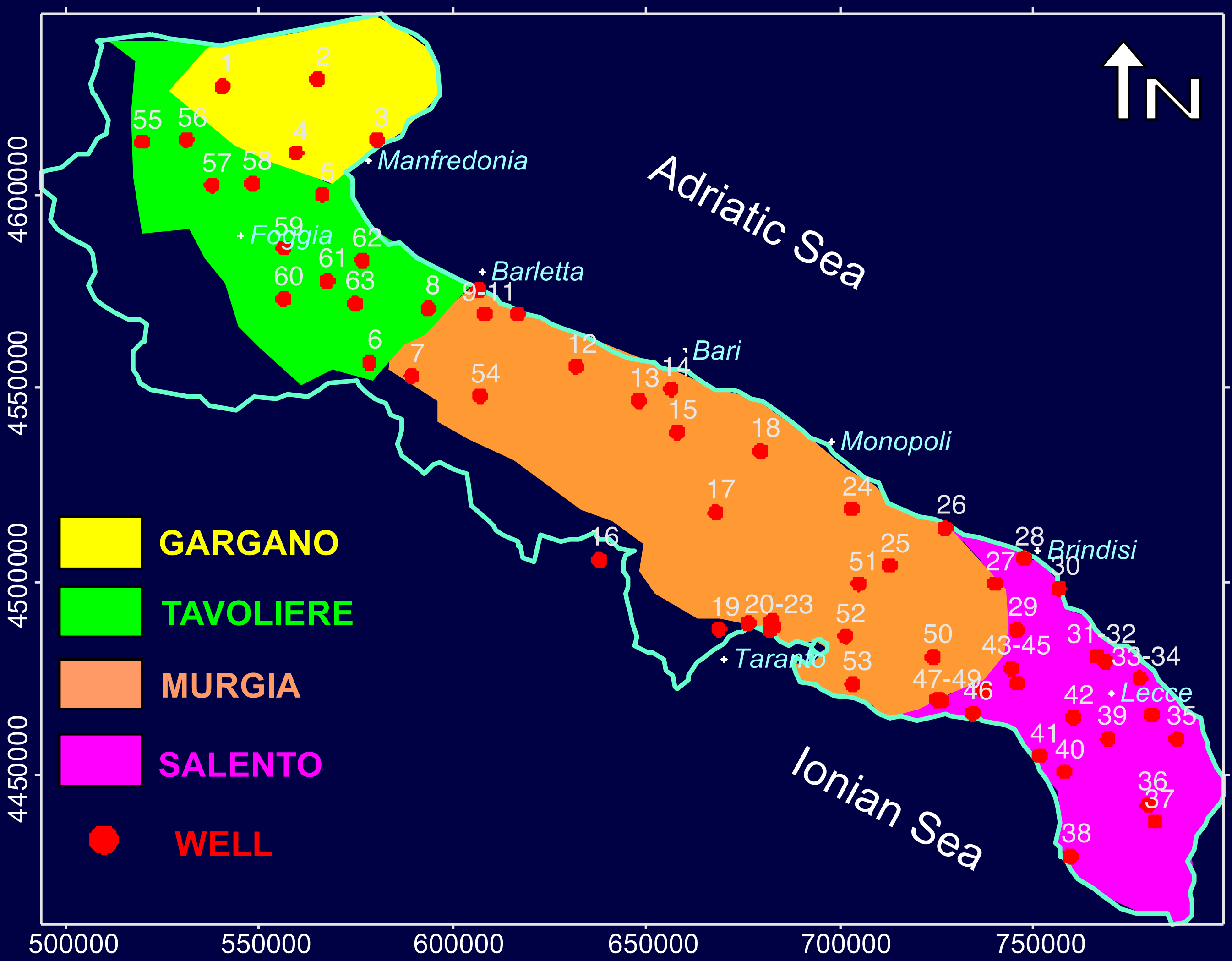
Polemio, M., and Casarano, D., 2008, Climate change, drought and groundwater availability in southern Italy: Geological Society Special Publication, v. 288, p. 39-51.



Monitoring network

- hundreds of wells and secondly springs were considered
- Study period from 1929 to 2008
- Monthly data if available
- Variables used:
  - salinity (**TDS**), **C**hloride ion **C**oncentration (**CC**), **Rainfall** (**R**) e atmospheric **T**emperature (**T**), chemical data (**CD**), piezometric head (**H**), spring yield (**Q**)
- "Time series" approach to low density and high frequency data
- Spatial and multi-temporal geostatistical approach to low frequency and high density data

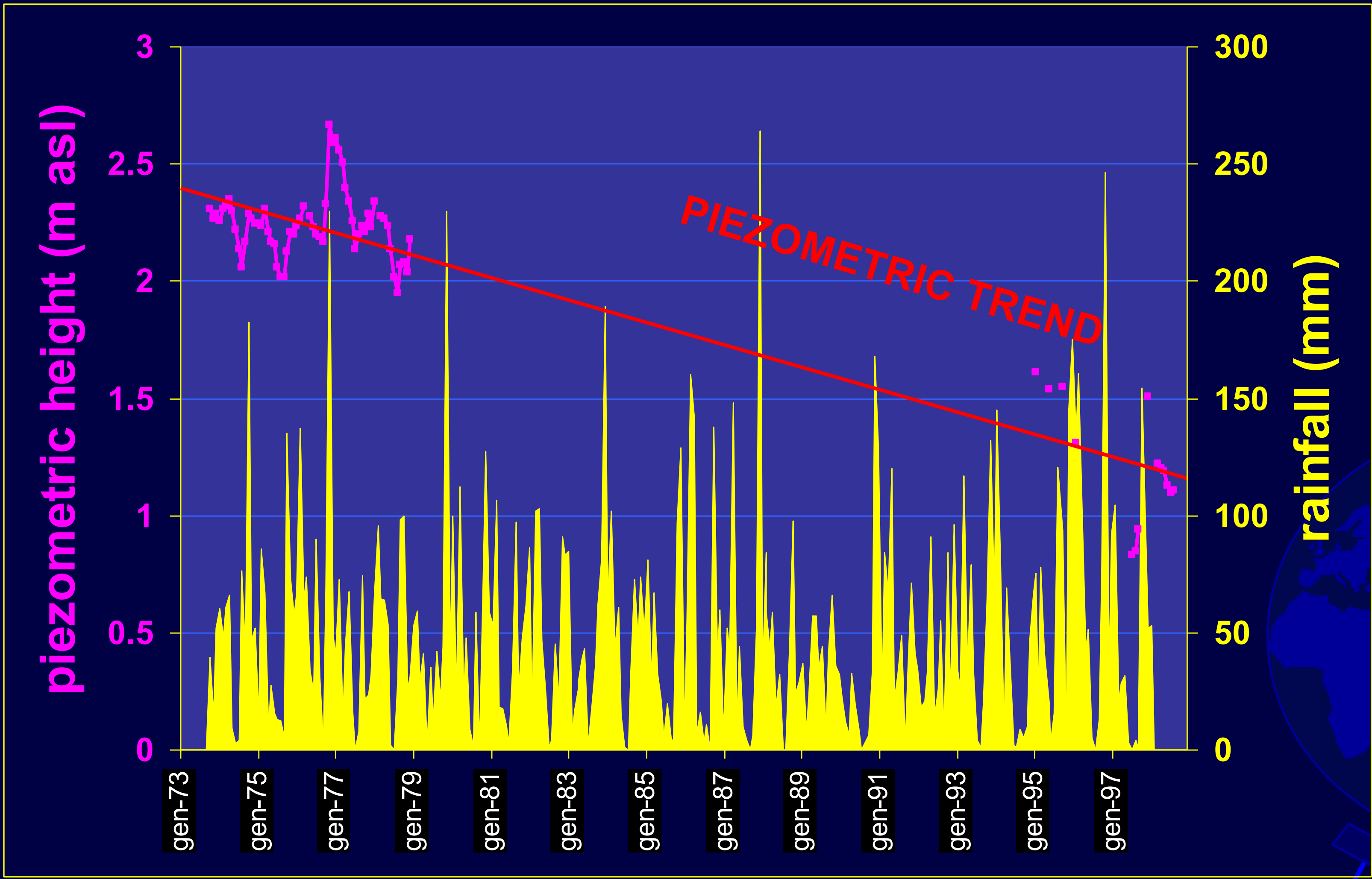
Wells and Time Series used for the Apulian piezometric trend analysis (1924-2003)



Polemio, M., Dragone, V., and Limoni, P. P., 2011, La disponibilità di acque sotterranee in Puglia negli ultimi 80 anni, *in* Polemio, M., ed., Le modificazioni climatiche e i rischi naturali: Bari, CNR IRPI, p. 201-204.

