Monitoring and management of coastal karstic aquifers

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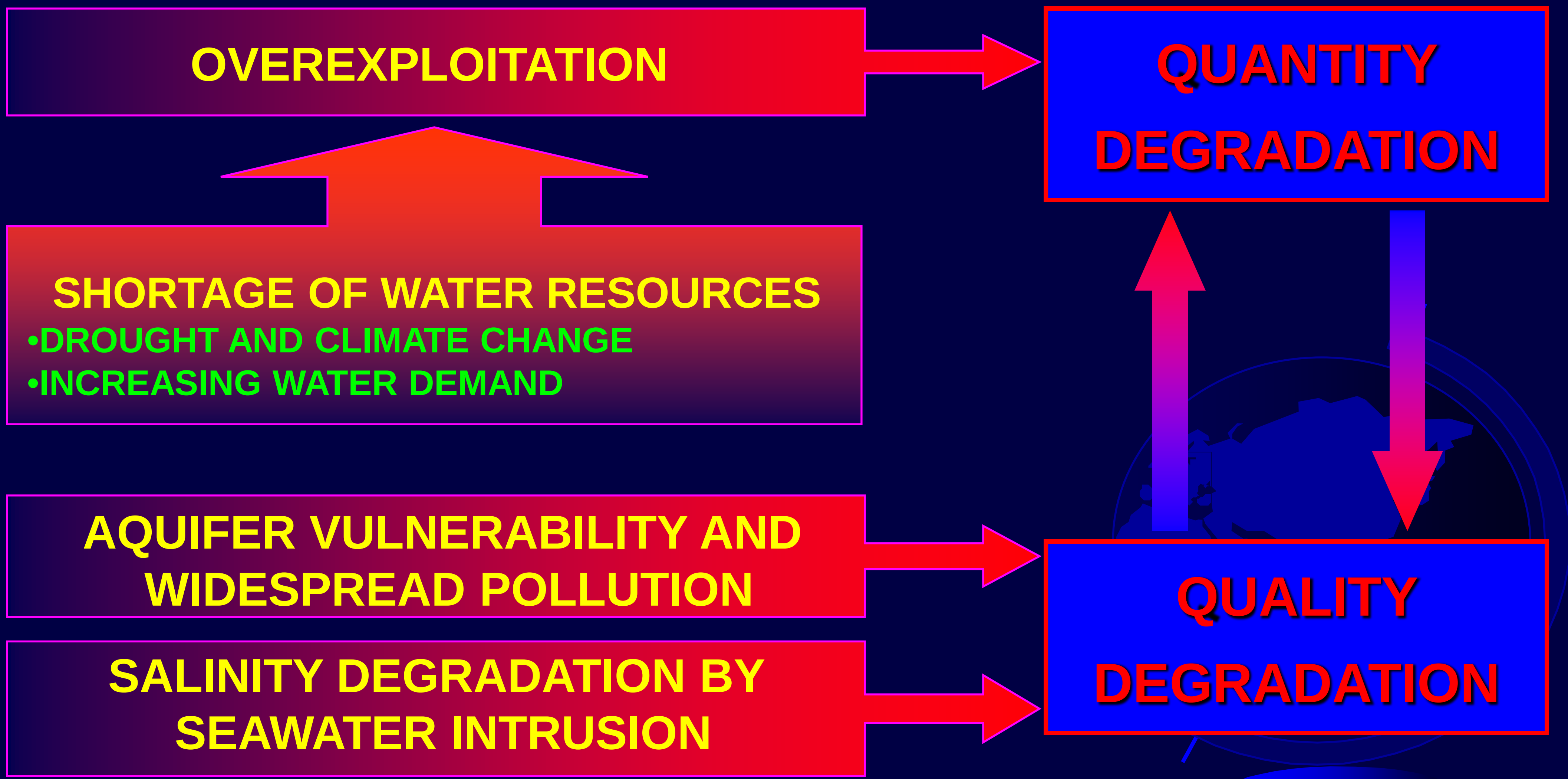
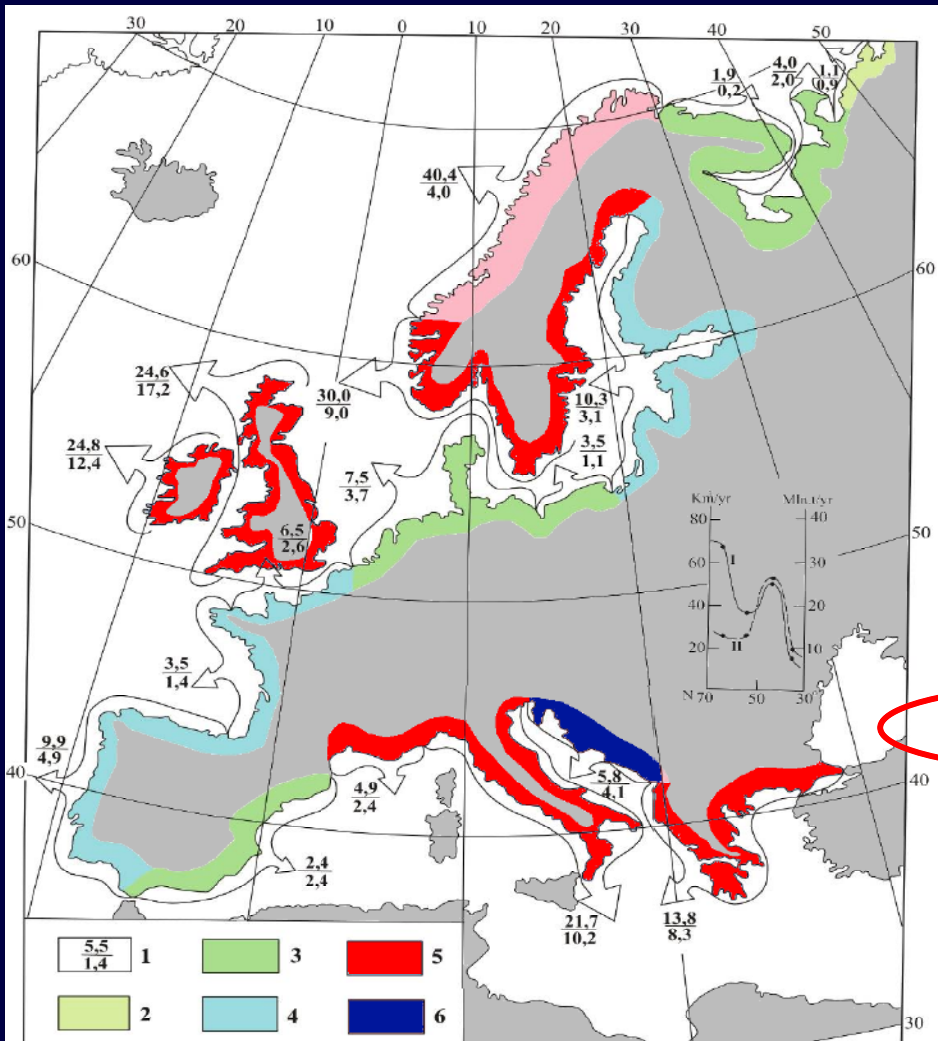
Quantity and quality degradation of Groundwater Resources



Schematic map of sub-marine groundwater discharge in Europe



1a) Numerator: discharge (km^3/year)

1b) Denominator: solid residue of discharge (10^6 t/year)

Underground discharge (l/(sec·km^2)):

2) 0.5-1.0,

3) 1.0-3.0,

4) 3.0-5.0,

5) 5.0-7.0,

6) 10.0-20.0.

