

7th EUREGEO

EUropean
Congress
on REgional
GEOscientific
Cartography
and
Information
Systems



Mapping Salinization in the Coastal Aquifer of Ravenna (Italy)

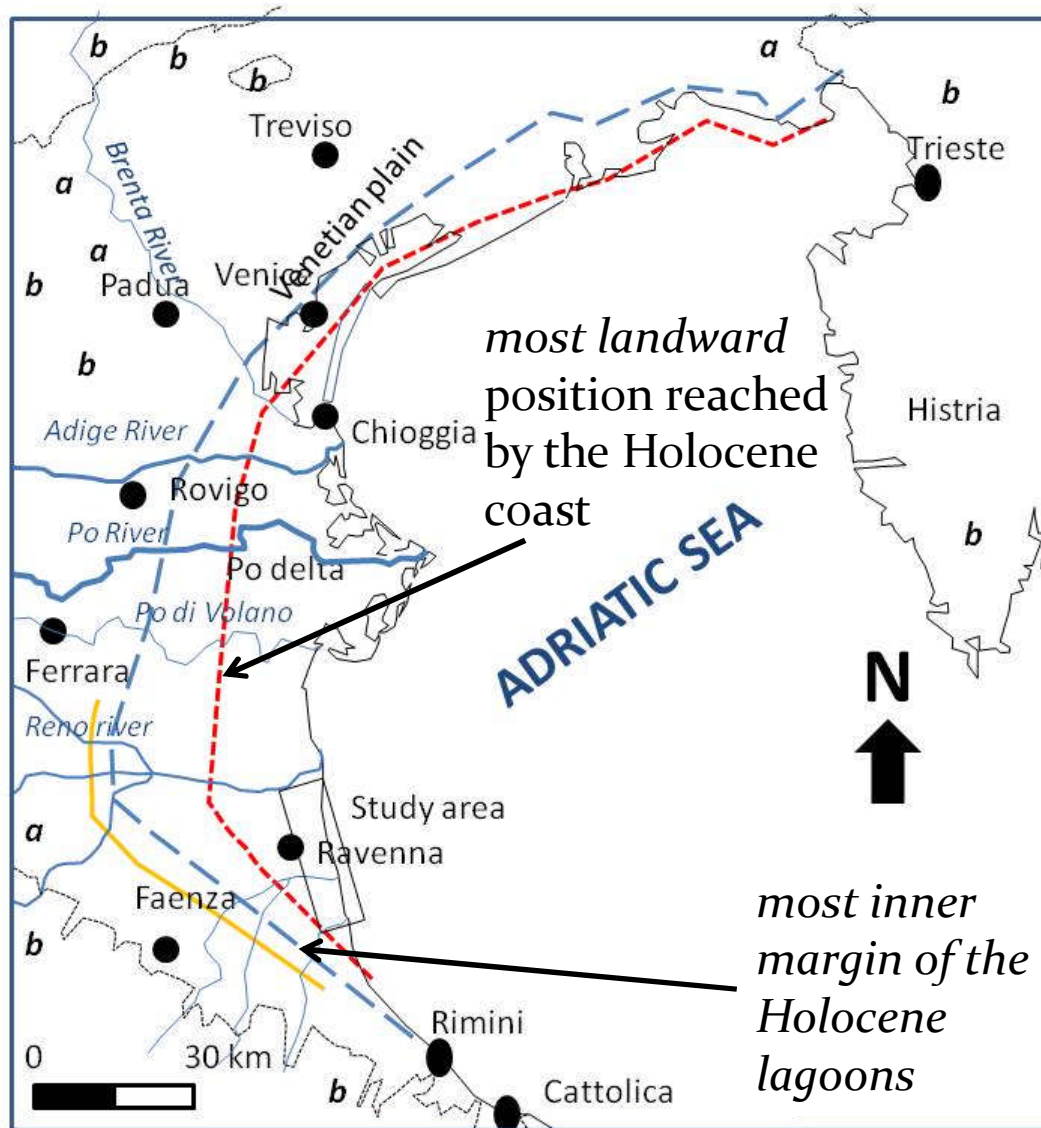
Marco Antonellini, Donato Capo, Giovanni Gabbianelli, Nicolas Greggio, Mario Laghi, and Pauline Mollema