Polemio, M., Dragone, V., and Limoni, P. P., 2009, The piezometric stress in the coastal aquifers of a karstic region, Apulia, Italy, *in* Taniguchi, M., Dausman, A., Howard, K., Polemio, M., and Lakshmanan, E., eds., Sustainability of groundwater in highly stressed aquifers, Volume 329: Hyderabad, India, IAHS, p. 138-144.

MURGIA AND *SALENTO*: WN 27 (*BRINDISI*)
MONTHLY RAINFALL, PIEZOMETRIC HEIGHT AND TREND



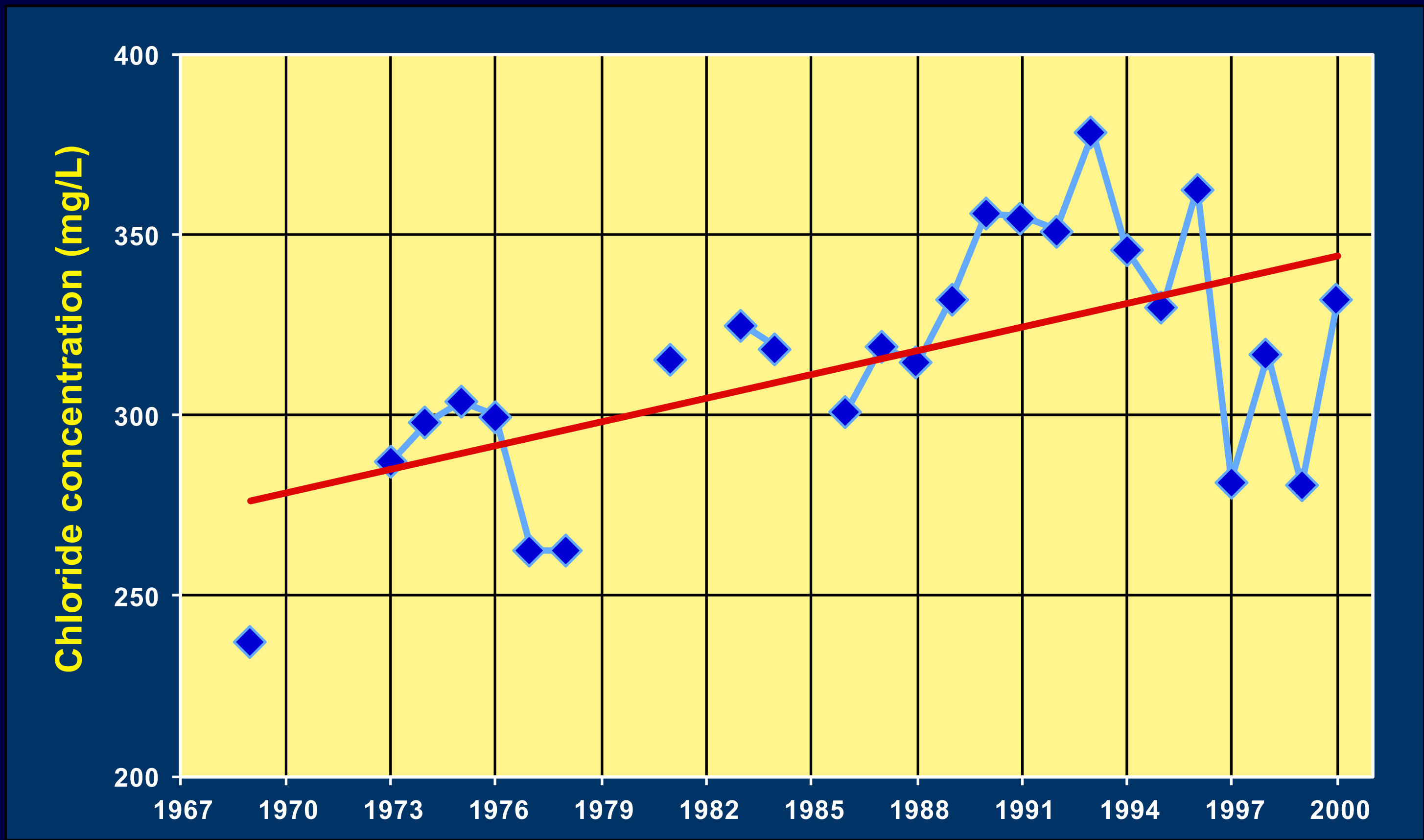
Polemio, M., Casarano, D., and Dragone, V., Trend termopluviometrici, siccità e disponibilità di acque sotterranee, *in* Proceedings Giornata di Studio: Metodi Statistici e Matematici per l'Analisi delle Serie Idrologiche, Napoli, 2004, p. 123-132.

Piezometric trend analysis summary

HS	DATA		AC(m/month) Minimum	More probable spatial trend
	From	to		
GARGANO	1975	1978	-0.034	?
TAVOLIERE	1929	2008	-0.060	Low decrease
MURGIA	1965	2008	-0.240	High decrease
SALENTO	1965	2008	-0.120	Decrease

Polemio, M., Dragone, V., and Limoni, P. P., 2011, La disponibilità di acque sotterranee in Puglia negli ultimi 80 anni, *in* Polemio, M., ed., Le modificazioni climatiche e i rischi naturali: Bari, CNR IRPI, p. 201-204.

Annual mean of chloride monthly data and trend
well 264 - Salento



Polemio, M., Dragone, V., and Limoni, P. P., L'evoluzione temporale dell'inquinamento salino negli acquiferi pugliesi, *in* Proceedings AVR05-Aquifer Vulnerability and Risk 2nd Int. Workshop, 4th Congress on the Protection and Management of Groundwater, Parma, 2005, p. 11.

Statistics and chloride concentration trend (Annual average of monthly data, mg/l)

HS	Murgia				Salento												
Well	302	303	305	306	28	264	93	155	14	59	18	278	201	175	150	245	292
Min	25.7	28.2	18.9	25.5	85.2	237.4	80.5	38.1	56.1	74.5	31.1	134.8	201.4	170.4	138.5	178.7	266.3
Mean	35.6	63.0	33.6	32.3	106.1	314.9	146.6	58.9	90.9	91.1	40.0	189.1	227.4	204.9	193.7	214.4	354.1
Max	40.4	80.9	57.8	51.1	141.3	378.4	238.2	258.5	147.1	104.9	65.7	236.1	261.3	244.9	273.4	230.3	390.5
BY	1973		1968	1975	1973	1969	1973	1980	1973	1971	1981	1973	1968	1969	1975	1981	1973
EY	1998			2000											2001	2000	
G	-0.08	-0.16	-0.58	0.01	1.53	2.19	5.72	3.16	2.56	0.06	0.08	-0.48	0.77	2.04	1.06	1.30	-0.76

BY) Beginning Year of observations

AF) End Yar of observations

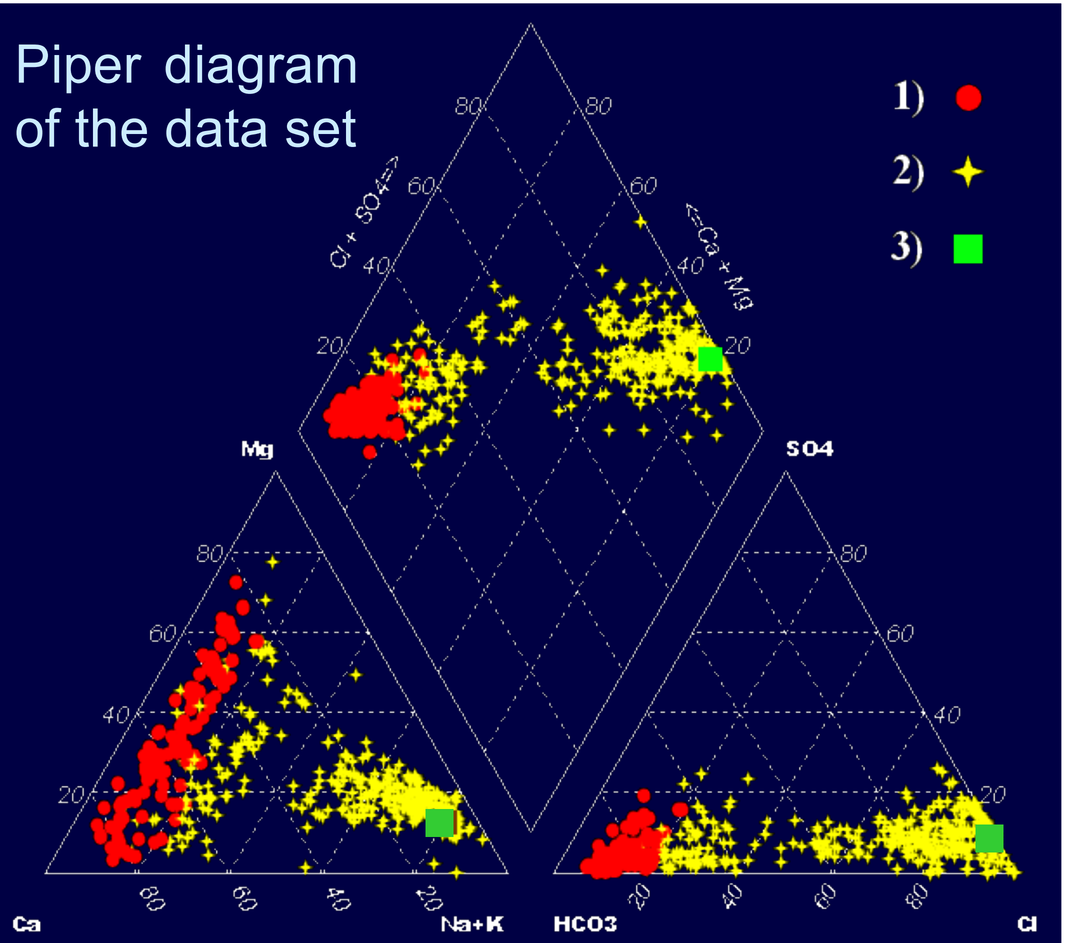
G) Gradient, linear trend (mg/(l yr), green for negative value