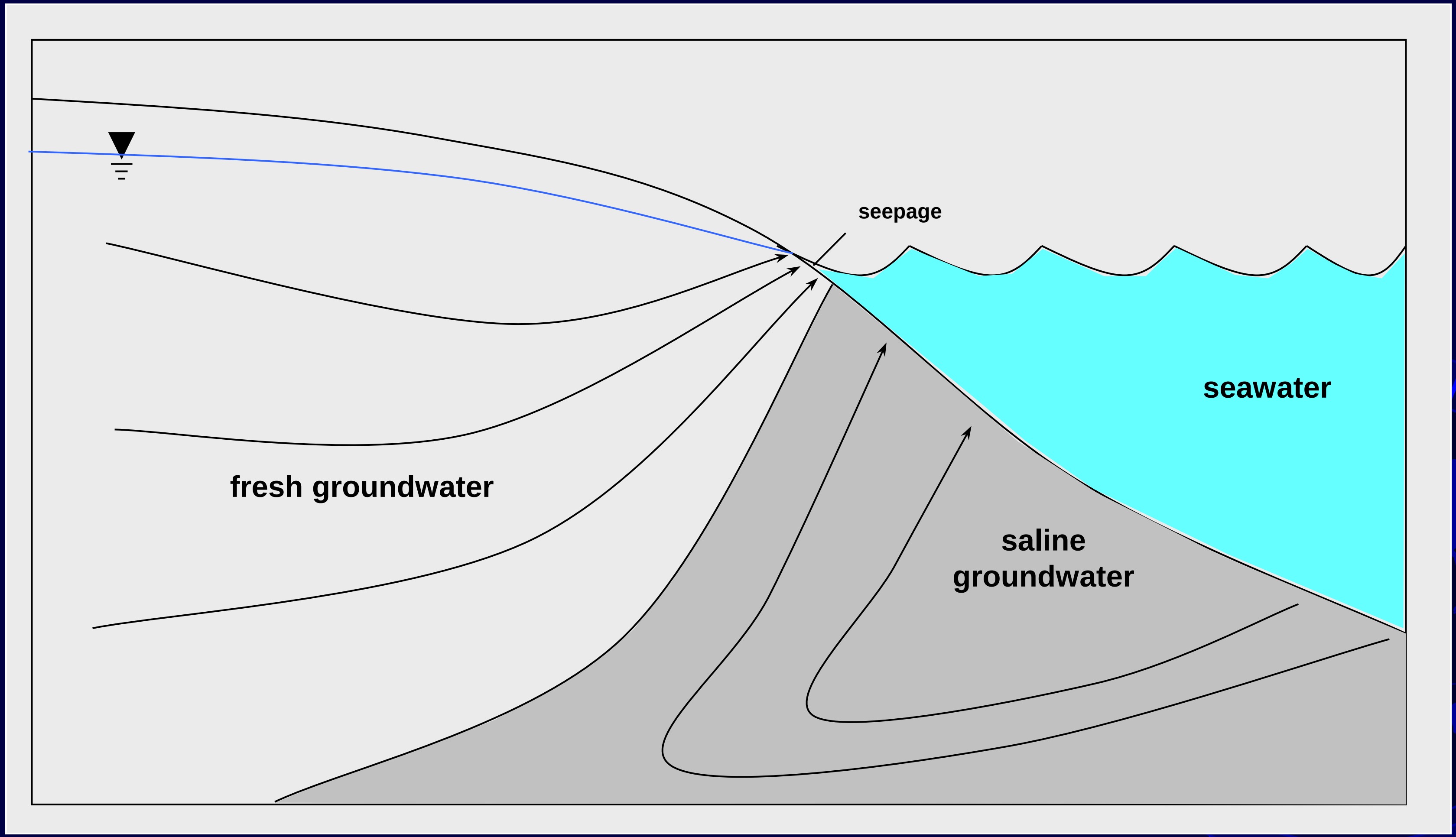
56.7 l/s*Km^2 for Salento

Zektser & Dzhamalov, 2007

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

A simple coastal aquifer

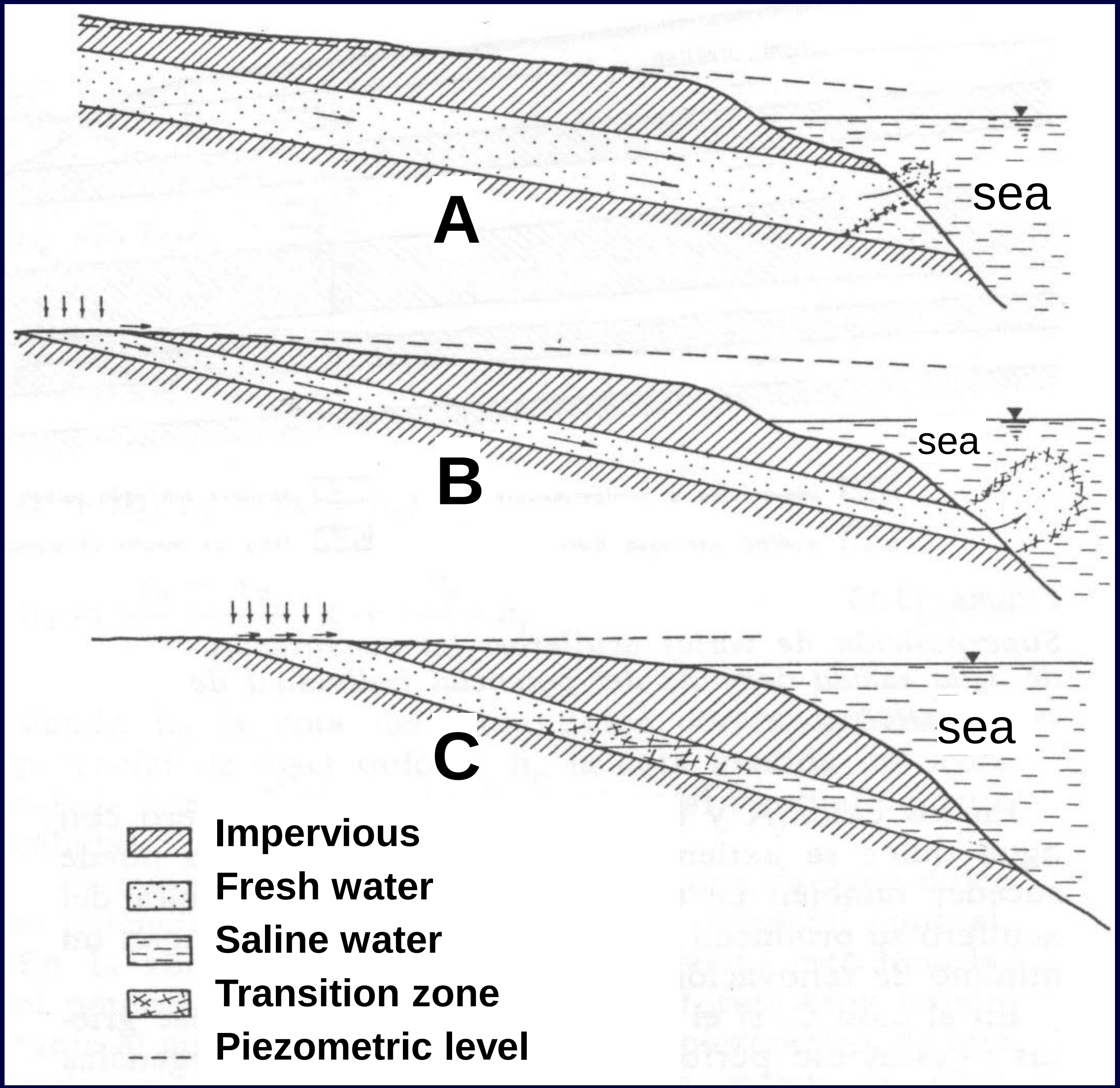


Coastline during previous glacial maximum (22 ka BP)

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)

Management approaches
for coastal groundwater resources

COMPLEXITY & EFFECTIVNESS

1. Engineering approach

The engineering approach is realised on local or site scale controlling the salinization of discharged fresh groundwater, by optimising well discharges:

- ✓ **well design optimisation**
- ✓ **artificial recharge**
- ✓ **Hydraulic (injection or extraction) or physical barriers**
- ✓ **salt water preventive well (single discharging and injecting well)**
- ✓ **Tunnels and shafts**

2.Discharge management approach

This approach should involve at least an entire coastal aquifer, on a regional scale. It should generally be applied by water authorities defining rules concerning groundwater utilisation and well characteristics and discharge.

- ✓ **monitoring and global discharge effect assessment**
- ✓ **numerical modelling**

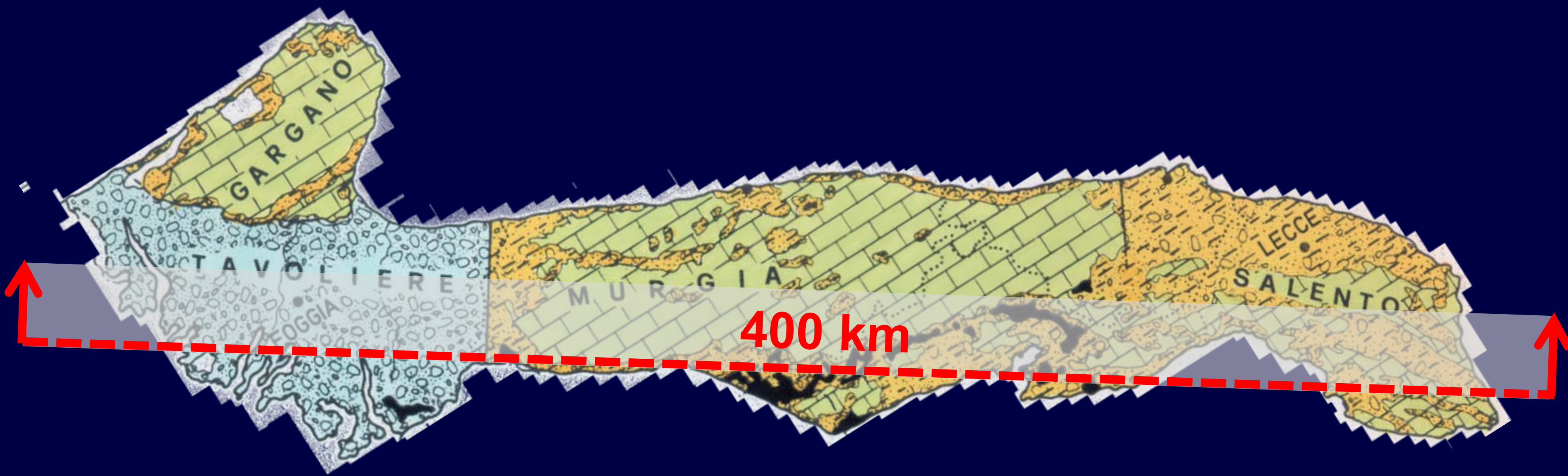
3.Water and Land management approach

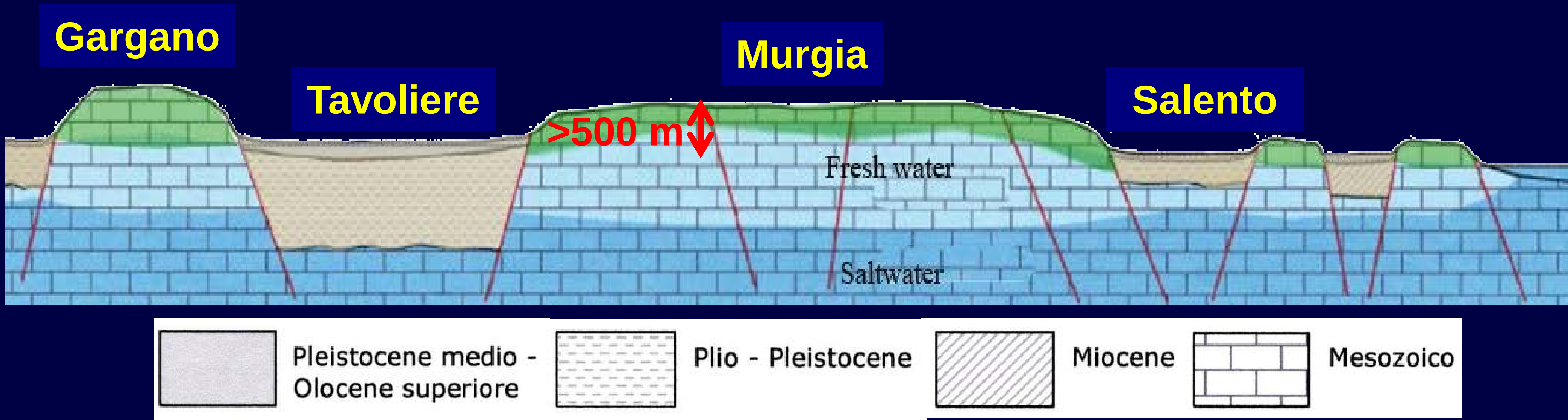
It is necessary when one or more need creates an overall framework for the scarcity of high-quality water that, sometimes combined with negative environmental effects, force people to accept new water saving practices or modify land use. The global framework of rules and modifications is usually defined and imposed by public administrative or scientific authorities at different territorial scales. It includes rules or regulatory instruments in order to:

- ✓ **water saving practices and modify land use**
- ✓ **groundwater abstraction reduction**
- ✓ **changing the pumping pattern**

AREAL EXTENT

The schematic hydrogeological map and section





Maggiore e Pagliarulo, 2002

Apulia groundwater utilisation over time

- Pallucchini summarised the Italian situation at 1939. 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.

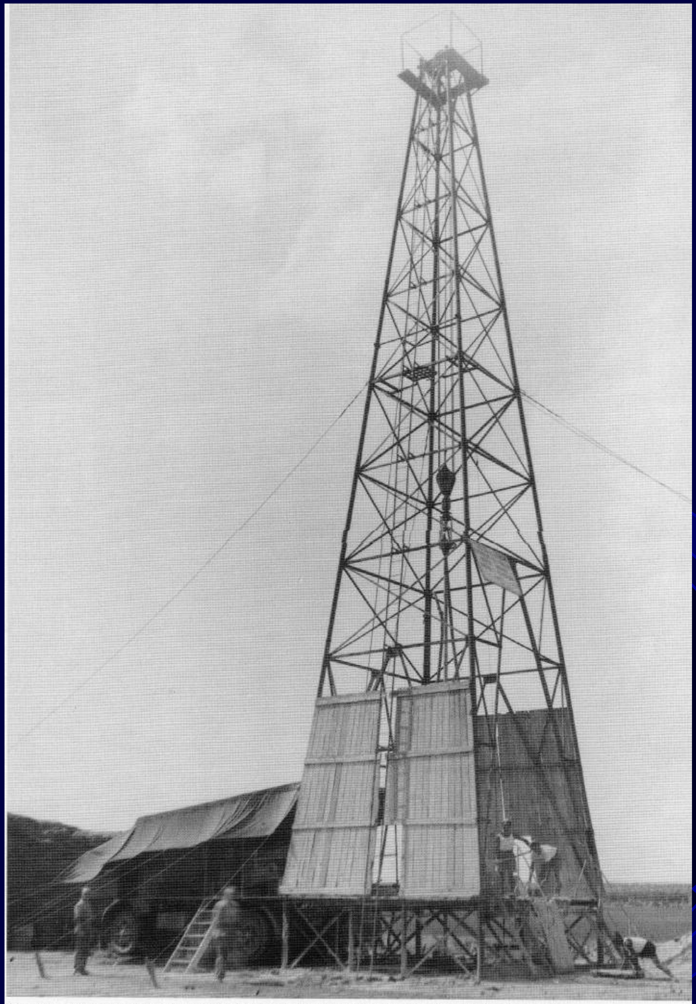
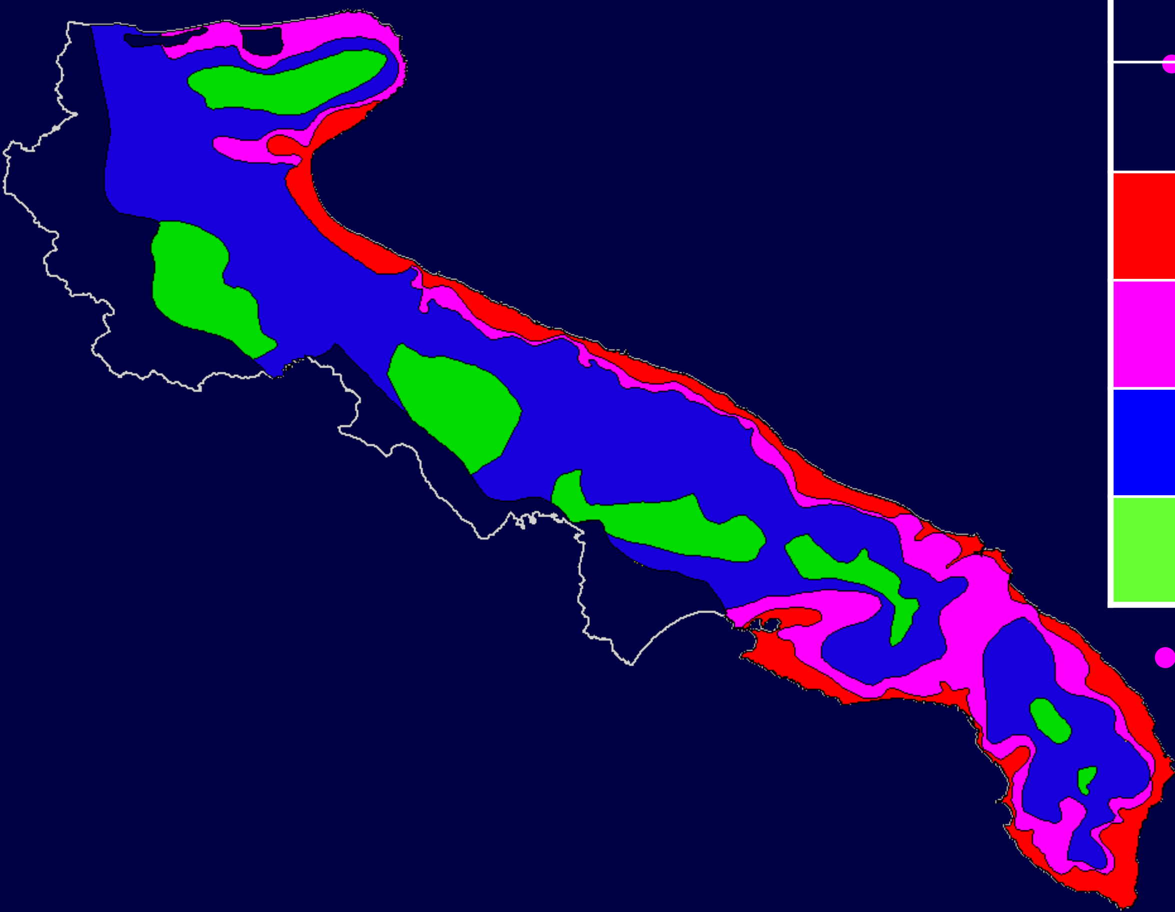