University of Bologna

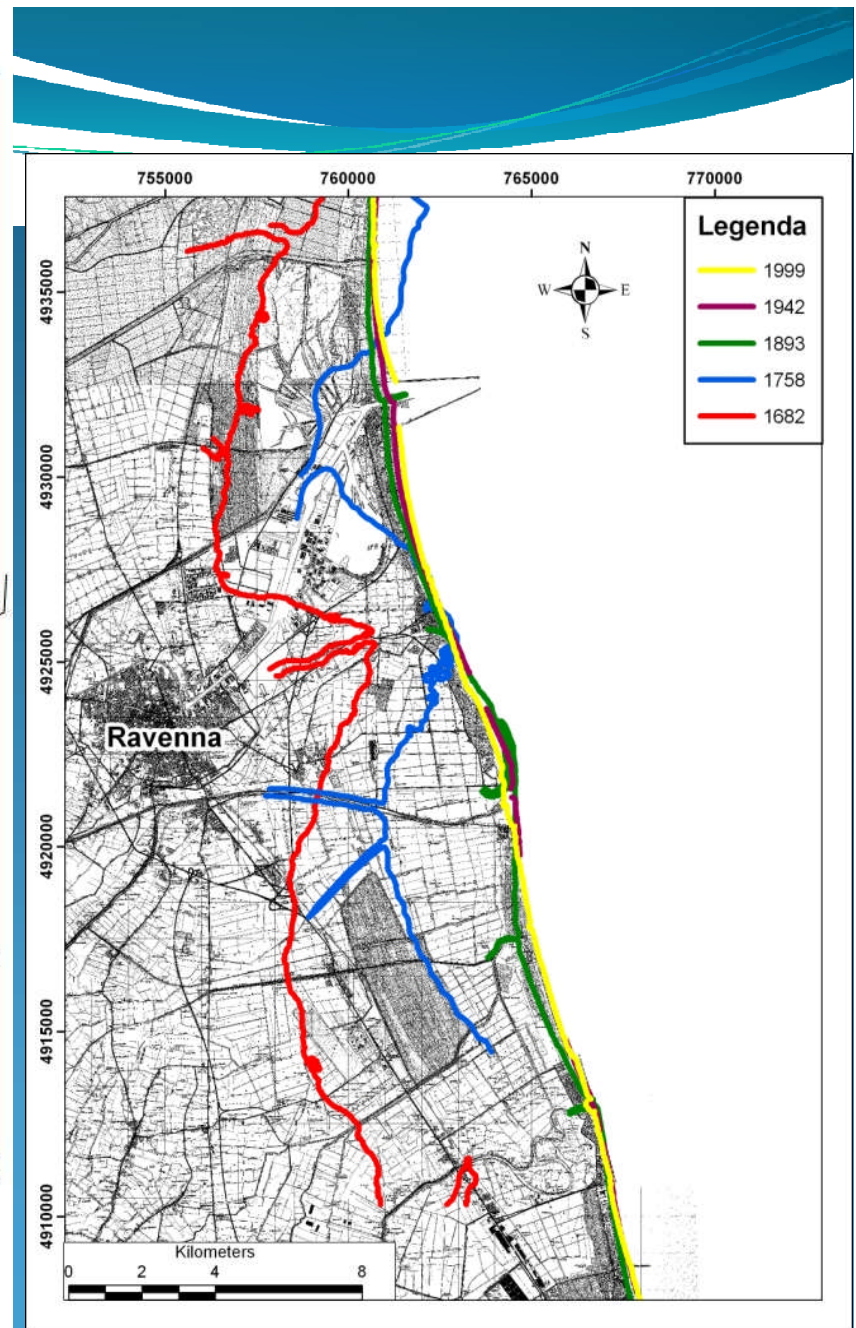
Funding and Collaborations

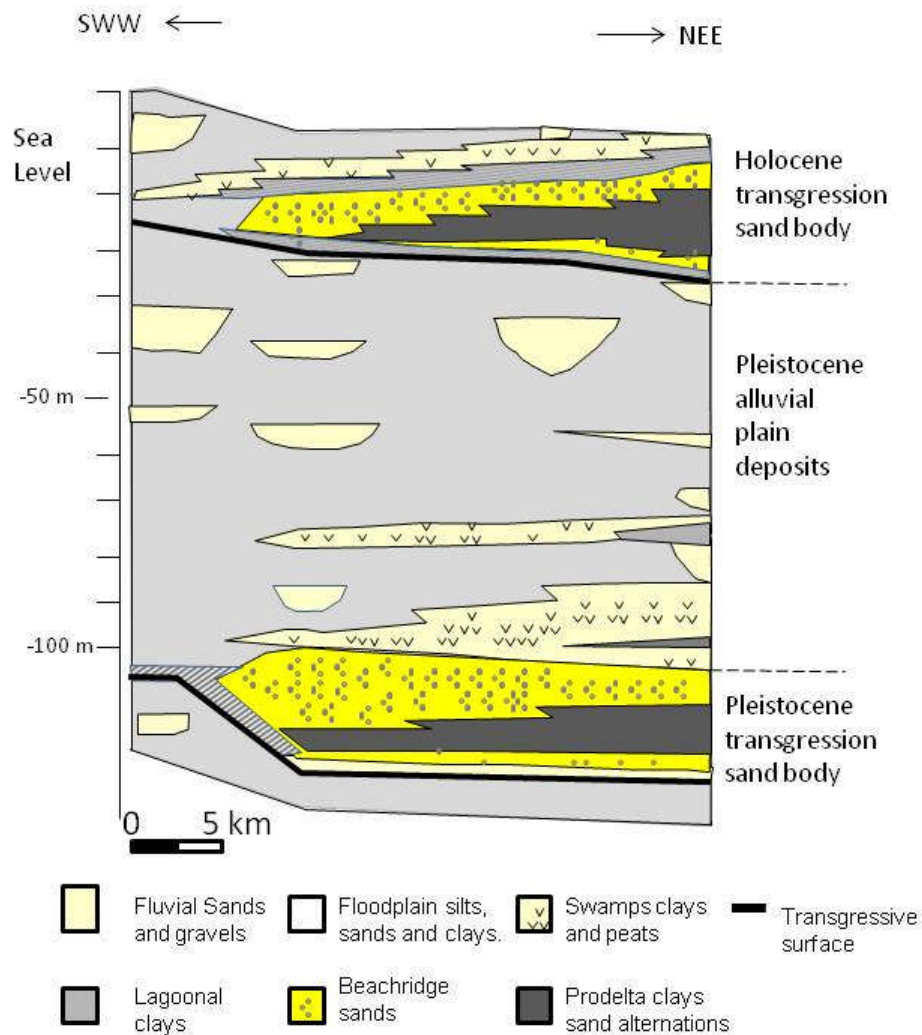
- Master Plan of the Po Delta Park
- University of Bologna – Strategic funds for innovative research
- Town of Ravenna – Pine Forests 1
- Town of Ravenna – Pine Forests 2
- Autorità dei Bacini Romagnoli (Local watershed authority) – Sea-water intrusion along the Romagna rivers
- Autorità dei Bacini Romagnoli (Local watershed authority) – Managed Aquifer Recharge to contrast sea-water intrusion
- EU FP6 CircleMed – WATERKNOW
- ENI – Town of Ravenna. CSI Coastal Salt-water Intrusion Project
- Collaborations: Deltares (The Netherlands), Vrije Universiteit Amsterdam (The Netherlands), University of Ghent (Belgium), Simon Fraser University (Vancouver, Canada)