Polemio, M., Dragone, V., and Limoni, P. P., 2008, Salt contamination of Apulian aquifers: spatial and time trend, *in* Proceedings 19th SWIM & 3rd SWICA jointed meeting, Cagliari, 24-29/09/2006 2008, p. 115-121

The basic or threshold criterion

Polemio, M., Dragone, V., and Limoni, P. P., 2009, Monitoring and methods to analyse the groundwater quality degradation risk in coastal karstic aquifers (Apulia, Southern Italy): Environmental Earth Sciences (formerly Environmental Geology), v. 58, no. 2, p. 299-312.

Piper diagram of the data set



1) Fresh groundwater and variable % of seawater (group S); 2) Pure fresh groundwater (Group F); 3) sea water.

- Need of a simple criterion, like as "absence-presence" of the salt groundwater degradation, or threshold approach
- On the basis of the of complete chemical analyses of more than 500 groundwater samples, the simplest grouping differentiated 2 groups:
  - absence or pure fresh groundwater, group F, "fresh", including water types Ca-HCO3, Ca-Mg-HCO3 and Mg-Ca-HCO3, TDS mean, standard deviation and 75th percentiles equal to, respectively, 0.41, 0.13, and 0.47 g/L. 75% percentile or the mean value plus a standard deviation= TDS≤0.5 g/L,
  - presence or remaining water types, (group S, "saline"), fresh groundwater mixed with variable percentages of seawater= TDS>0.5 g/L

Spatial and multi-temporal approach:

protected, vulnerable and hit areas to/from GDSI

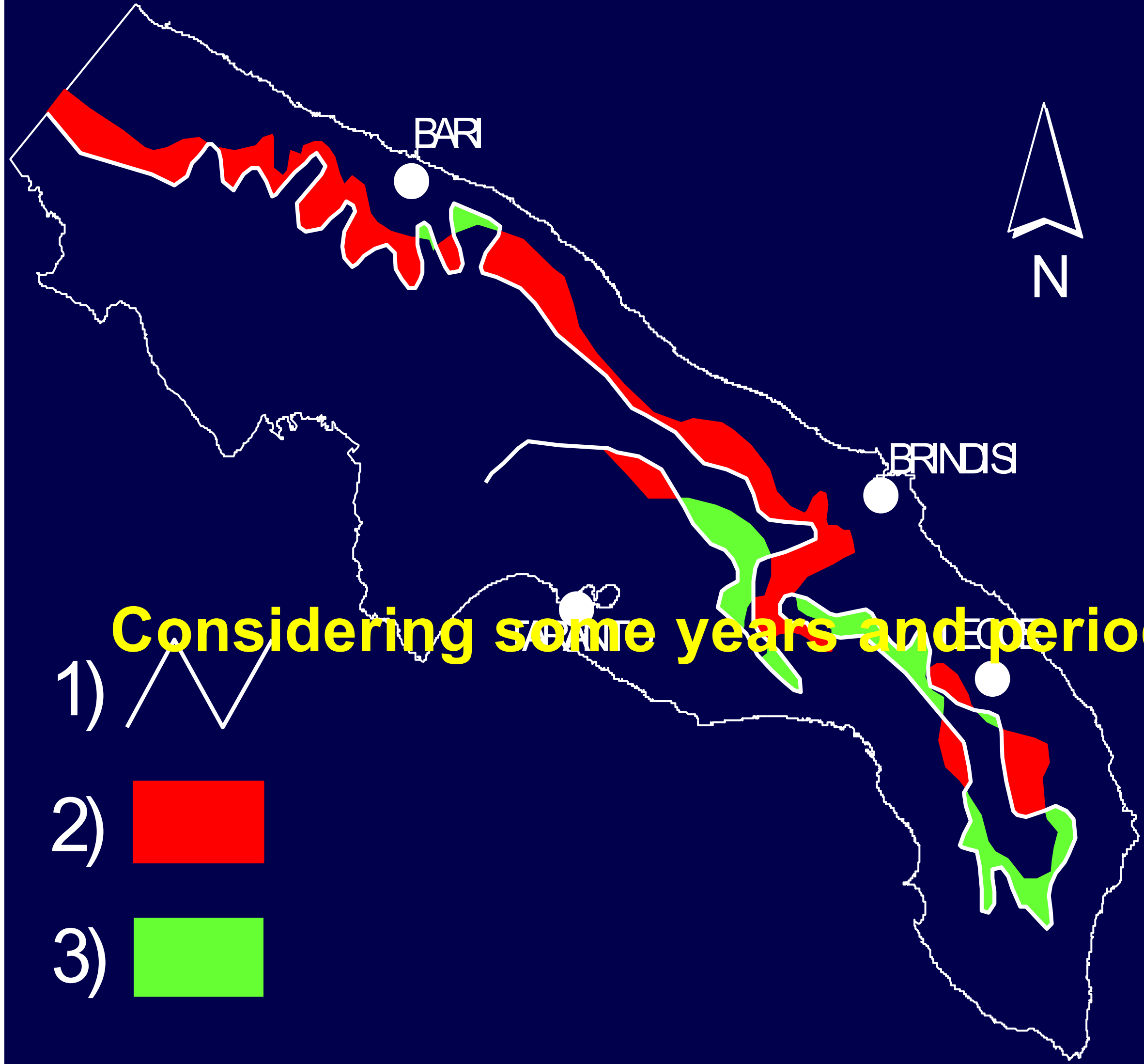
To characterise the spatial trend of salt pollution due to seawater intrusion it can be useful to define the

Reference Salt Contour Line (RSCL)

simply considering the threshold between pure fresh groundwater and that contaminated by seawater intrusion, about equal to 0.5 g/L, **to use with each available data and wells (also in the past)….**

Polemio, M., Dragone, V., and Limoni, P. P., 2009, Monitoring and methods to analyse the groundwater quality degradation risk in coastal karstic aquifers (Apulia, Southern Italy): Environmental Earth Sciences (formerly Environmental Geology), v. 58, no. 2, p. 299-312.