Fig. 77 - Impianto a rotazione a circolazione diretta di acqua per pozzi a carotaggio continuo tavoliere di Puglia

Apulia groundwater utilisation and regulation

Water Protection Plan I (PRA, 1984)

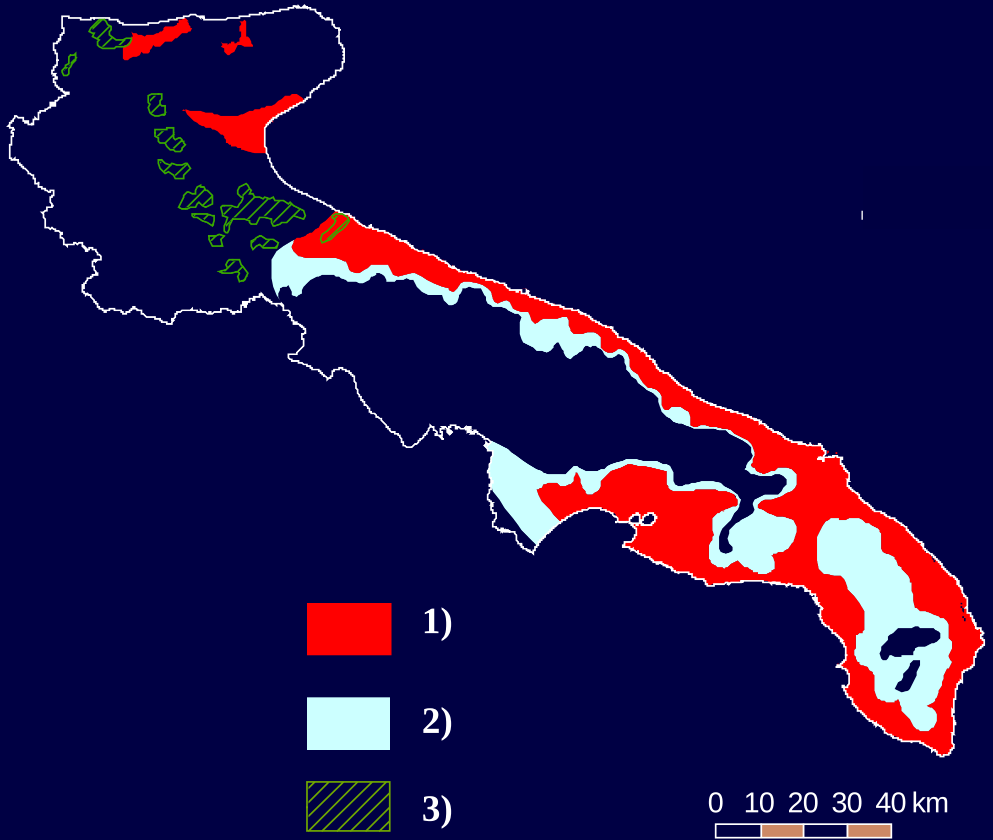


	DISCHARGE			SAFEGUARD
	Forbidden	Possible	Drinking use	
	Yes			
	Yes			Yes
		Yes		Yes
		Yes	Yes	Yes

- 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**, the **Water Protection Plan**, called **PRA,** defined the quality zonation of Apulian groundwater and the regulation of groundwater utilisations as a function of the risk of groundwater degradation

Apulia groundwater utilisation and regulation

Water Protection Plan II (PTA, 2009)



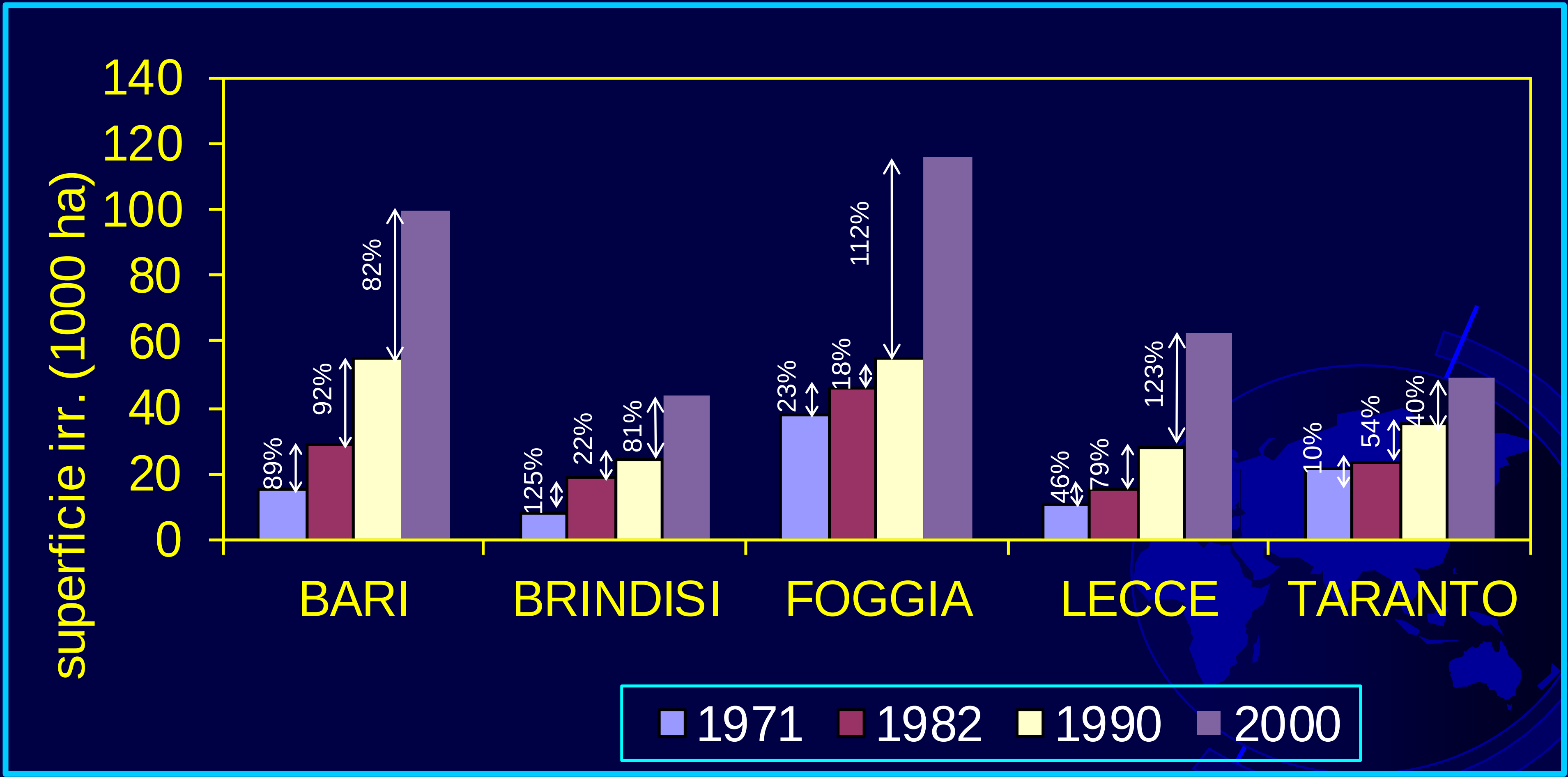
NOD	**Authorization extension (existing well):** • well bottom (-m asl) less than 20-30 piez. head (m asl) • drawdown (m) of max discharge yield less than 30-50% piez. head (m asl)
QQP	**New wells are possible if:** • If unconfined, well bottom (-m asl) less than 20-25 piez. head (m asl) • drawdown (m) 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)

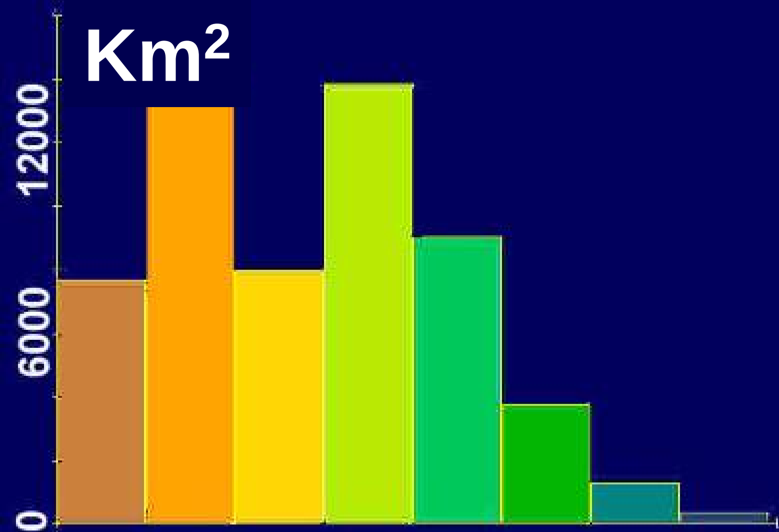
2) qualitative and quantitative protection zone (QQP zone, regulated new discharge)

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

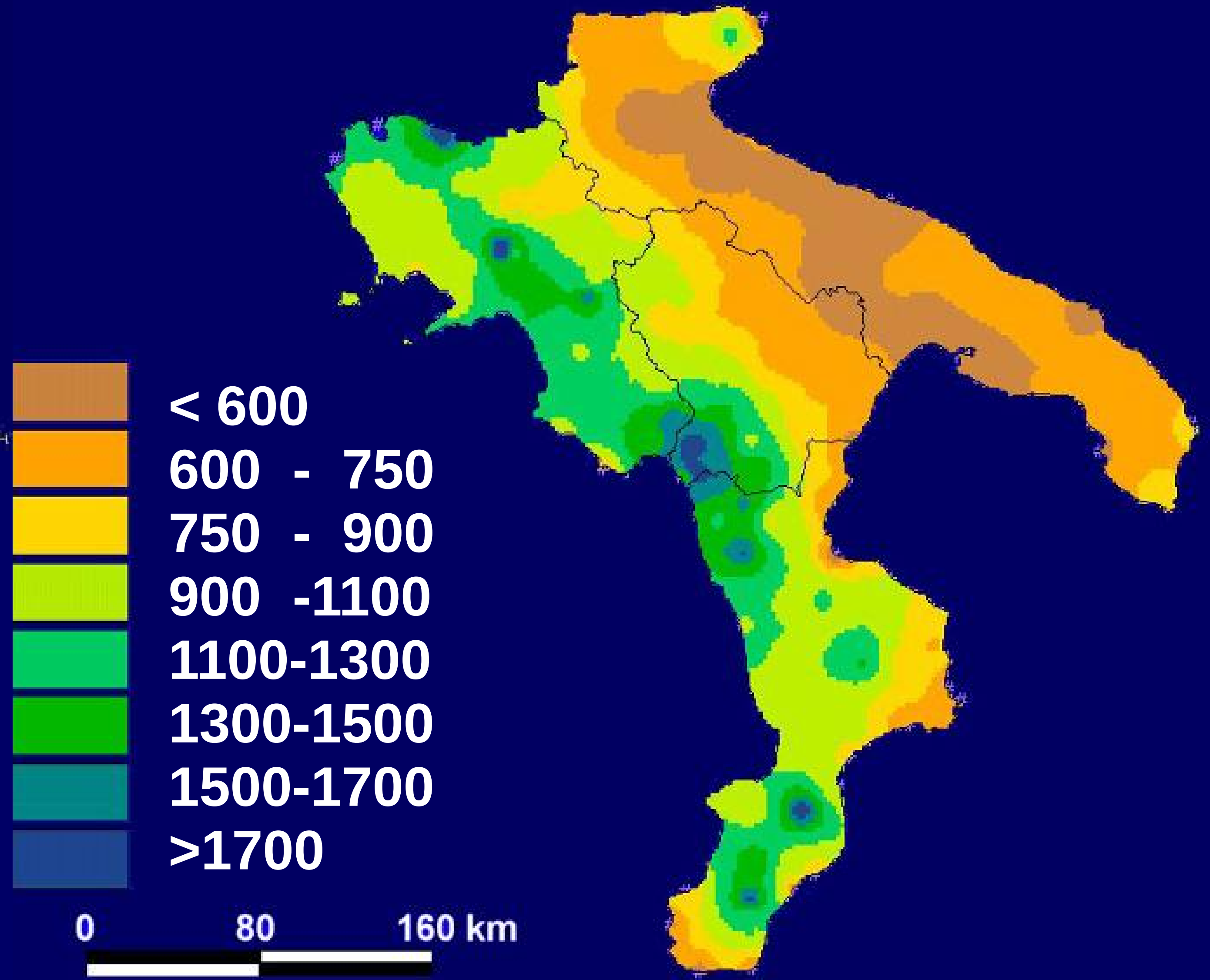
Surface watered with grounwater in Apulia region