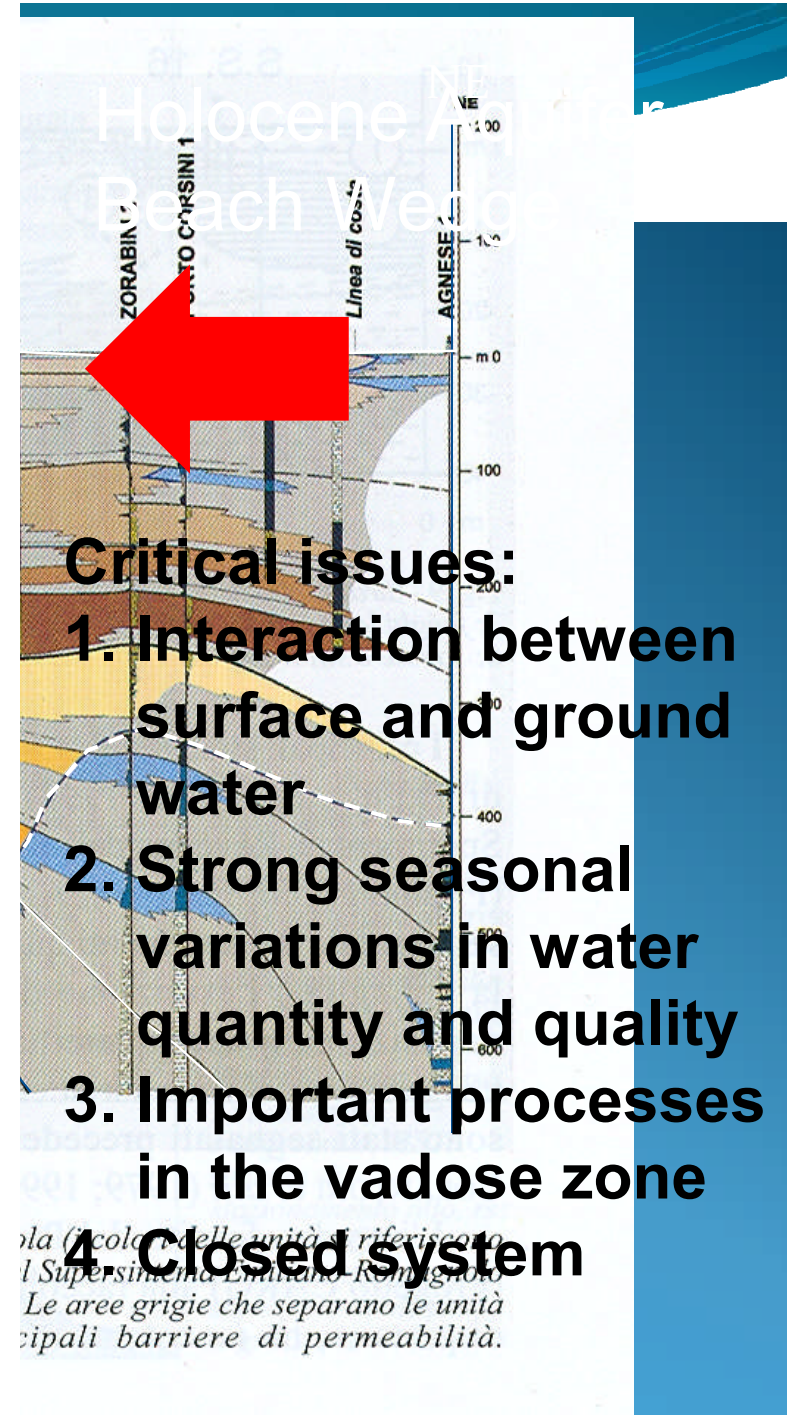
modified from Antonioli et al (2009) and Amorosi et al. (2008).

A very young area...