Spatial modification of RSCL (0.5 g/l)
1989 referred to 1981



Considering some years and periods from 1981 to 2003

from 1981 to 1989

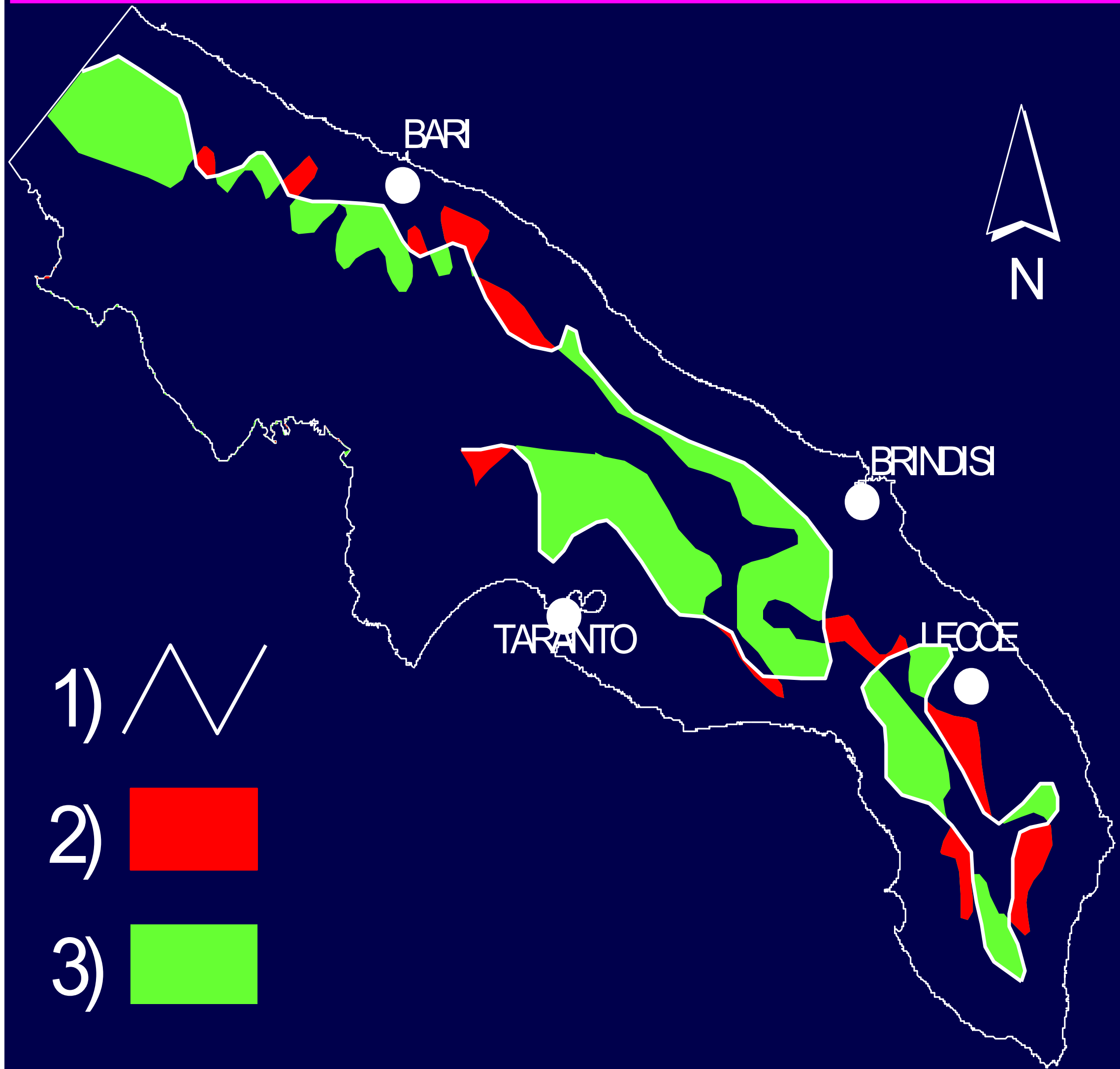
1) 1989 RSCL

2) RSCL moves landward

3)RSCL moves seaward

Polemio, M., Dragone, V., and Limoni, P. P., L'evoluzione temporale dell'inquinamento salino negli acquiferi pugliesi, *in* Proceedings AVR05-Aquifer Vulnerability and Risk 2nd Int. Workshop, 4th Congress on the Protection and Management of Groundwater, Parma, 2005, p. 11.

Spatial modification of RSCL (0.5 g/l)
1997 referred to 1989



From 1989 to 1997

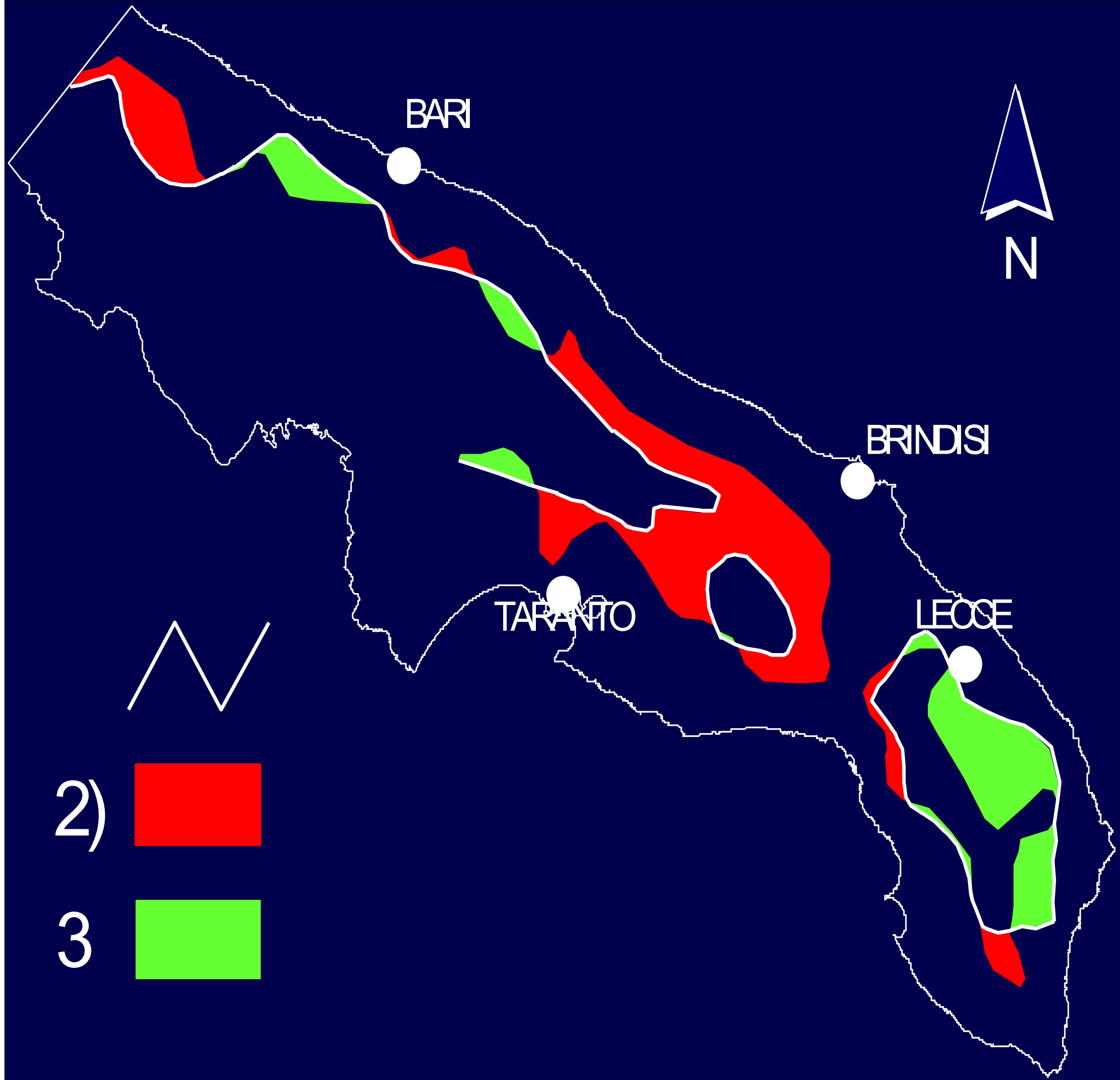
1) ***1997 RSCL***

2) ***RSCL moves landward***

3) ***RSCL moves seaward***

Polemio, M., Dragone, V., and Limoni, P. P., L'evoluzione temporale dell'inquinamento salino negli acquiferi pugliesi, *in* Proceedings AVR05-Aquifer Vulnerability and Risk 2nd Int. Workshop, 4th Congress on the Protection and Management of Groundwater, Parma, 2005, p. 11.