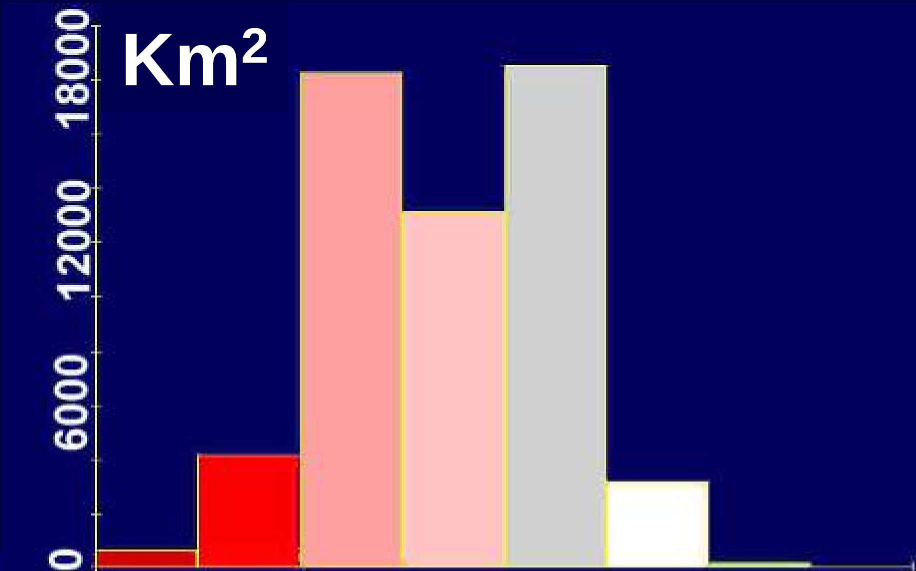
MEAN ANNUAL RAINFALL MAP (PERIOD 1921-2001, mm)



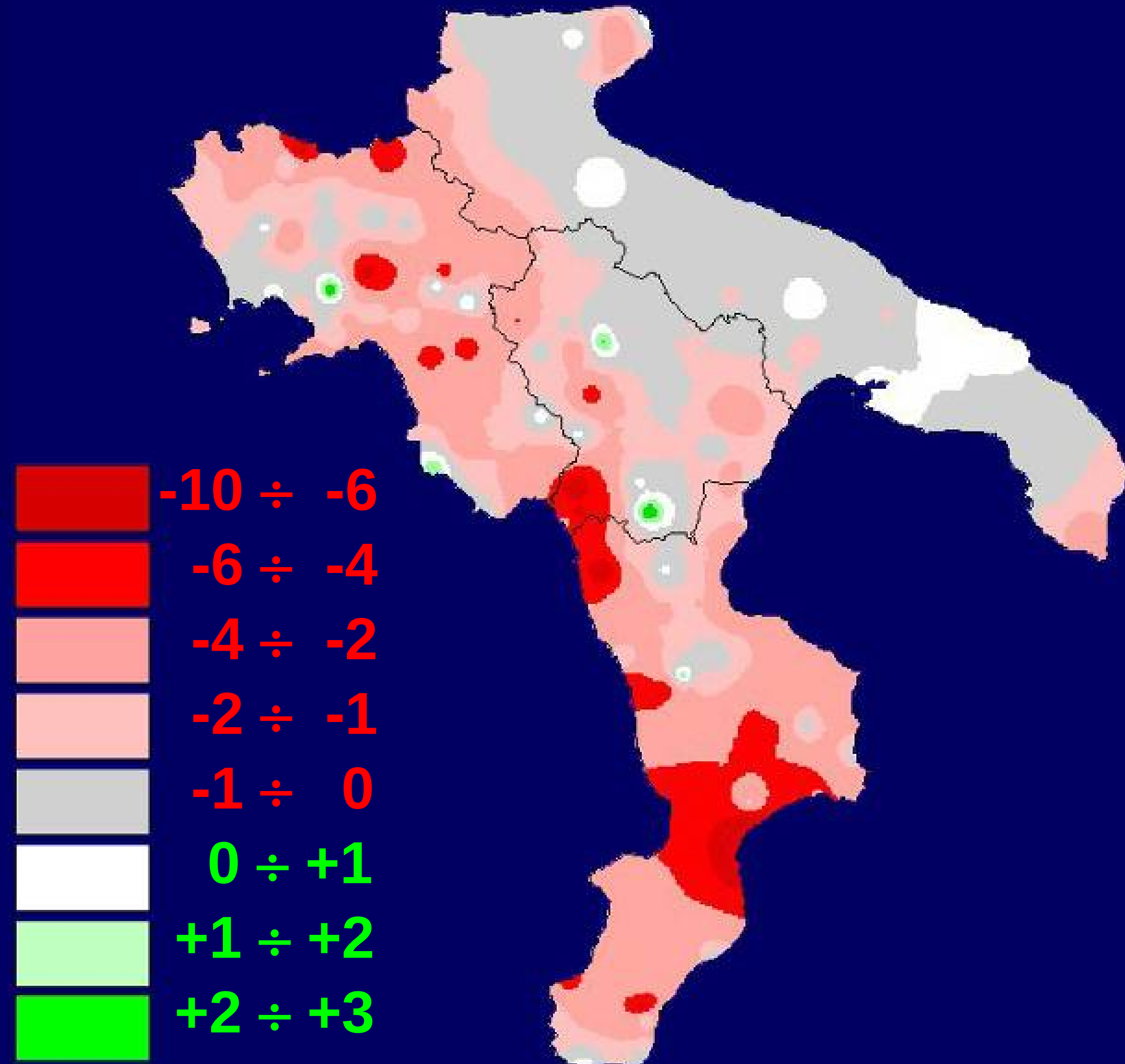
REGION	MEAN ANNUAL RAINFALL	
	mm	Mm^3
APULIA	644	12,500
BASILICATA	893	9,000
CALABRIA	1043	16,000
CAMPANIA	1148	15,000



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



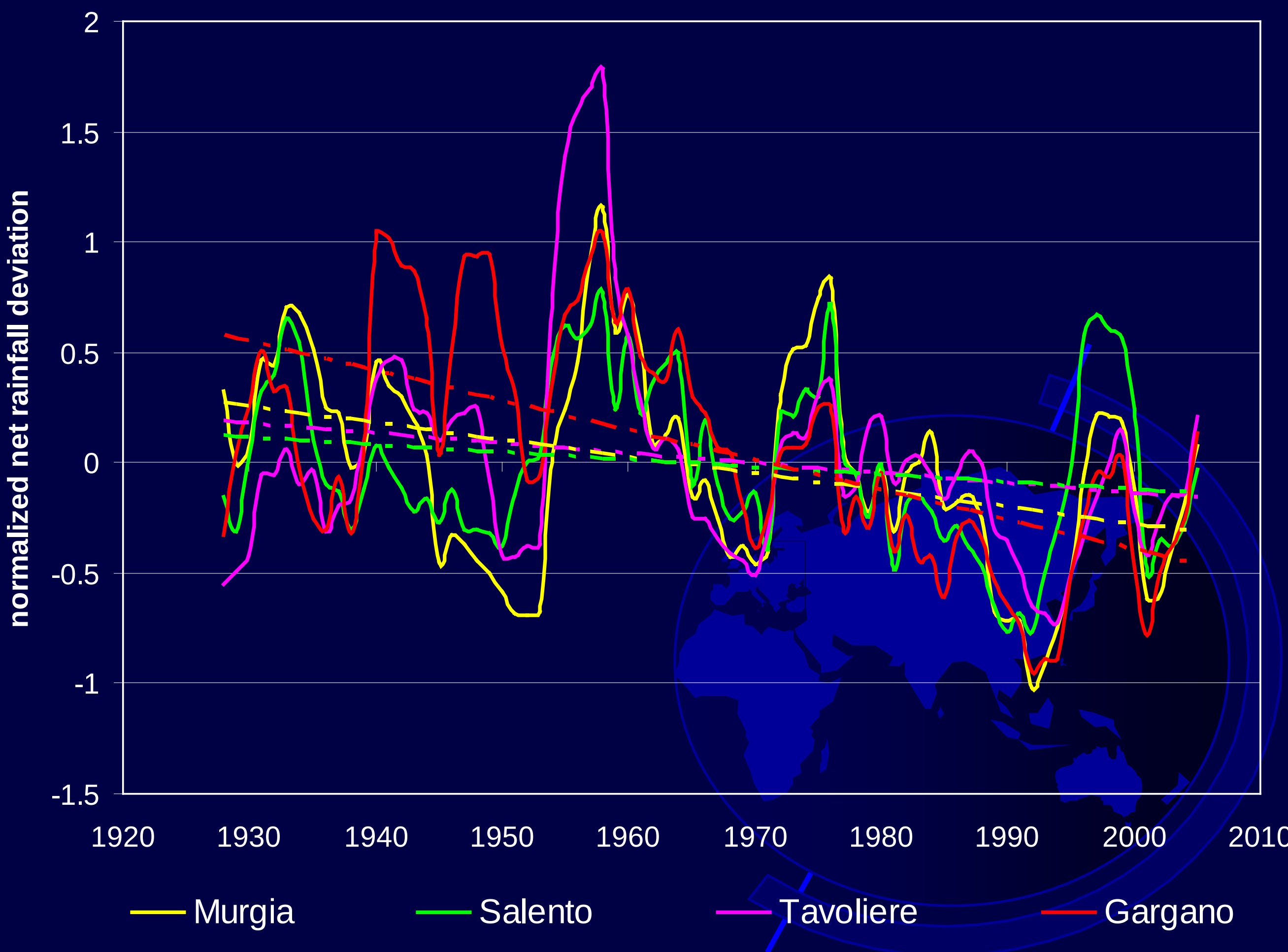
REGION	MEAN RAINFALL TREND	
	mm/y	80 YEARS (mm,%)
APULIA	-0.8	-65 (-10%)
BASILICATA	-1.8	-145 (-16%)
CALABRIA	-2.9	-230 (-22%)
CAMPANIA	-2.5	-196 (-18%)



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

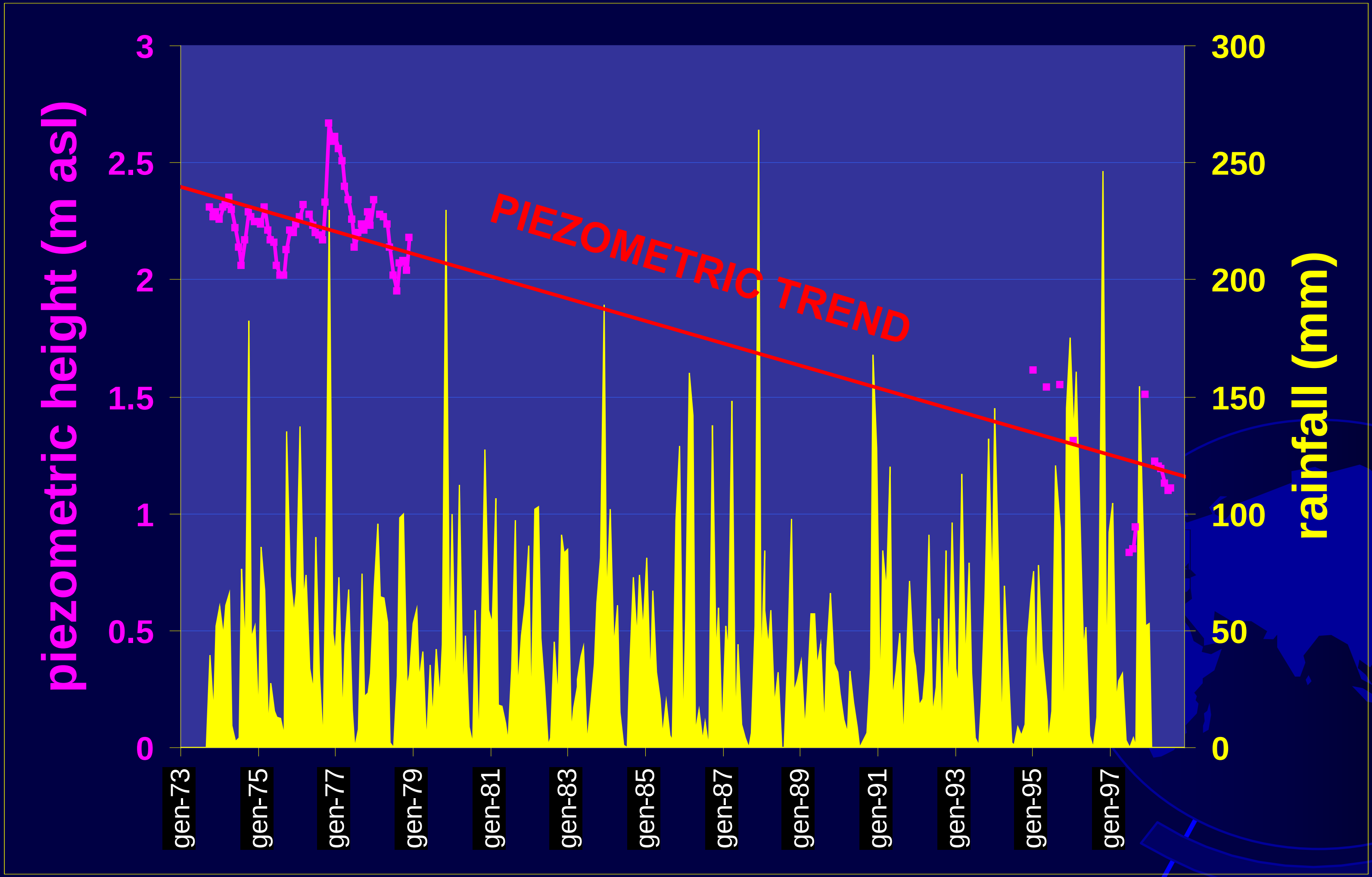
- Negative net rainfall trend
  - ranging from –3.52 to -0.23 mm/yr,
- In the whole period decrease from 22 to 42% of the mean net rainfall
  - percentage range much higher than similar actual rainfall percentage range