Modified from
Amorosi et al. 2002

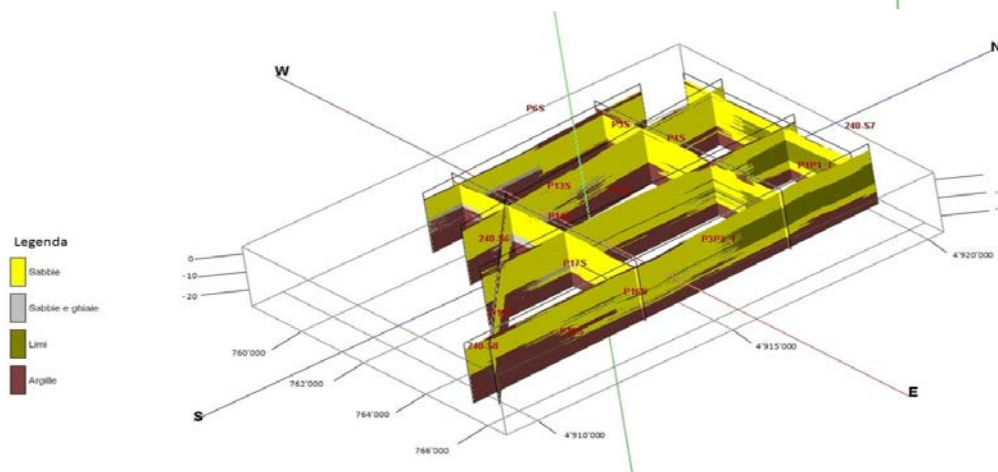
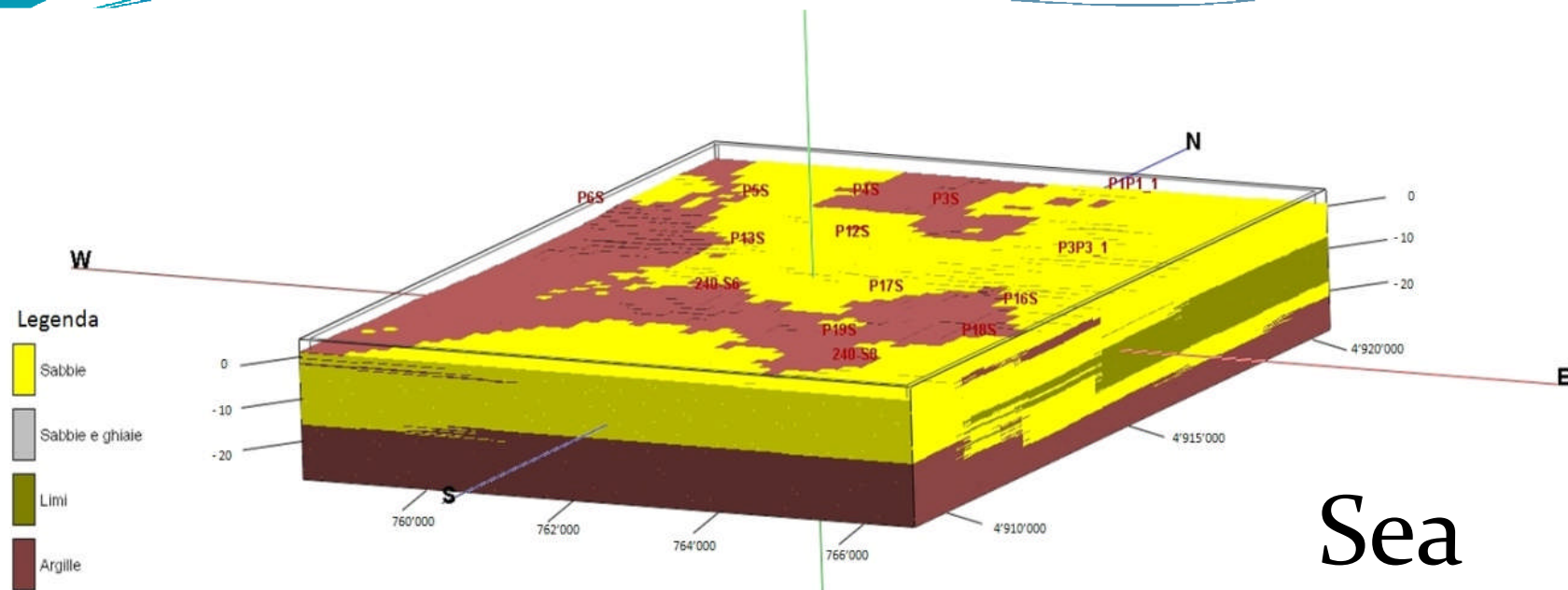


Critical issues:

1. Interaction between surface and ground water
2. Strong seasonal variations in water quantity and quality
3. Important processes in the vadose zone
4. Closed system

ola (color delle unità si riferiscono al Supersistema Emiliano-Romagnolo. Le aree grigie che separano le unità principali barriere di permeabilità.