Spatial modification of RSCL (0.5 g/l)
2003 referred to 1997



From 1997 to 2003

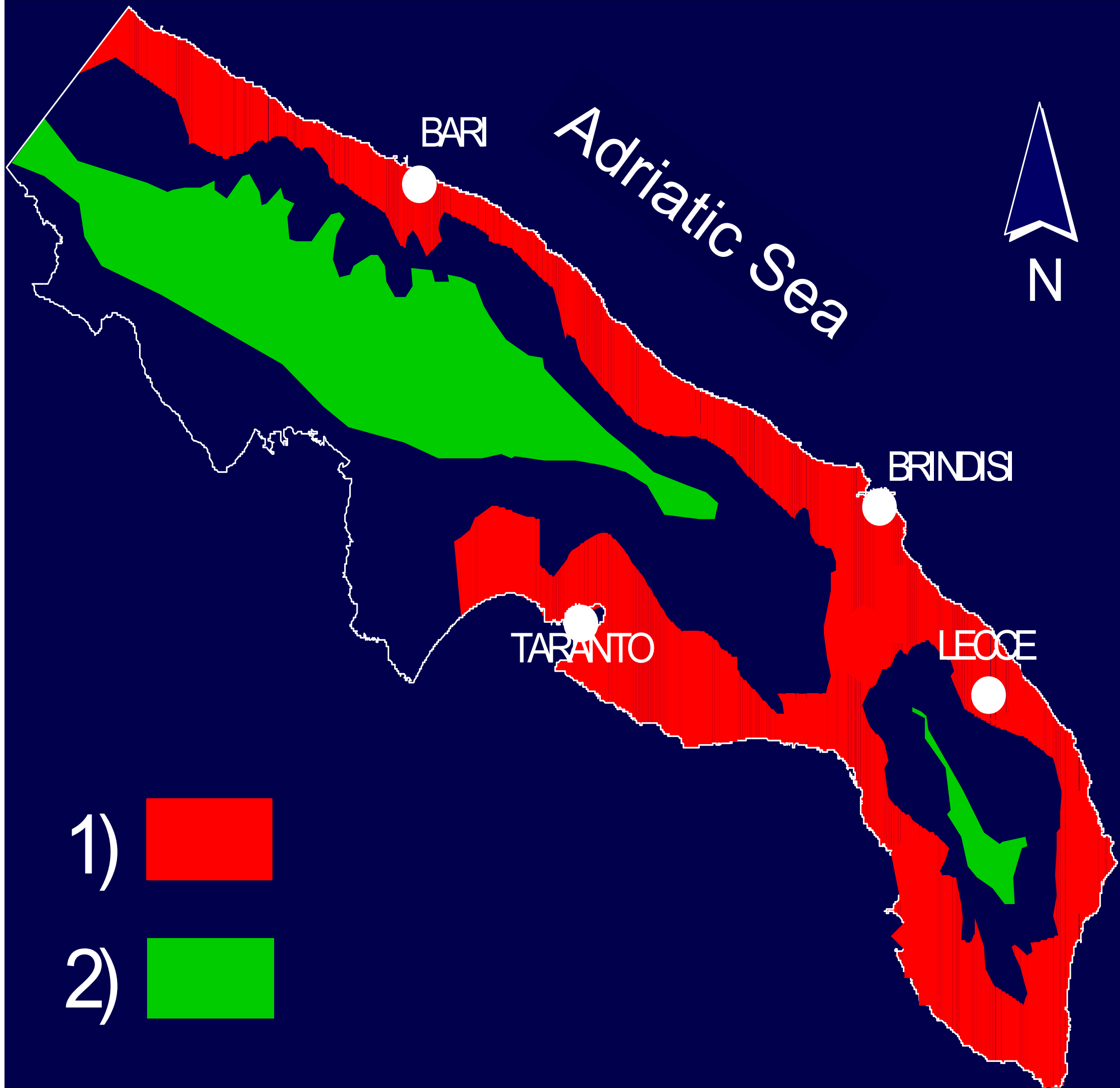
1) 2003 RSCL

2) RSCL moves landward

3) RSCL moves seaward

Polemio, M., Dragone, V., and Limoni, P. P., L'evoluzione temporale dell'inquinamento salino negli acquiferi pugliesi, *in* Proceedings AVR05-Aquifer Vulnerability and Risk 2nd Int. Workshop, 4th Congress on the Protection and Management of Groundwater, Parma, 2005, p. 11.

GDSI spatial trend: Spatial multi-temporal modification of RSCL (0.5 g/l, 1981-2003)



In the whole period

1) TDS always >0.5 g/l

2) TDS always <0.5 g/l

Numerical model approach

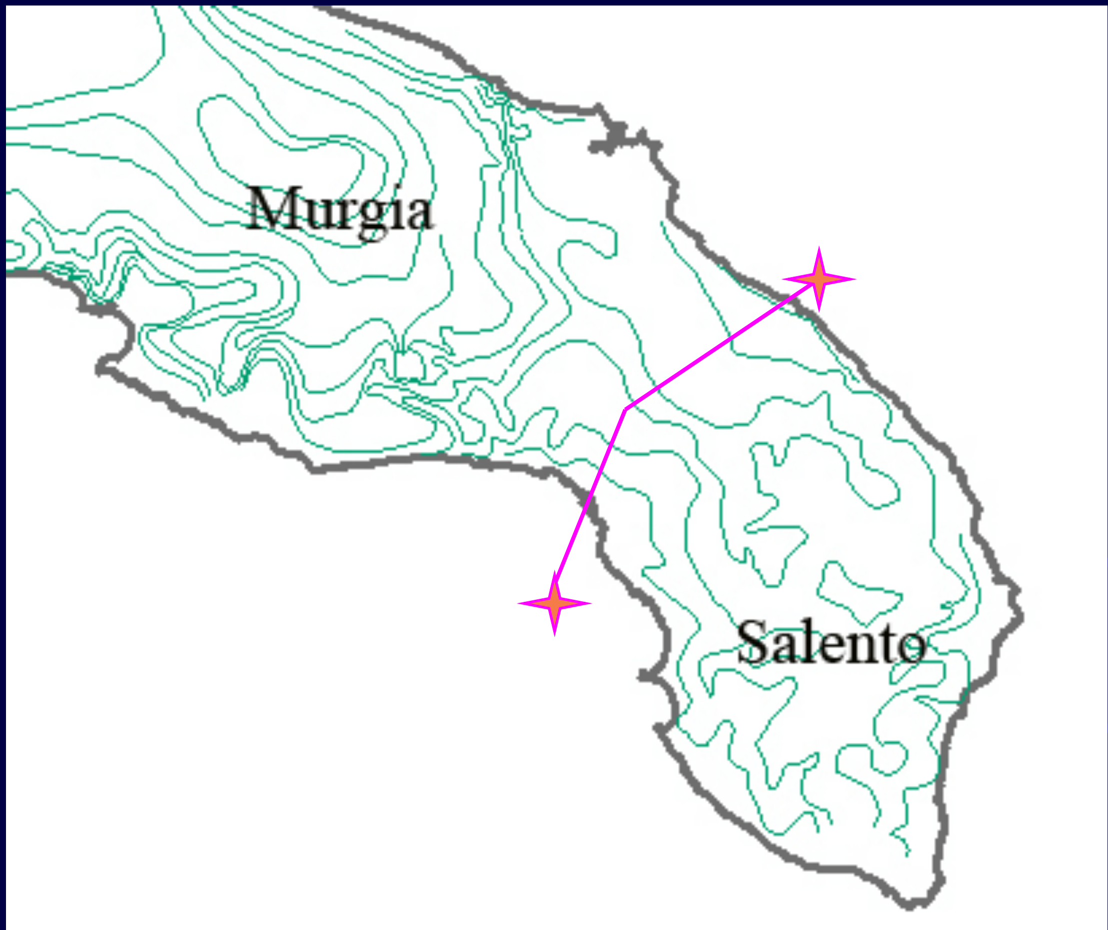
Romanazzi, A., and Polemio, M., 2013, Modelling of coastal karst aquifers for management support: Study of Salento (Apulia, Italy): Italian Journal of Engineering Geology and Environment, v. 13, no. 1, p. 65-83.

- to show the capability of large-scale numerical model in the management of groundwater developing forecast scenarios to evaluate the impact of climate change on groundwater resources.

Qualitative and quantitative groundwater changes from 1930 to 2060 were modelled based on the effects of climate change, sea level rise and changes in sea salinity.