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

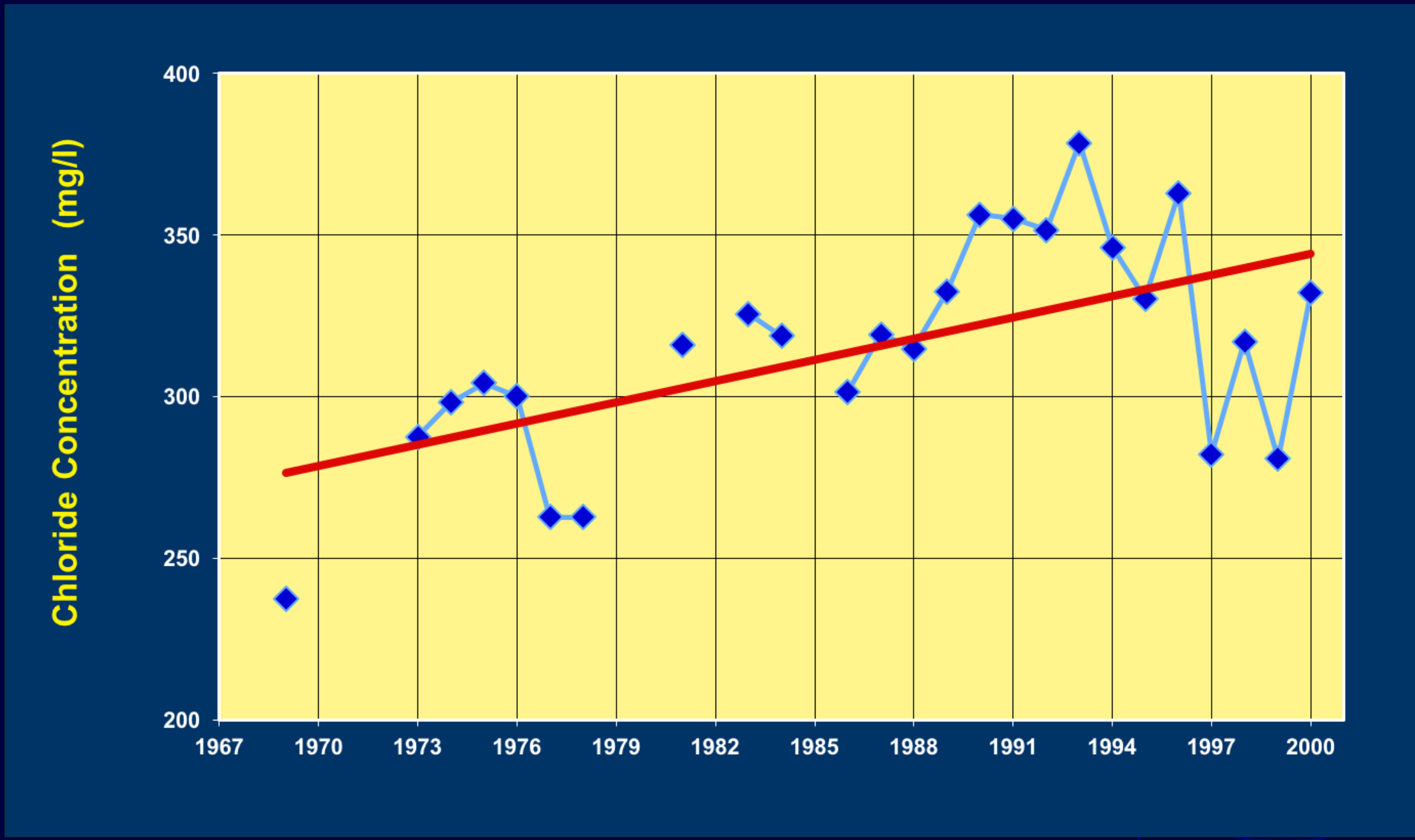
MURGIA AND *SALENTO*: WN 27 (*BRINDISI*)
MONTHLY RAINFALL, PIEZOMETRIC HEIGHT AND TREND



Piezometric trend analysis summary

HS	DATA		G=Gradient (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

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



Statistics and CC 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

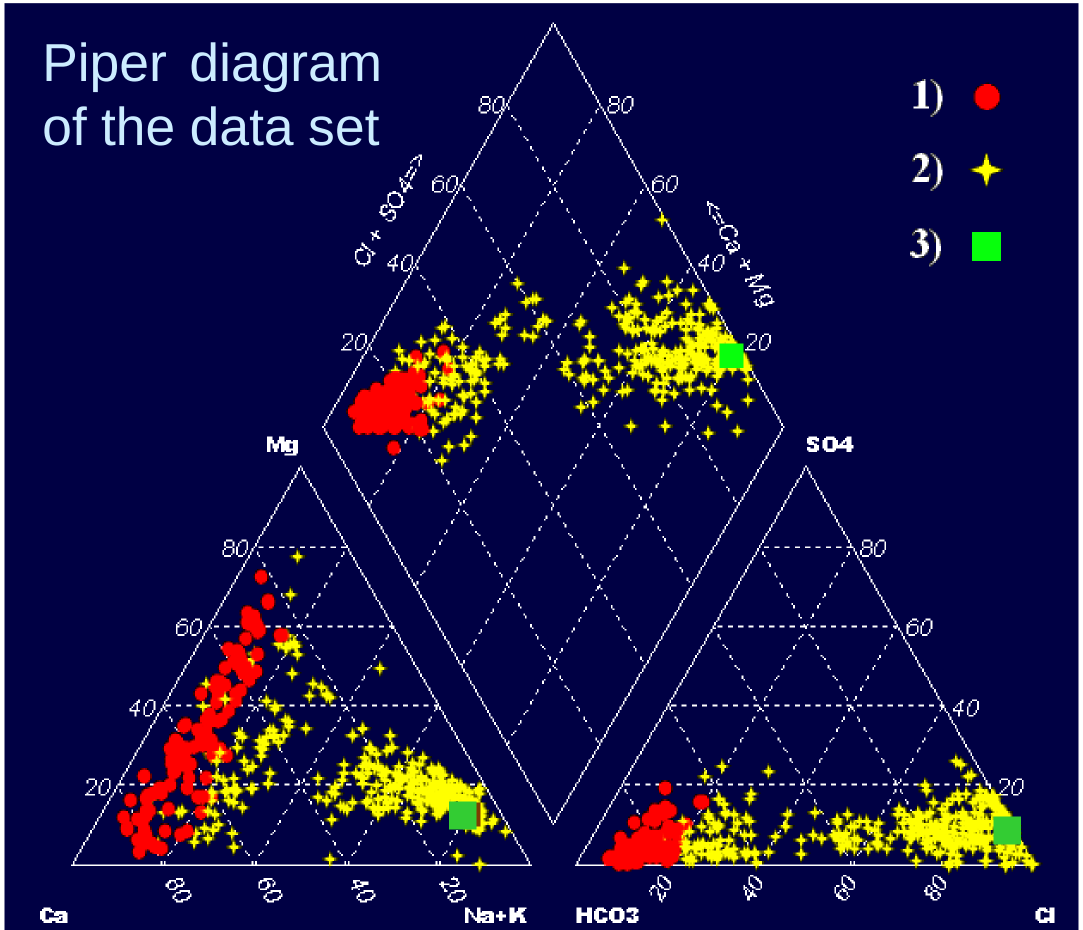
BY) Beginning Year of observations

AF) End Yar of observations

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

The basic or threshold criterion

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 75[th] 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)….**