Unconfined and Semi-Confined Aquifer



Volumetric computations of the sand in the model south of Ravenna show that the aquifer has a potential volume of $1,5 \times 10^9 \text{ m}^3$

Hydrogeologic History

1760:

new dunes



1900: Pine forest
Reduce recharge

0 AD
Pine forest
Reduce recharge



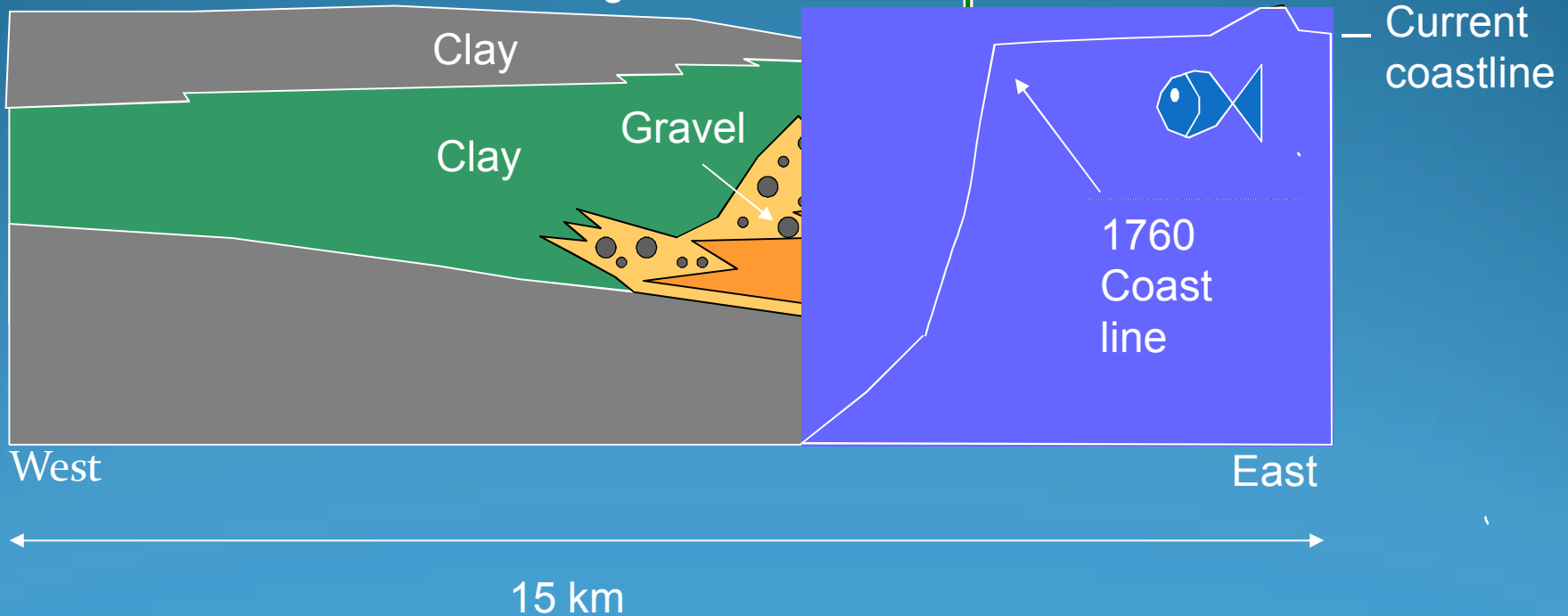
Quarries



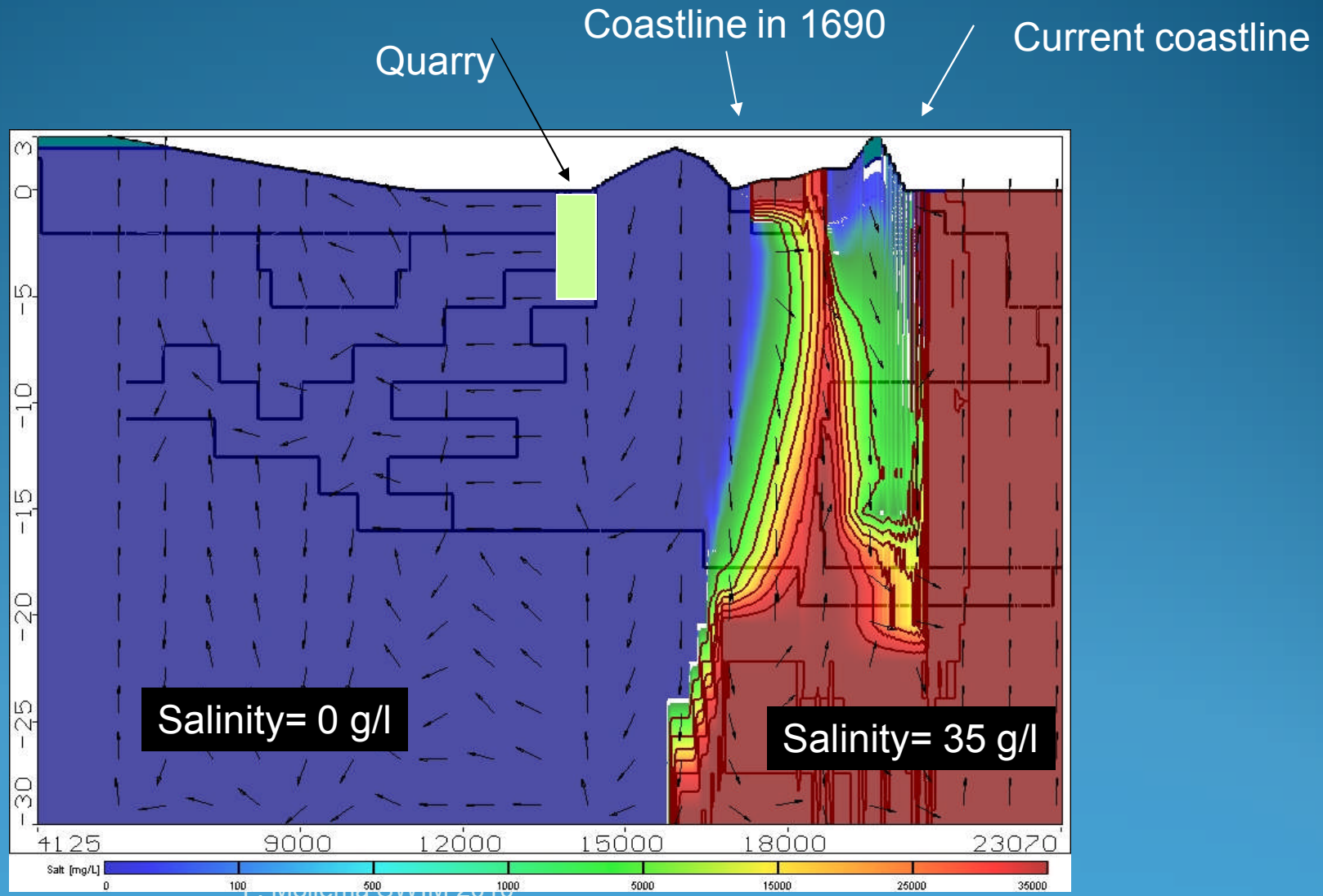
Drainage

1960

1935