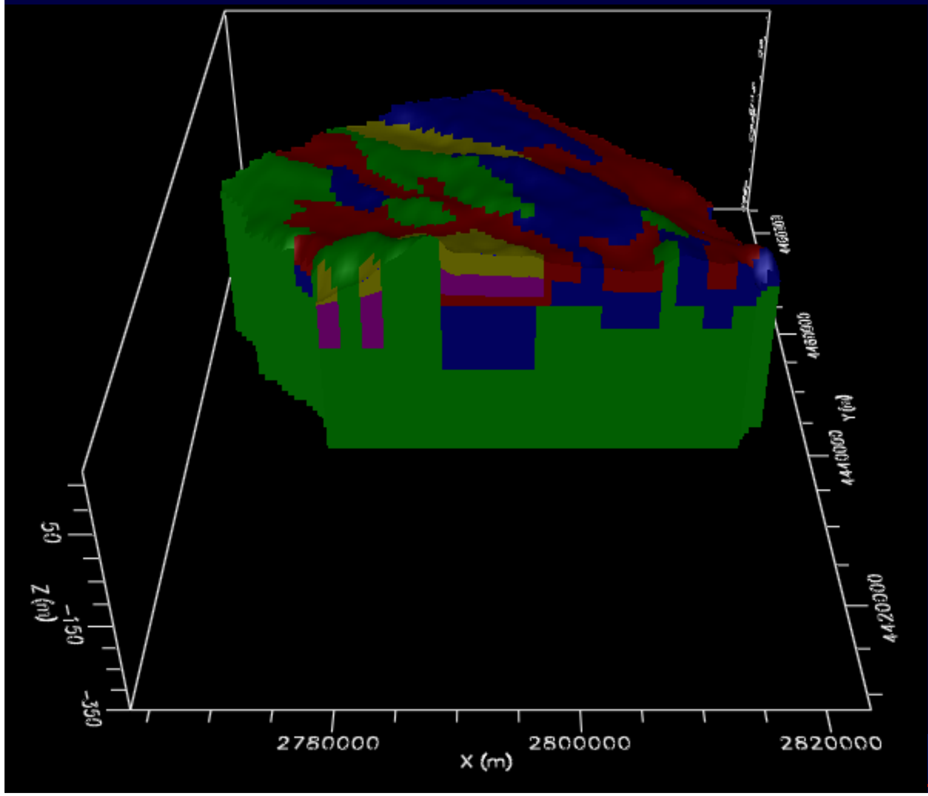
Modelling test area: Salento

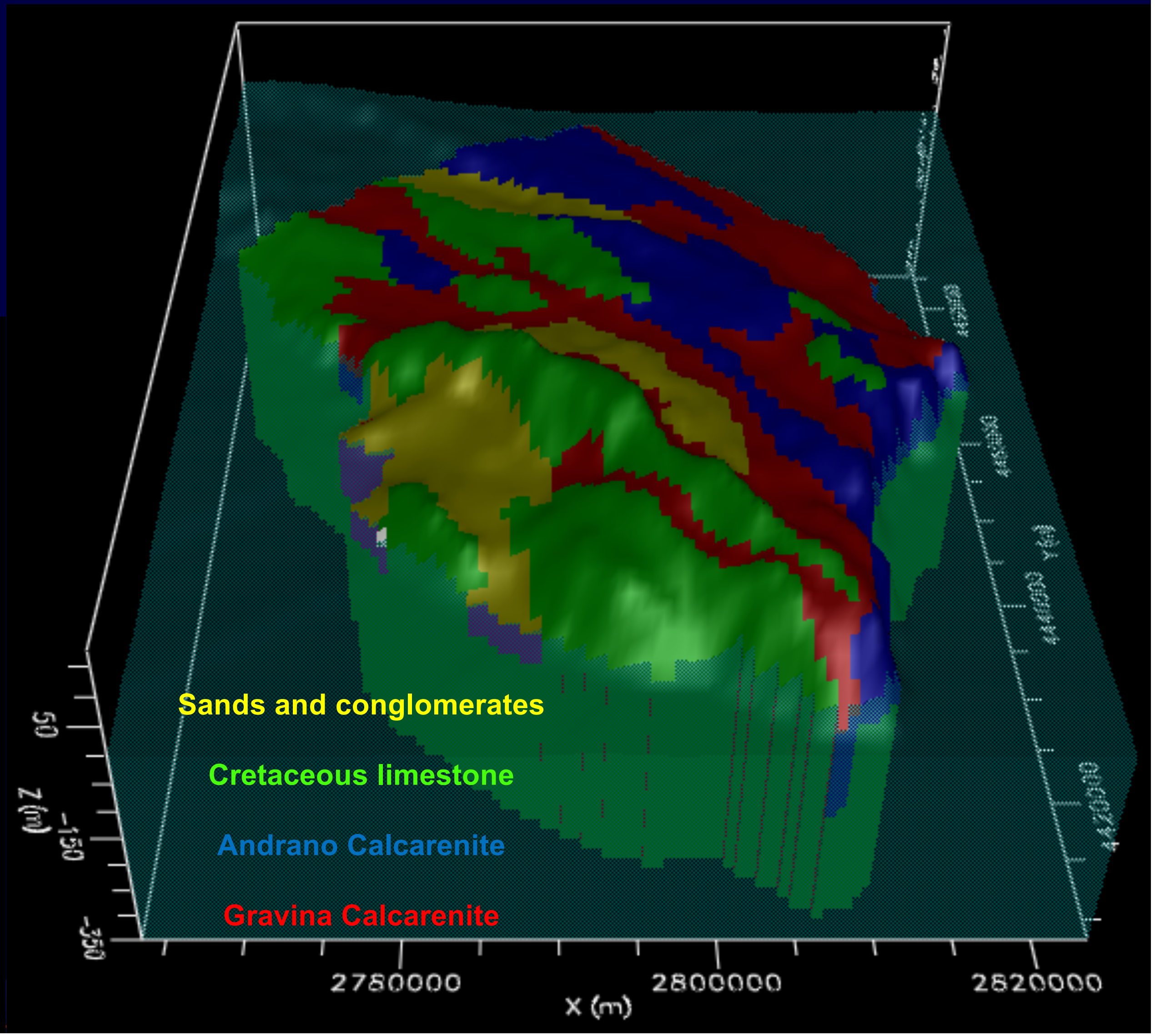
- The highest risks due to seawater effects are observed in Salento
- The boundary was defined using the coastline and the potenziometric surface



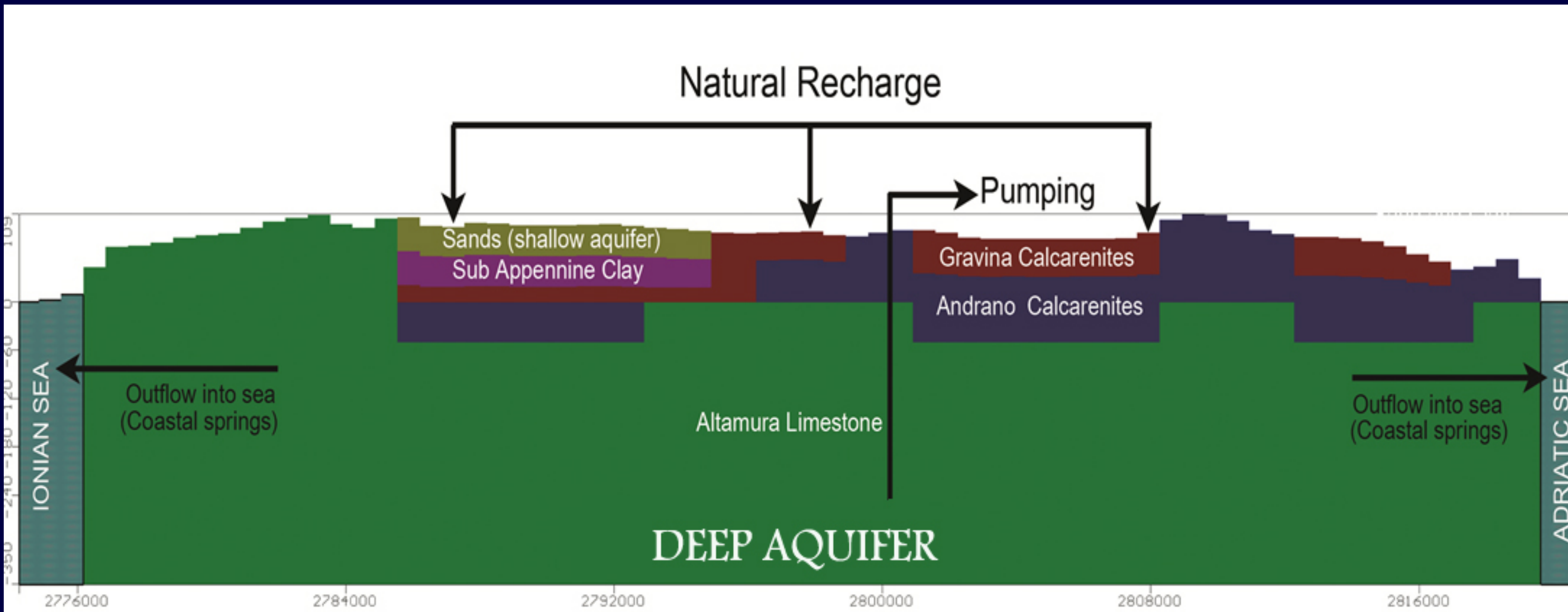
3D modelling of hydrogeological complexes

Romanazzi, A., Gentile, F., and Polemio, M., 2015, Modelling and management of a Mediterranean karstic coastal aquifer under the effects of seawater intrusion and climate change: Environmental Earth Sciences, v. 74, no. 1, p. 115-128.