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

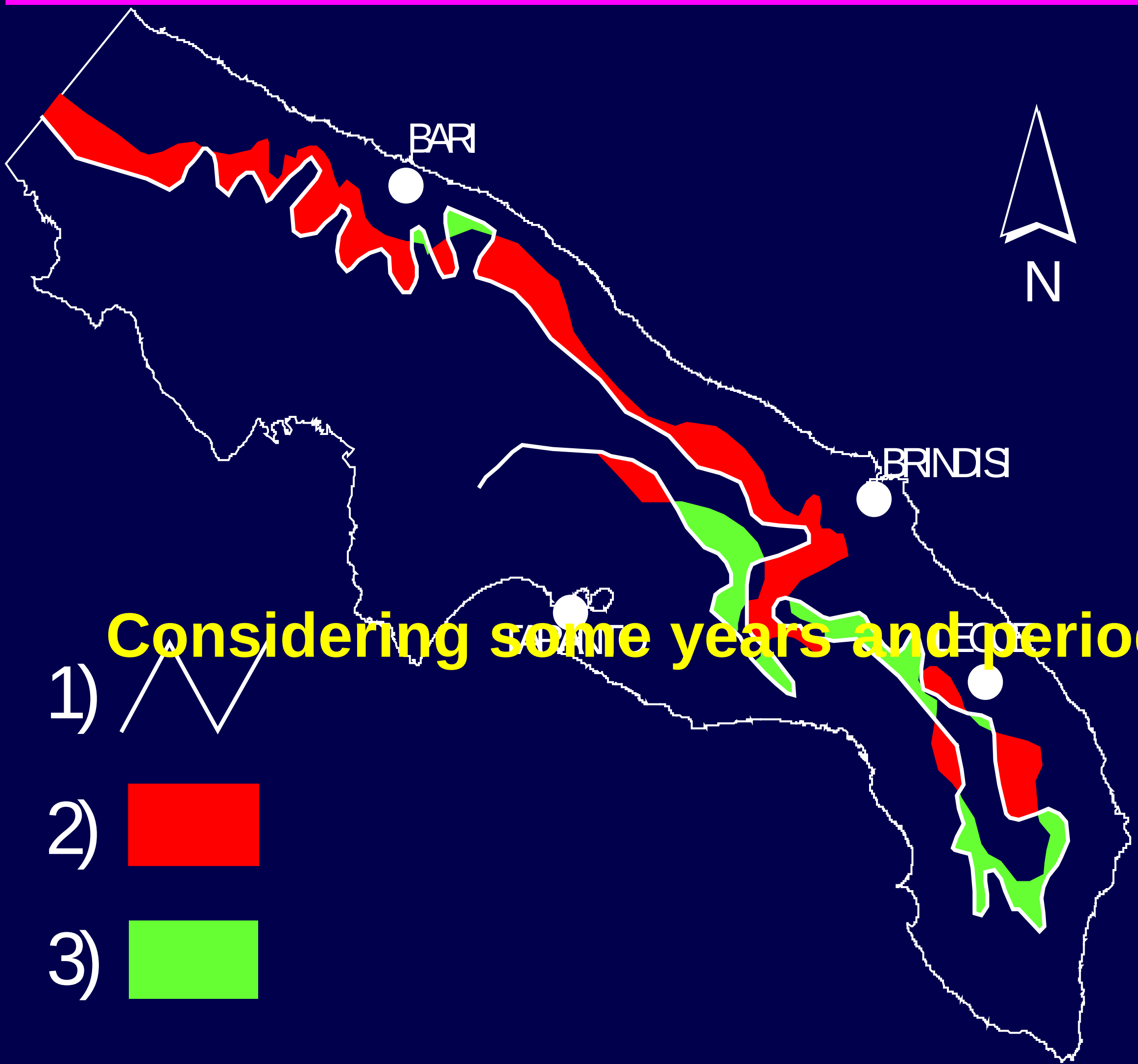
from 1981 to 1989

1) 1989 RSCL

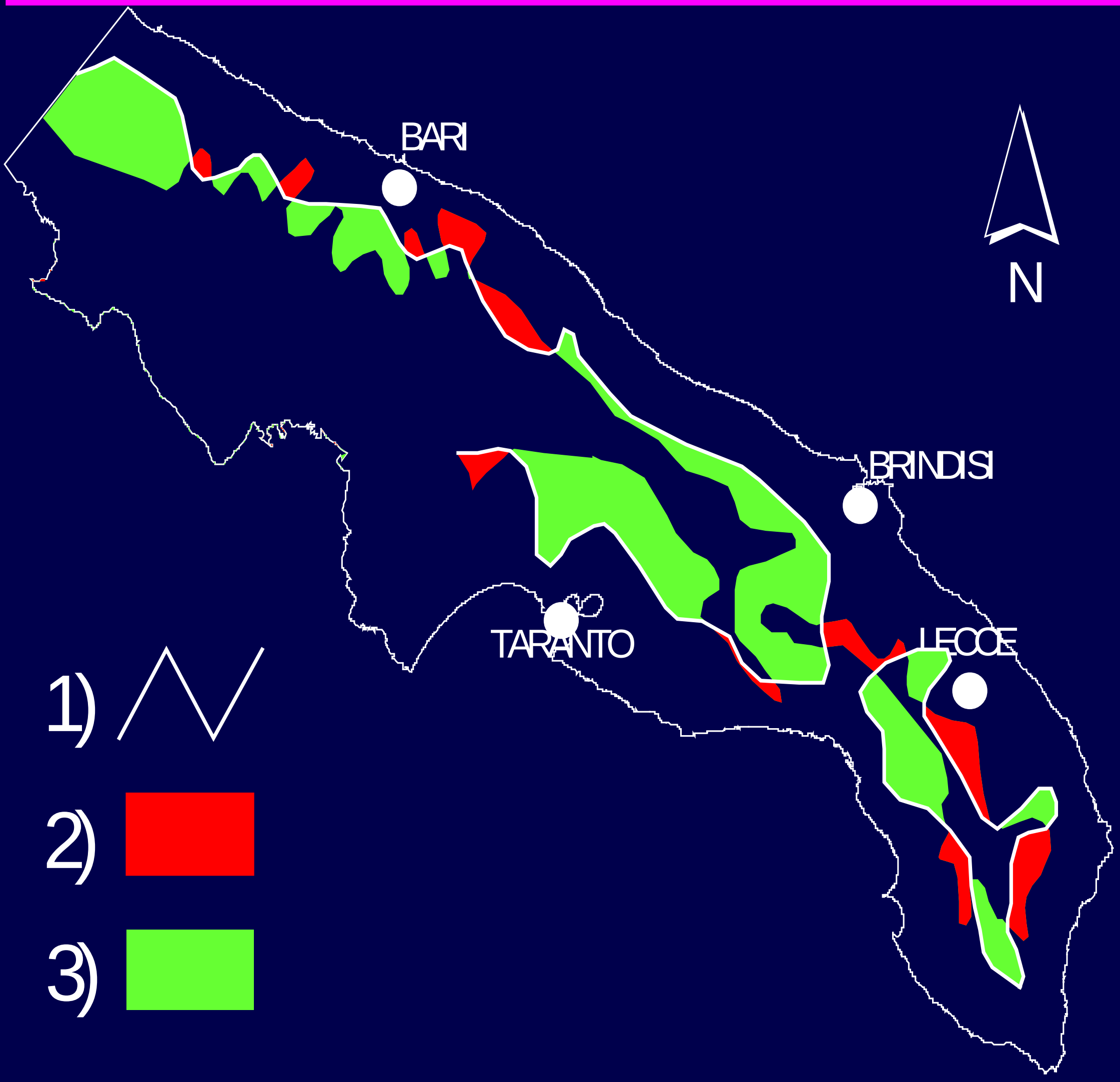
2) RSCL moves landward

3)RSCL moves seaward

Considering some years and periods from 1981 to 2003



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



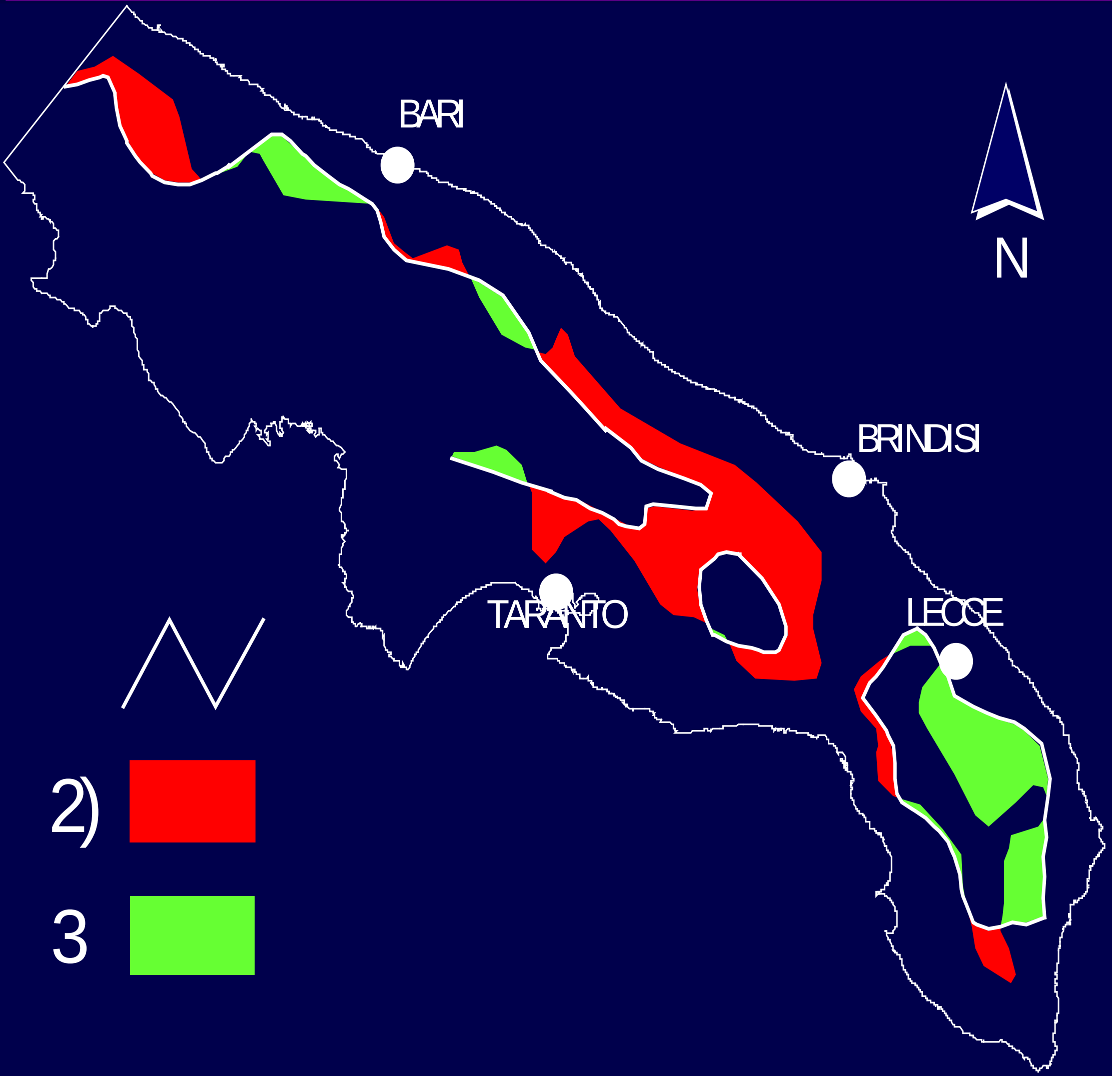
From 1989 to 1997

1) 1997 RSCL

2) RSCL moves landward

3) RSCL moves seaward

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



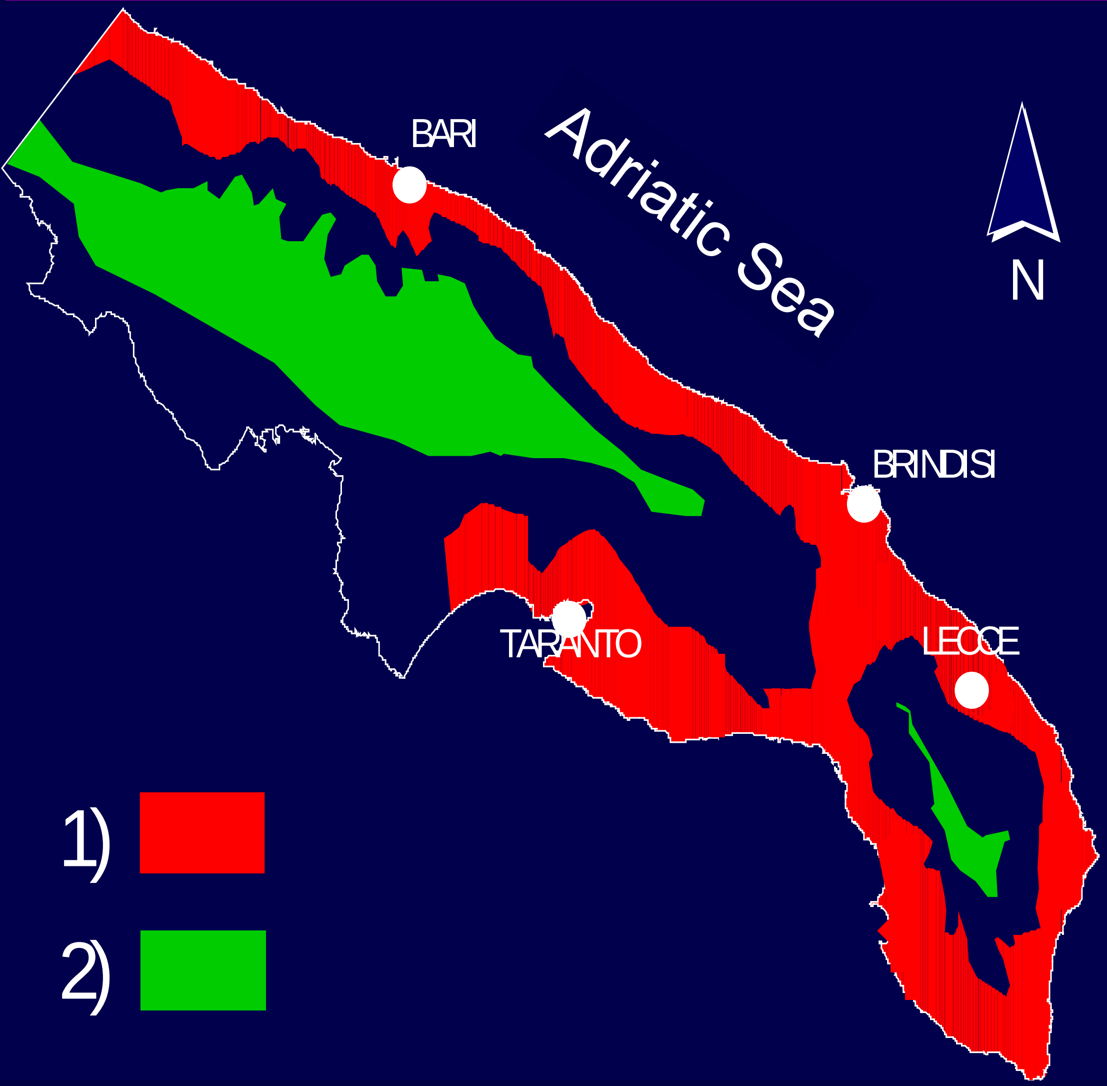
From 1997 to 2003

1) 2003 RSCL

2) RSCL moves landward

3) RSCL moves seaward

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*

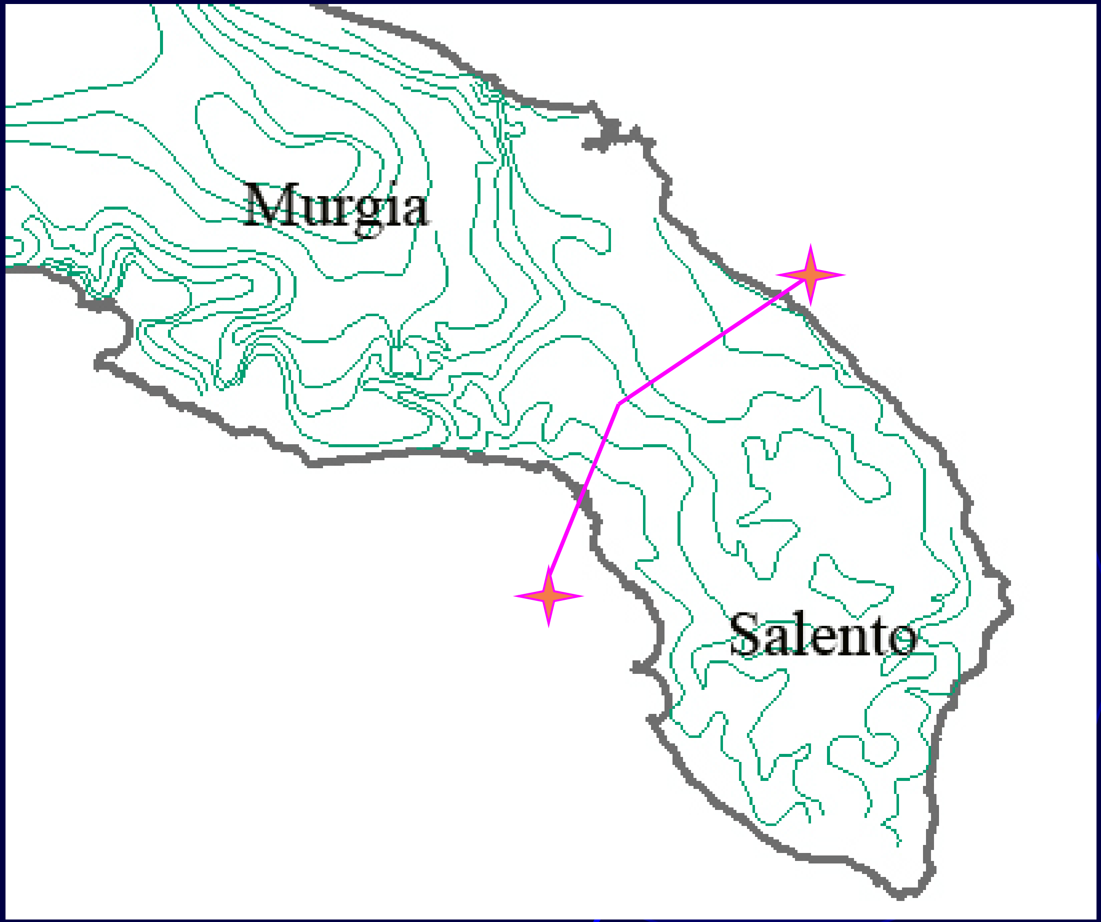
Numerical model approach

- 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.