Salt concentration after 250 years of recharge on dunes: not enough time to flush salt water before salinization trend starts again





Rocca Brancaleone

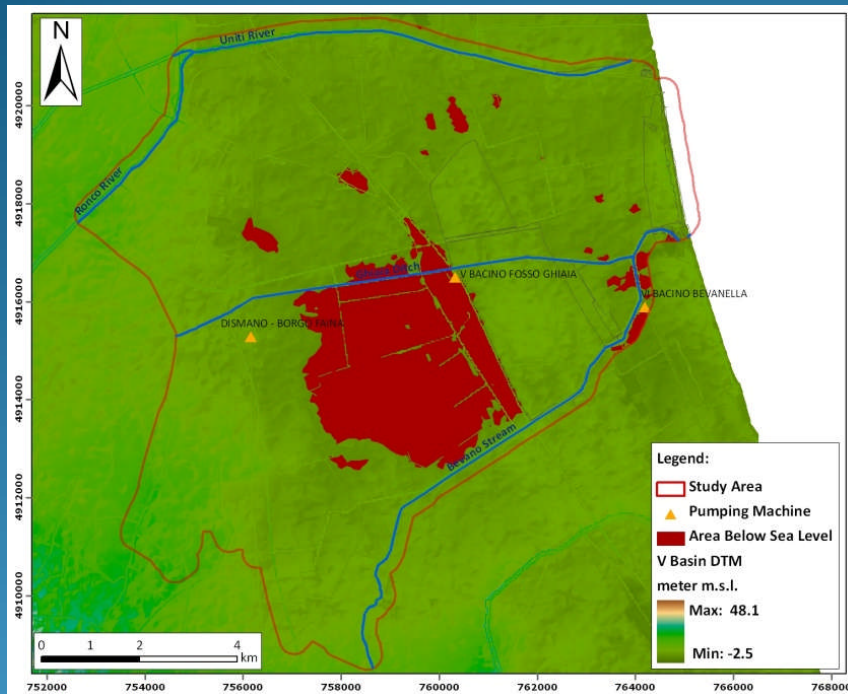


Battistero degli Ariani

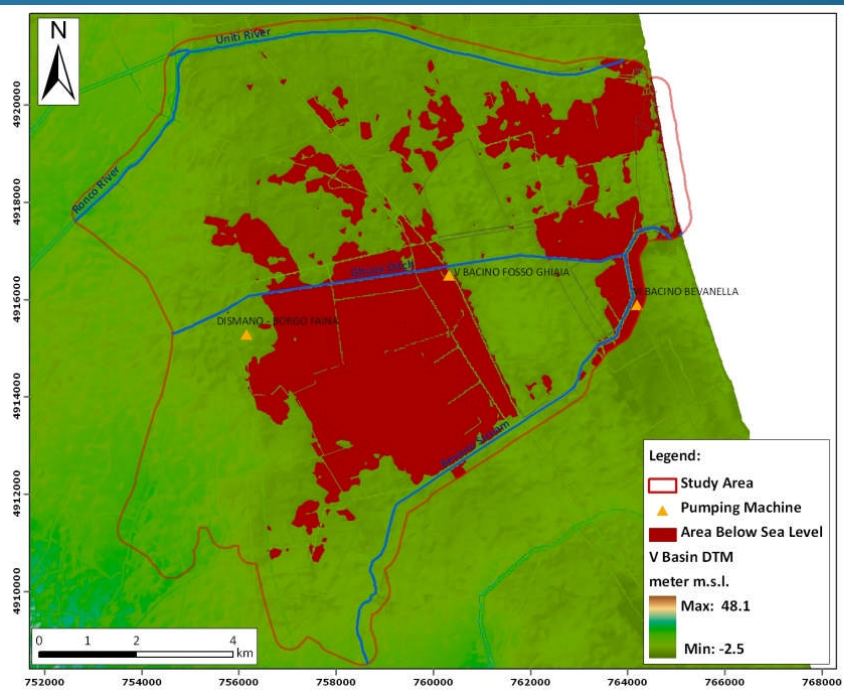
Land subsidence has been one of the major causes for groundwater salinization. The physical law is rather explicit: one cm lost to land subsidence is equivalent to 30 cm of aquifer lost to salinization (Ghijben-Herzberg)