Conceptual model



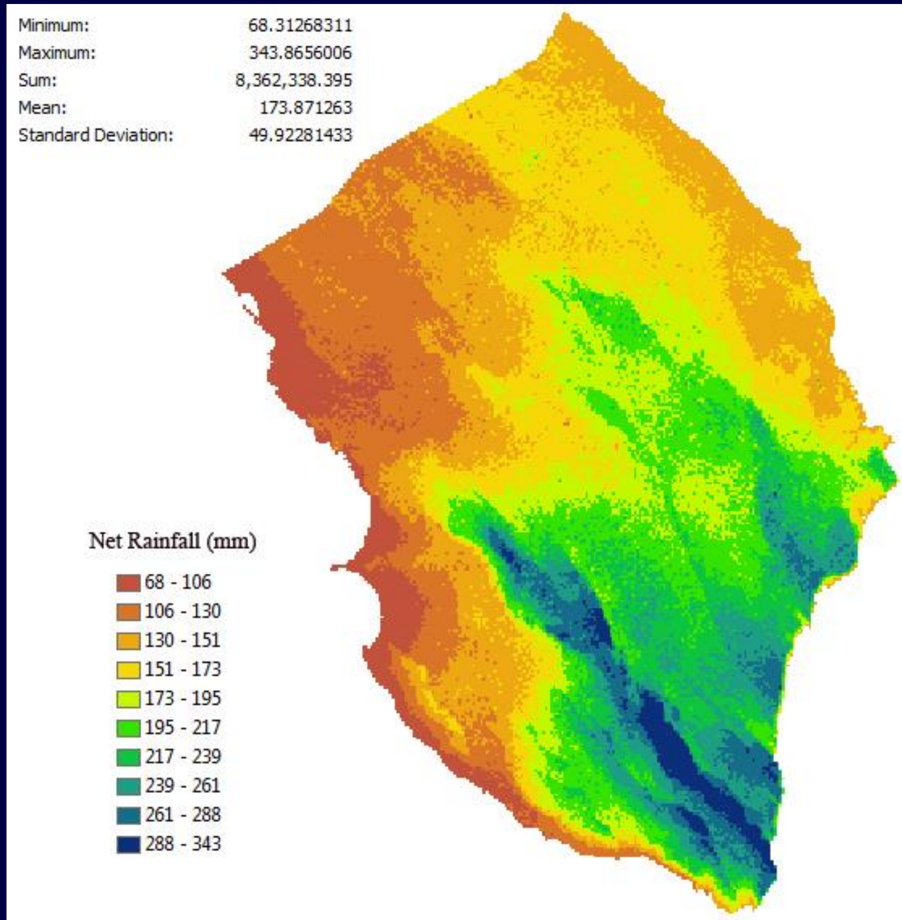
Romanazzi, A., Gentile, F., and Polemio, M., 2015, Modelling and management of a Mediterranean karstic coastal aquifer under the effects of seawater intrusion and climate change: Environmental Earth Sciences, v. 74, no. 1, p. 115-128.

Climate and net rainfall (steady period, 1925-1975)

- Study areas 2300 km^2, from 0 to 214 m asl
- Coastal length 175 km
- 16 climatic gauges
- GIS: 150-meter cells were used
- Altitude (DEM) and distance from the Adriatic Sea were considered

Annual values

- Temperature: from 15.5 to 17.5 C° (mean: 16.6 C°)
- Rainfall: from 544 to 946 mm (mean: 727 mm)
- Real evapotranspiration: from 476 to 601 mm (mean: 553 mm)
- Net rainfall: from 68 to 343 mm (mean: 173 mm)



Mean annual recharge equal to 150 mm (10.6 m^3/s)

Forecast Scenarios: **2000-19, 2020-39, 2040-60**

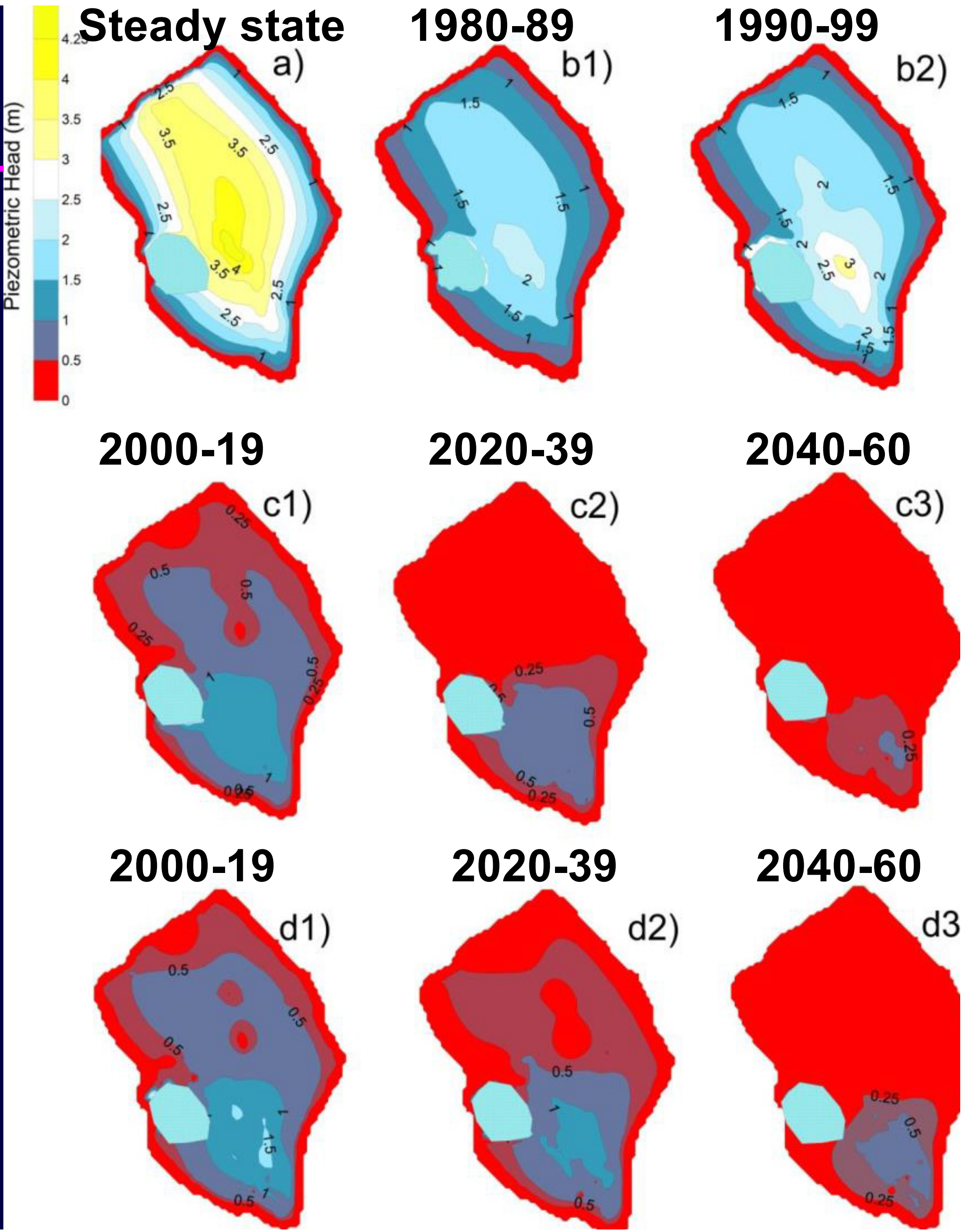
Piezometric results

Romanazzi, A., Gentile, F., and Polemio, M., 2015, Modelling and management of a Mediterranean karstic coastal aquifer under the effects of seawater intrusion and climate change: Environmental Earth Sciences, v. 74, no. 1, p. 115-128.