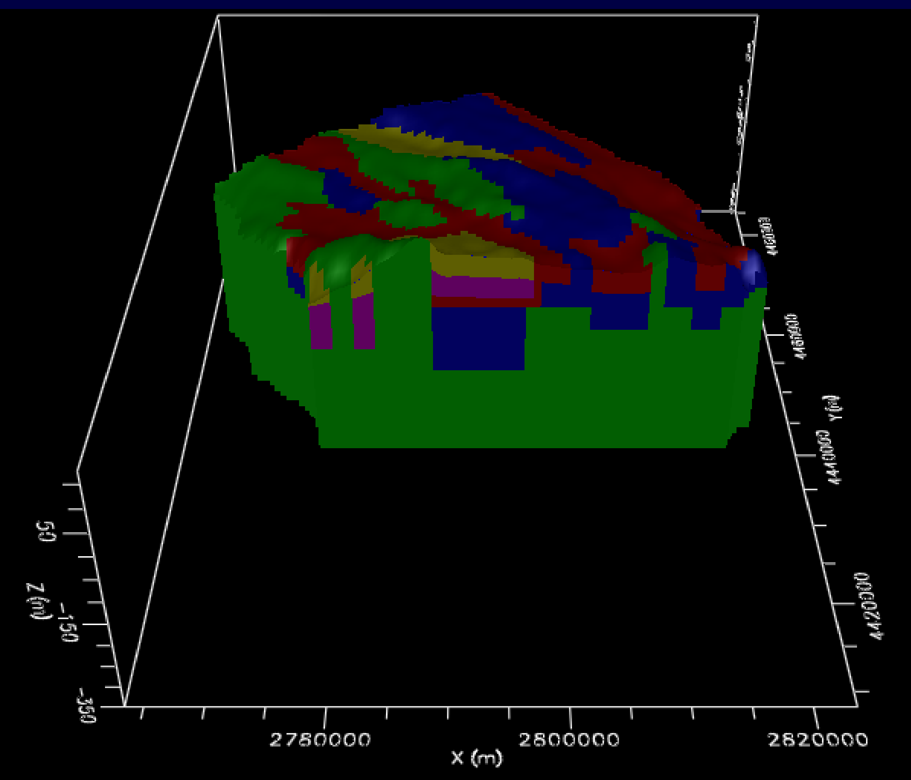
Qualitative and quantitative groundwater changes from 1930 to 2060 were modelled based on the effects of climate change, sea level rise and changes in sea salinity.