Areas below sea level south of Ravenna

Quinto Basin



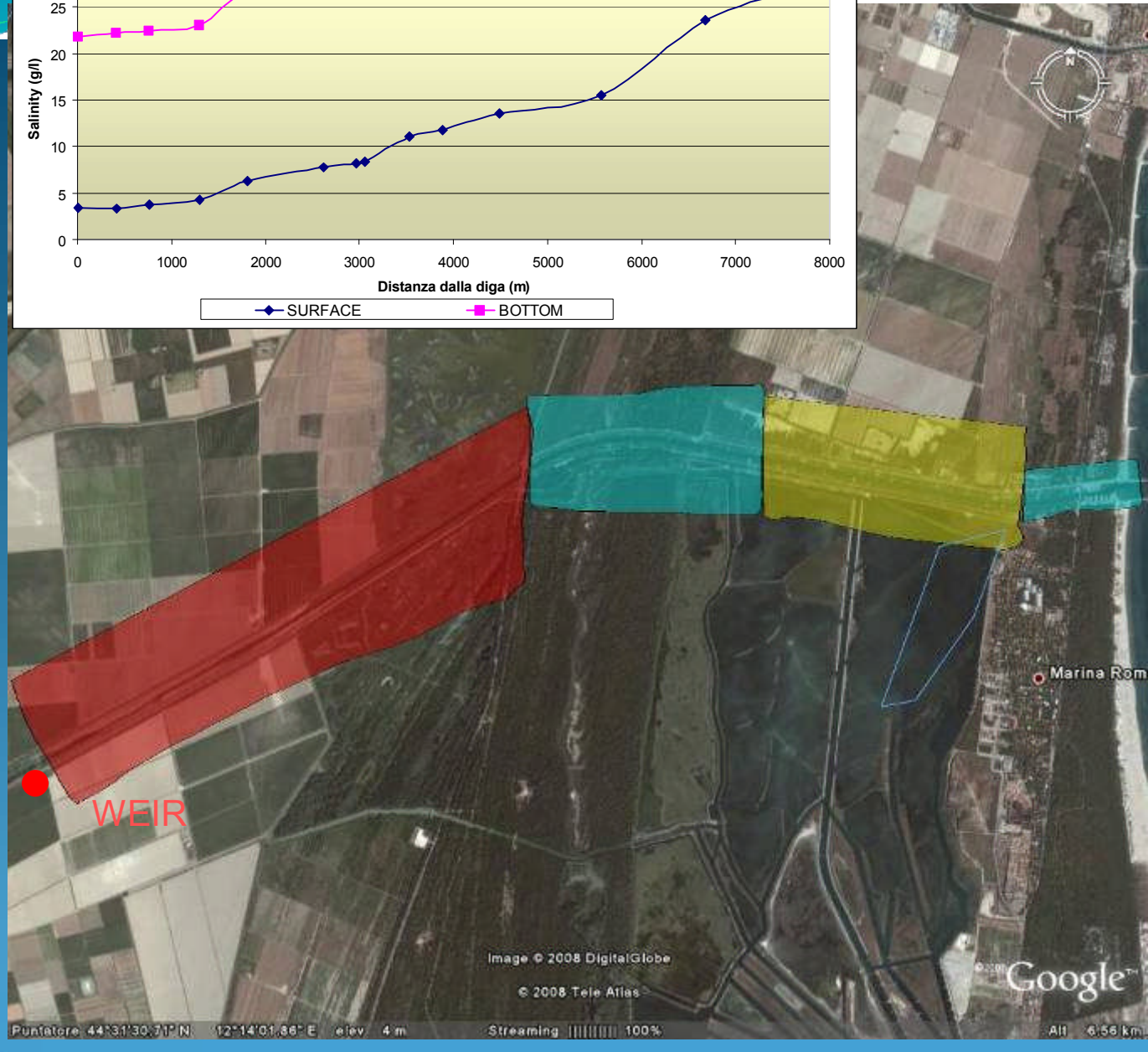
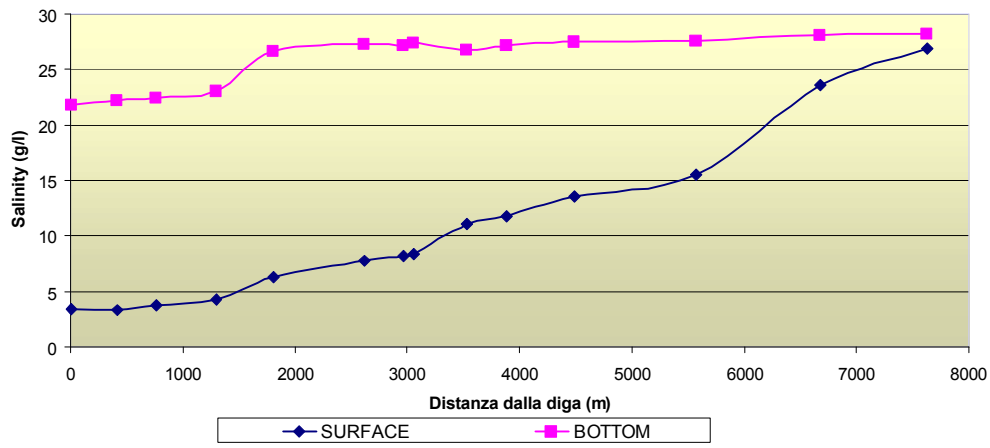
Today