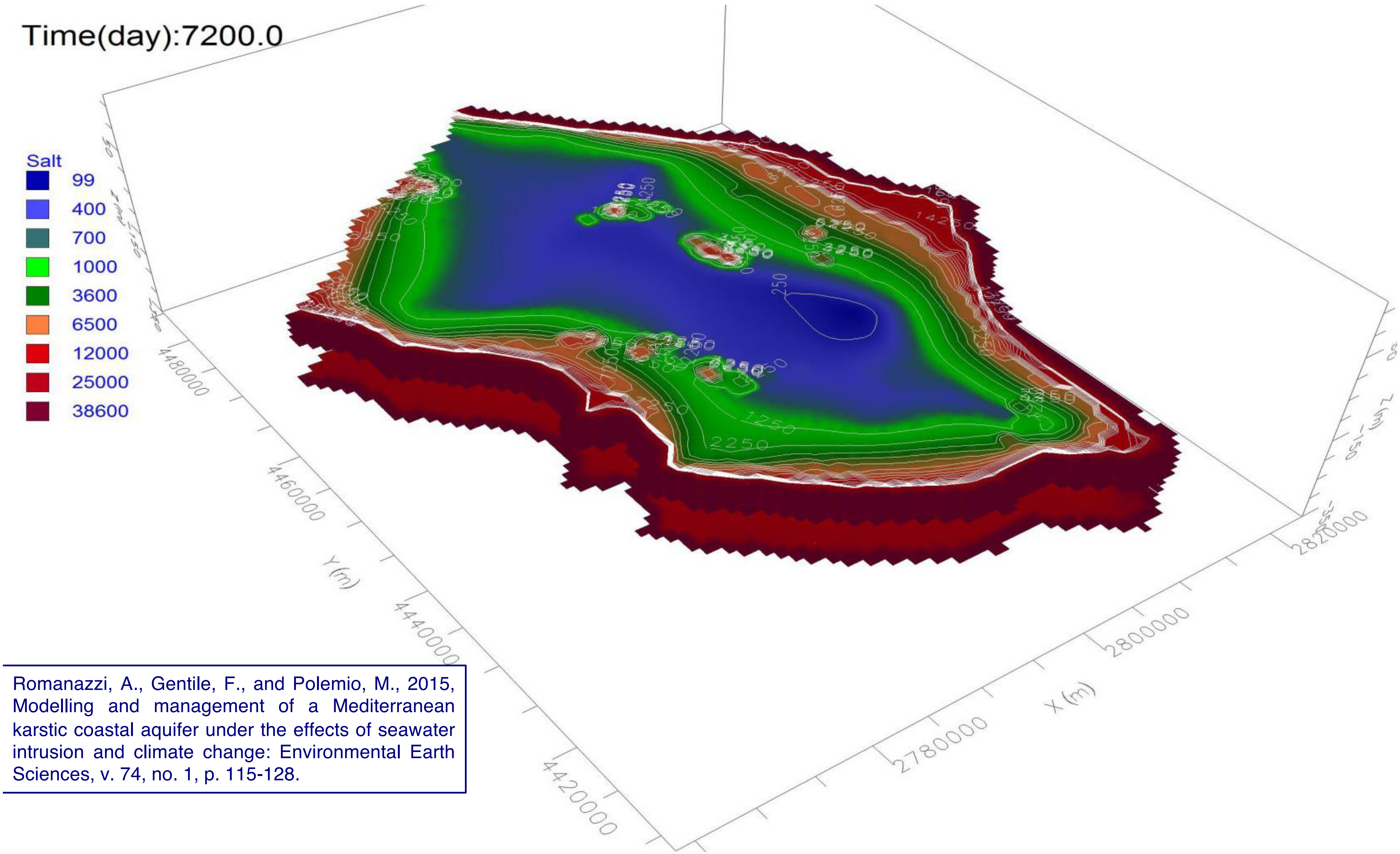
First scenario

- **steady drinking discharge**
- **increasing irrigation discharge**

Second hypothesis
Steady irrigation discharge

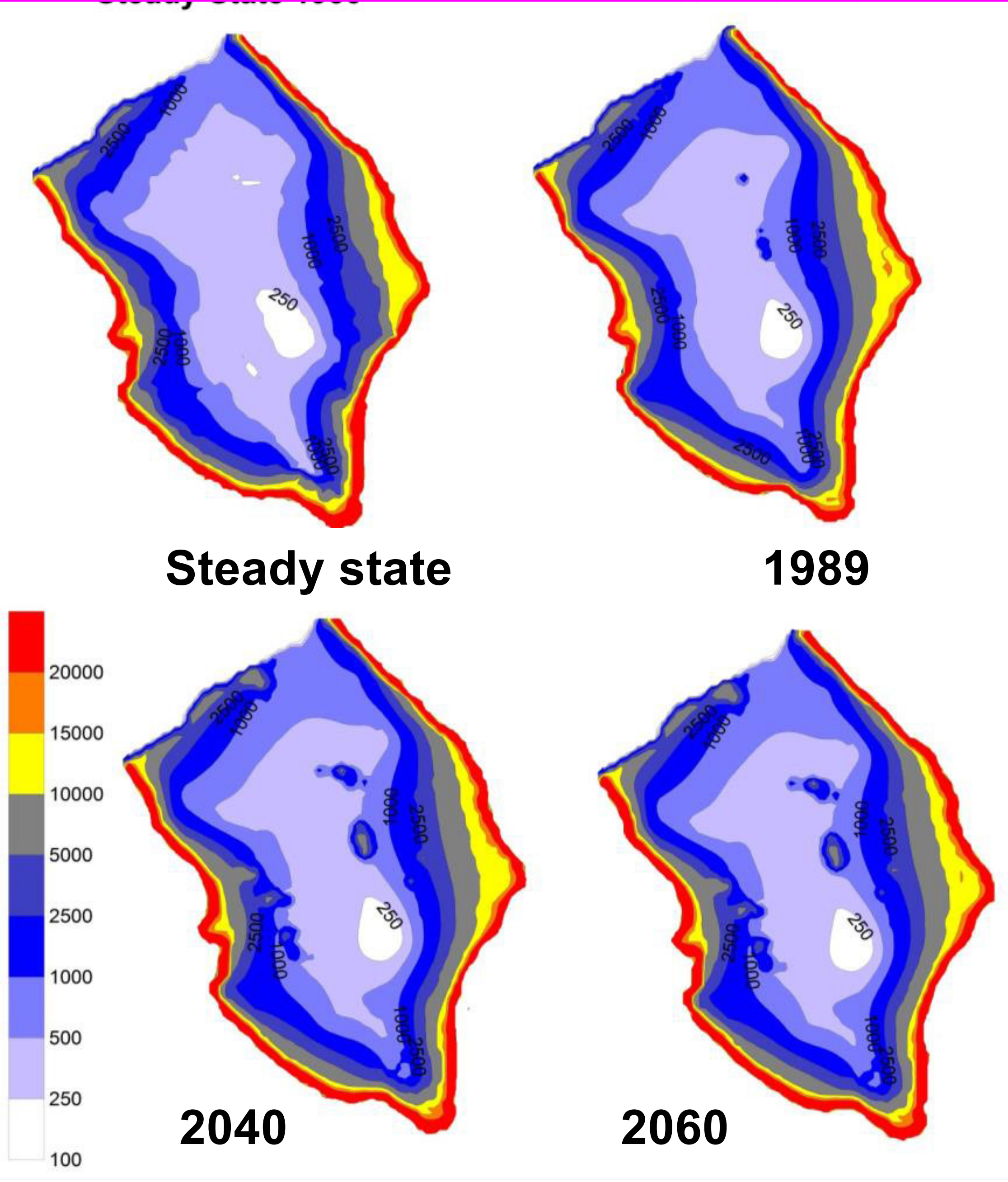


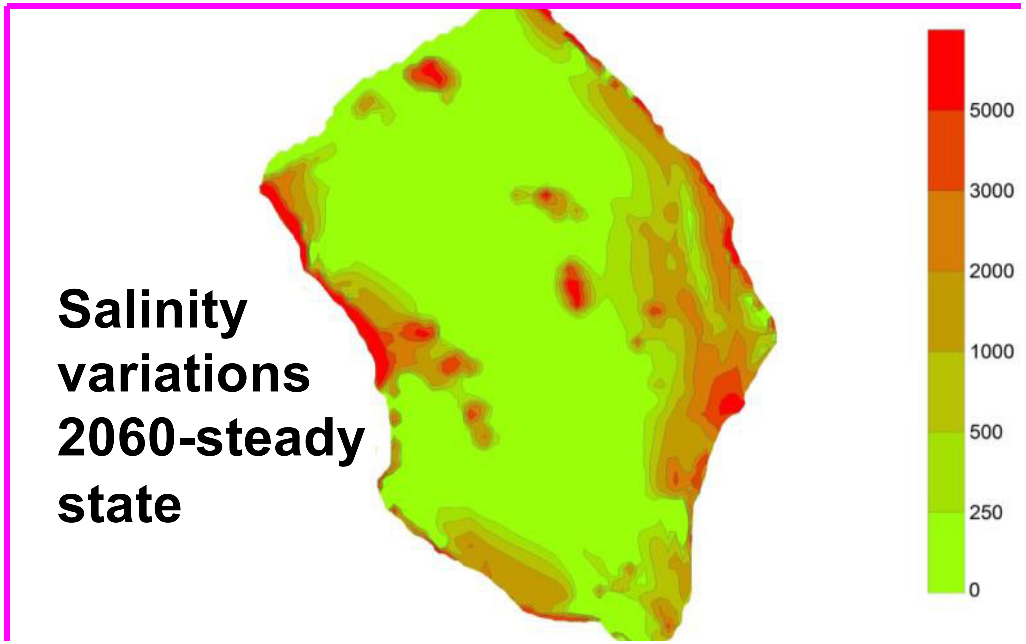
Seawater Intrusion Simulation 2040-2060 (mg/l)



Romanazzi, A., Gentile, F., and Polemio, M., 2015, Modelling and management of a Mediterranean karstic coastal aquifer under the effects of seawater intrusion and climate change: Environmental Earth Sciences, v. 74, no. 1, p. 115-128.

Salinity maps (mg/l) from -65 to -50 m asl (II hypothesis)





Main conclusions

- Both future scenarios are unsustainable
- Well design should be improved
  - Overlapping well effects should be considered
- The drinking use should be better designed
  - distributed on larger areas
  - as much as possible, reduced
- Adaptation measures are necessary, focusing on agricultural uses
- The artificial recharge should be pursued
- The use of brackish spring water should be pursued
- More efforts should be realised to test and optimise management proposals to be adopted by public authorities

For more details, all useful papers can been downloaded from the web site of the Hydrogeology Research Group http://hydrogeology.ba.irpi.cnr.it/

Thank you for the attention!