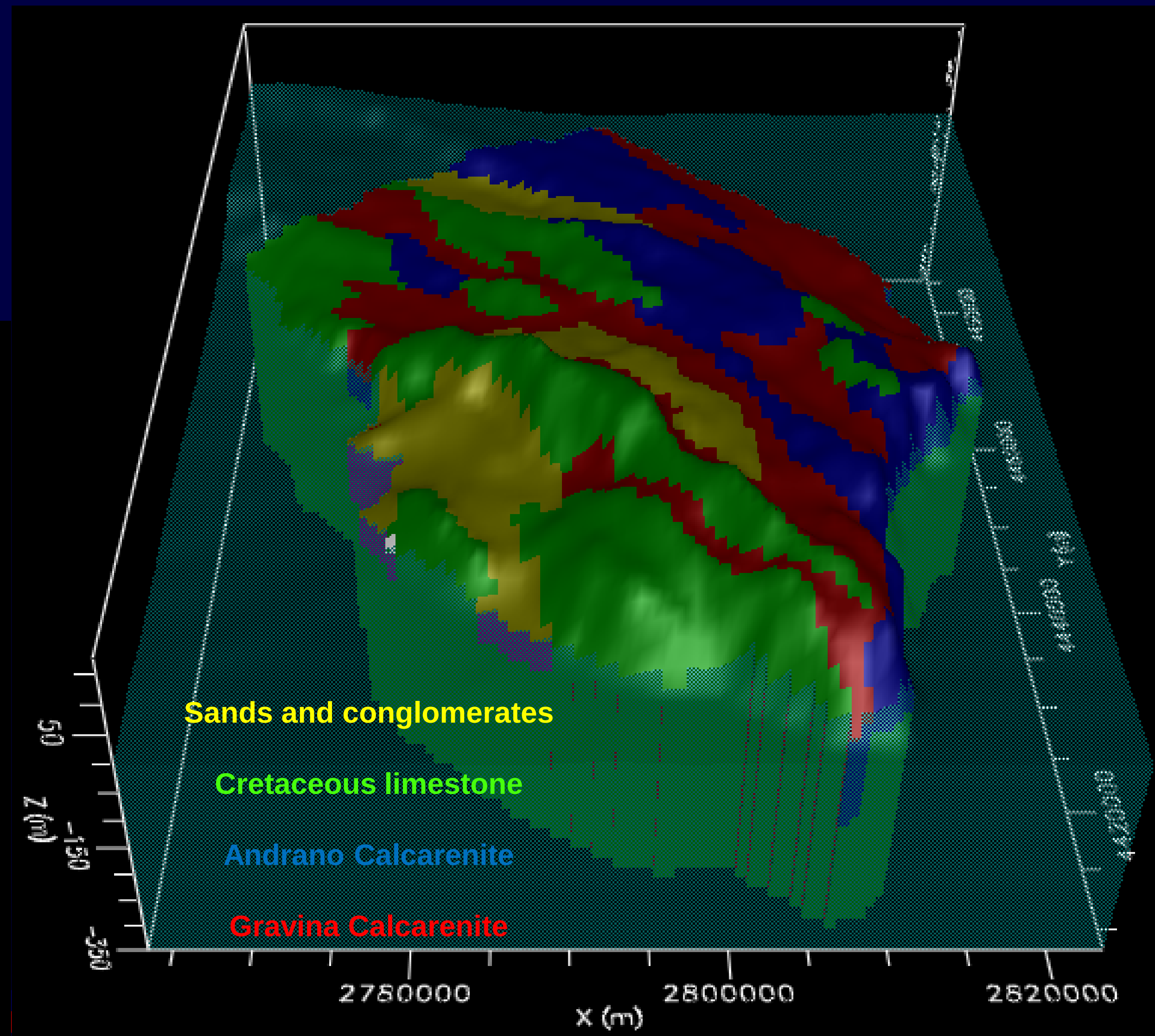
Modelling test area: Salento

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

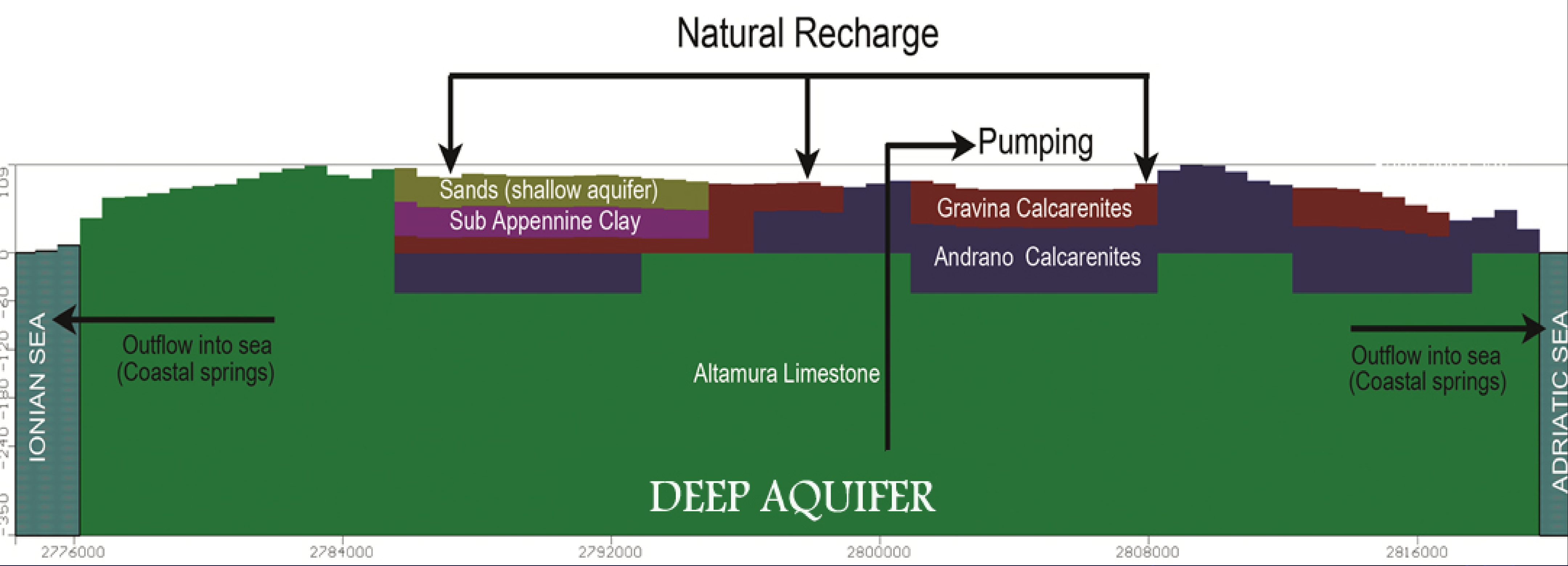


3D modelling of hydrogeological complexes





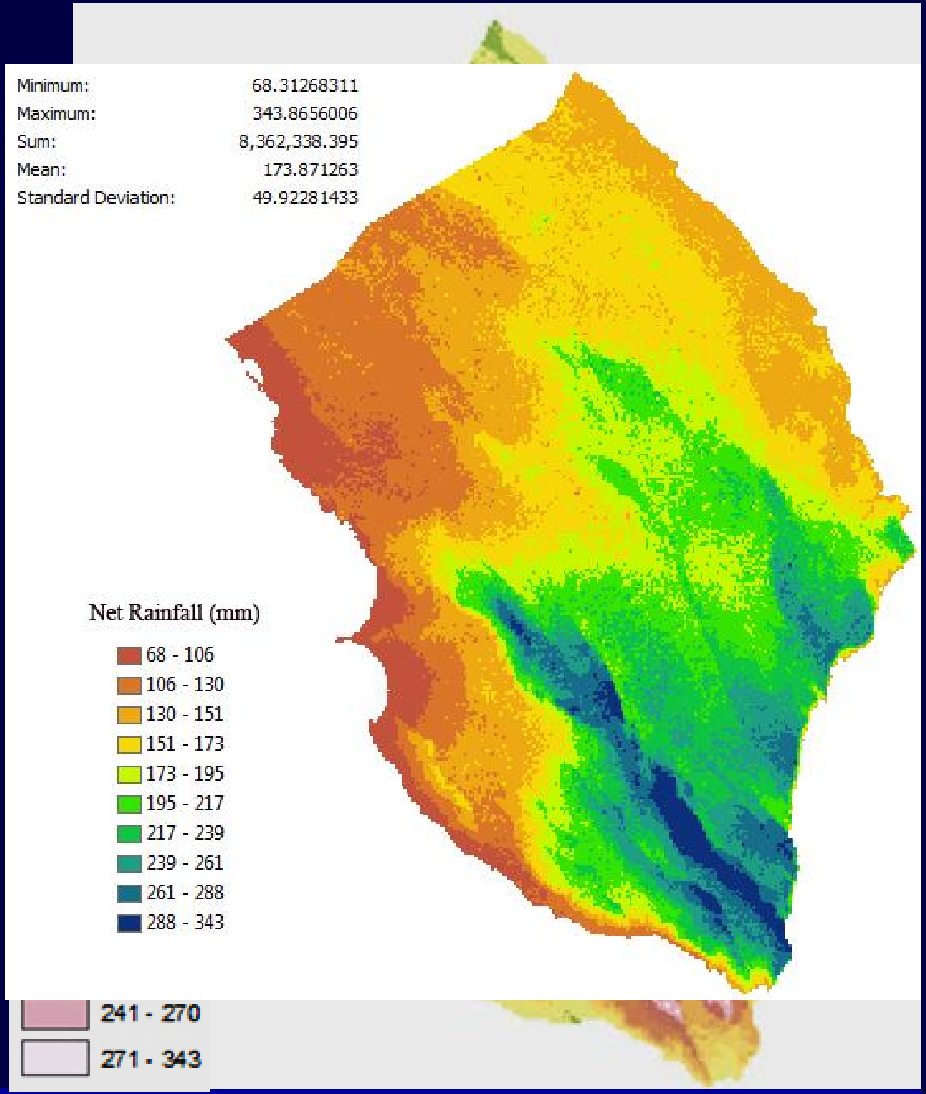
Conceptual model



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
- A … atic Se…

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

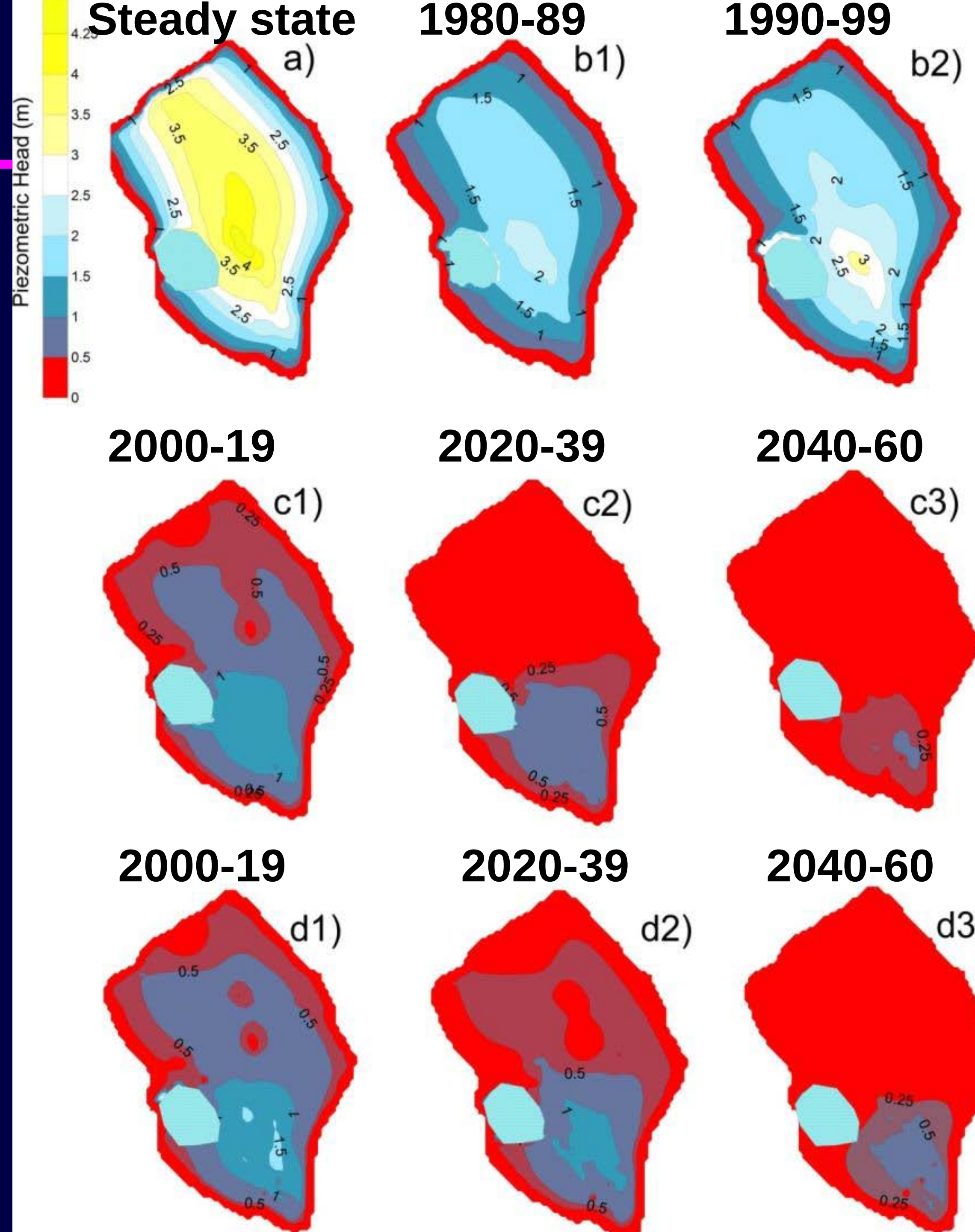


Annual values

- 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)

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

Piezometric results



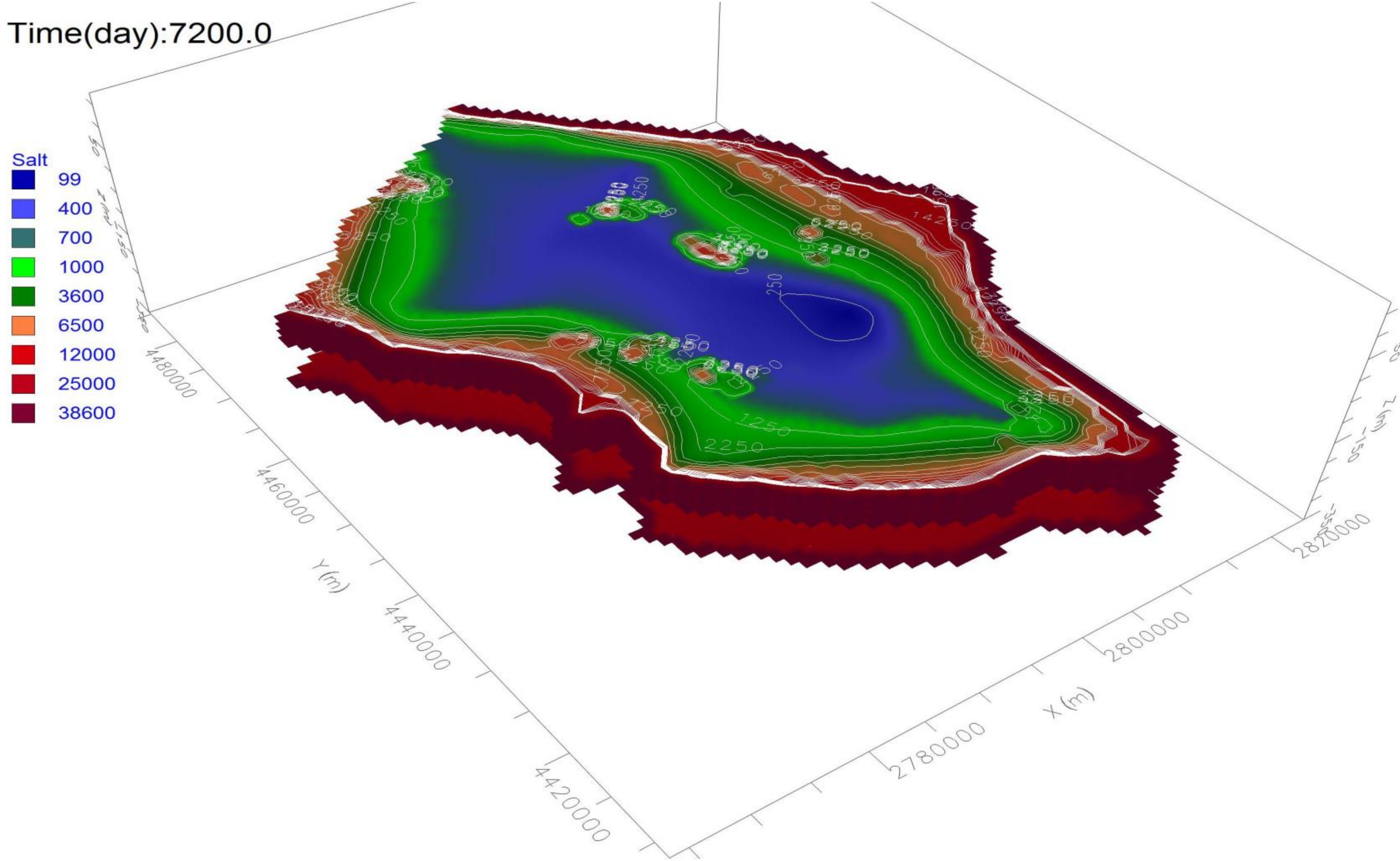
<u>First scenario</u>

- steady drinking discharge
- increasing irrigation discharge

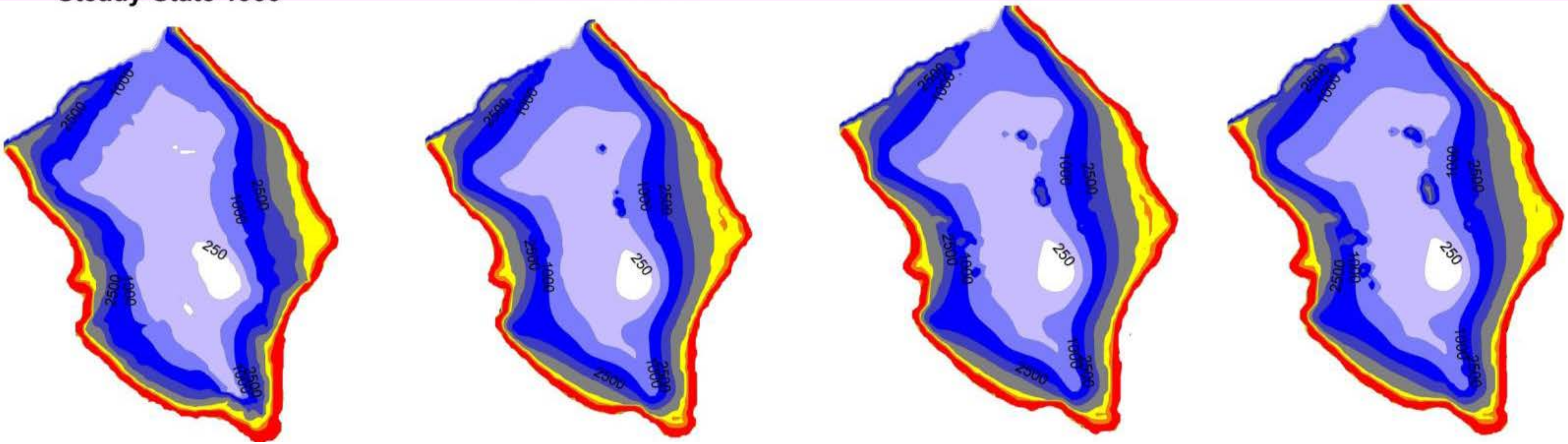
<u>Second scenario</u>

Steady irrigation discharge

Seawater Intrusion Simulation 2040-2060 (mg/l)



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

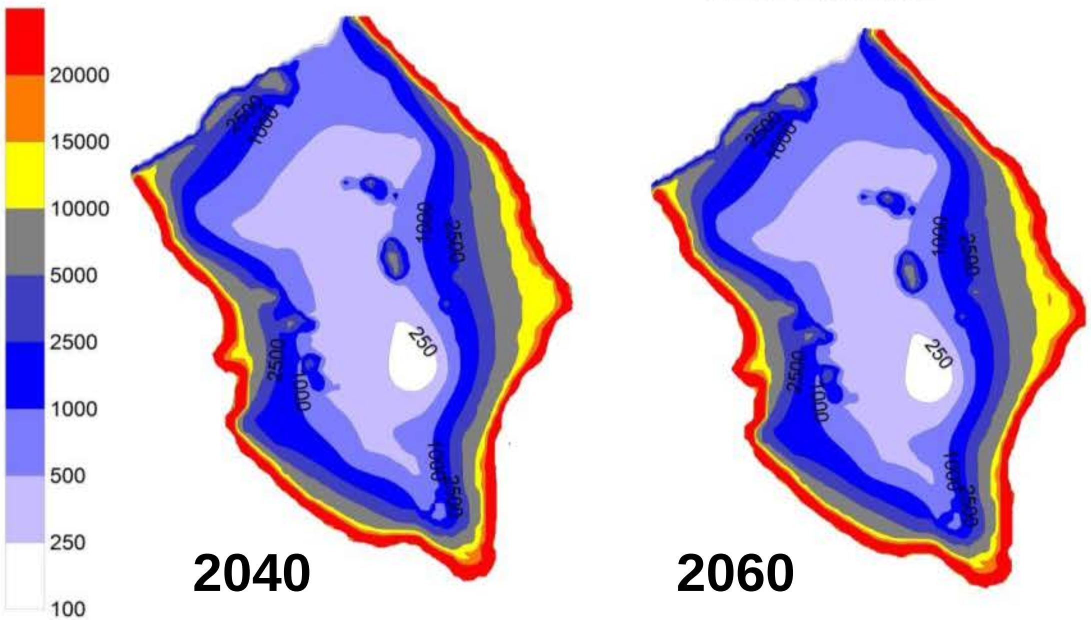


Steady state

1989

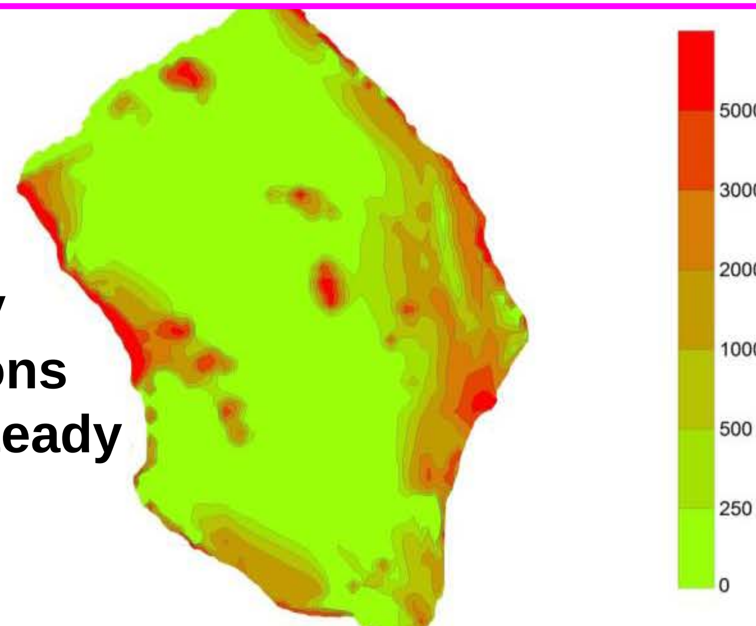
1999

2019



2040

2060



Salinity variations 2060-steady state

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!