2100

Estrapolazione from actual land subsidence rates

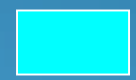
Lamone Salinity - 18/07/2005



Low permeability: clay



Medium permeability: silty sands – sandy silts



High permeability: sands

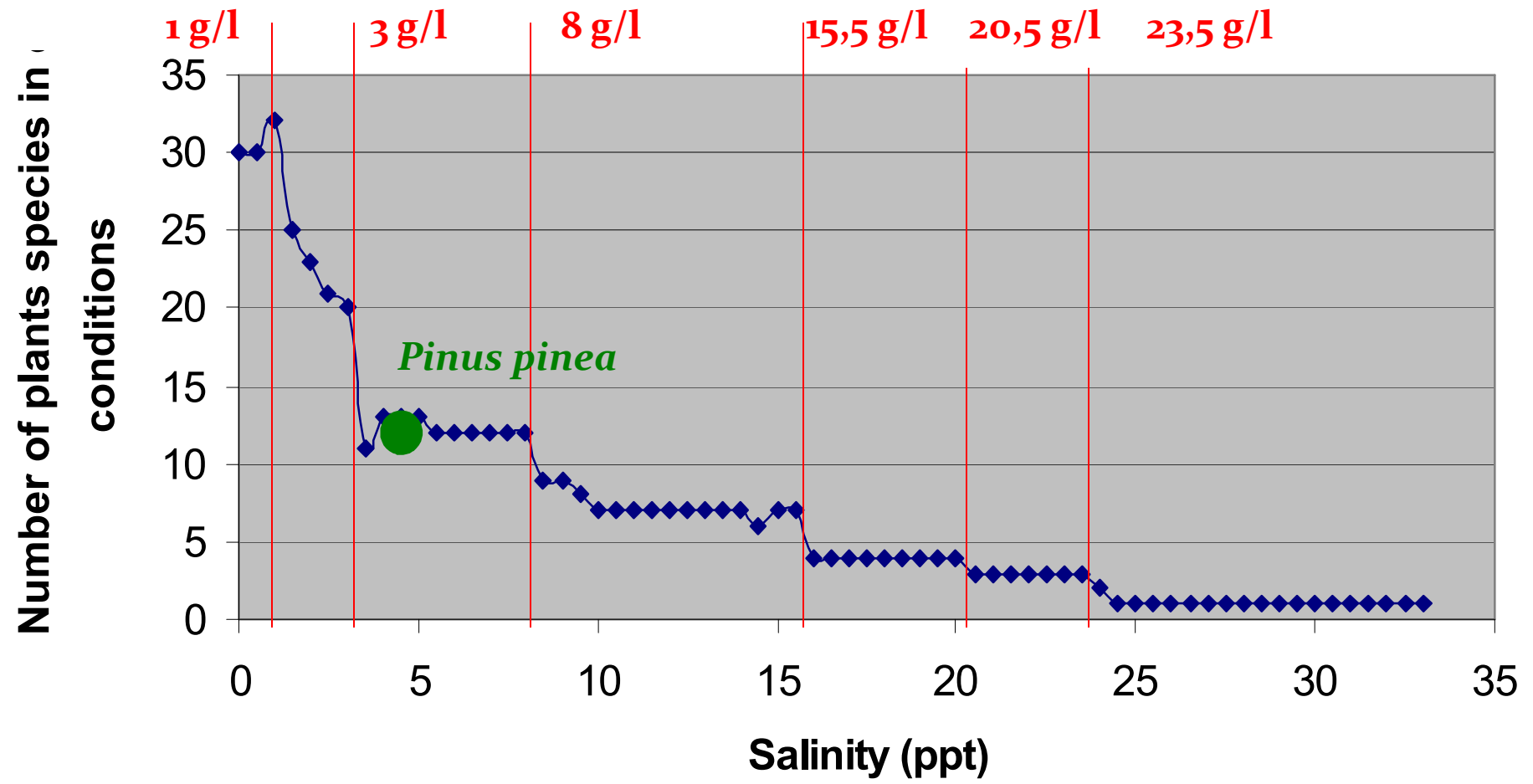
(from Laghi 2008)

Salinization and Biodiversity



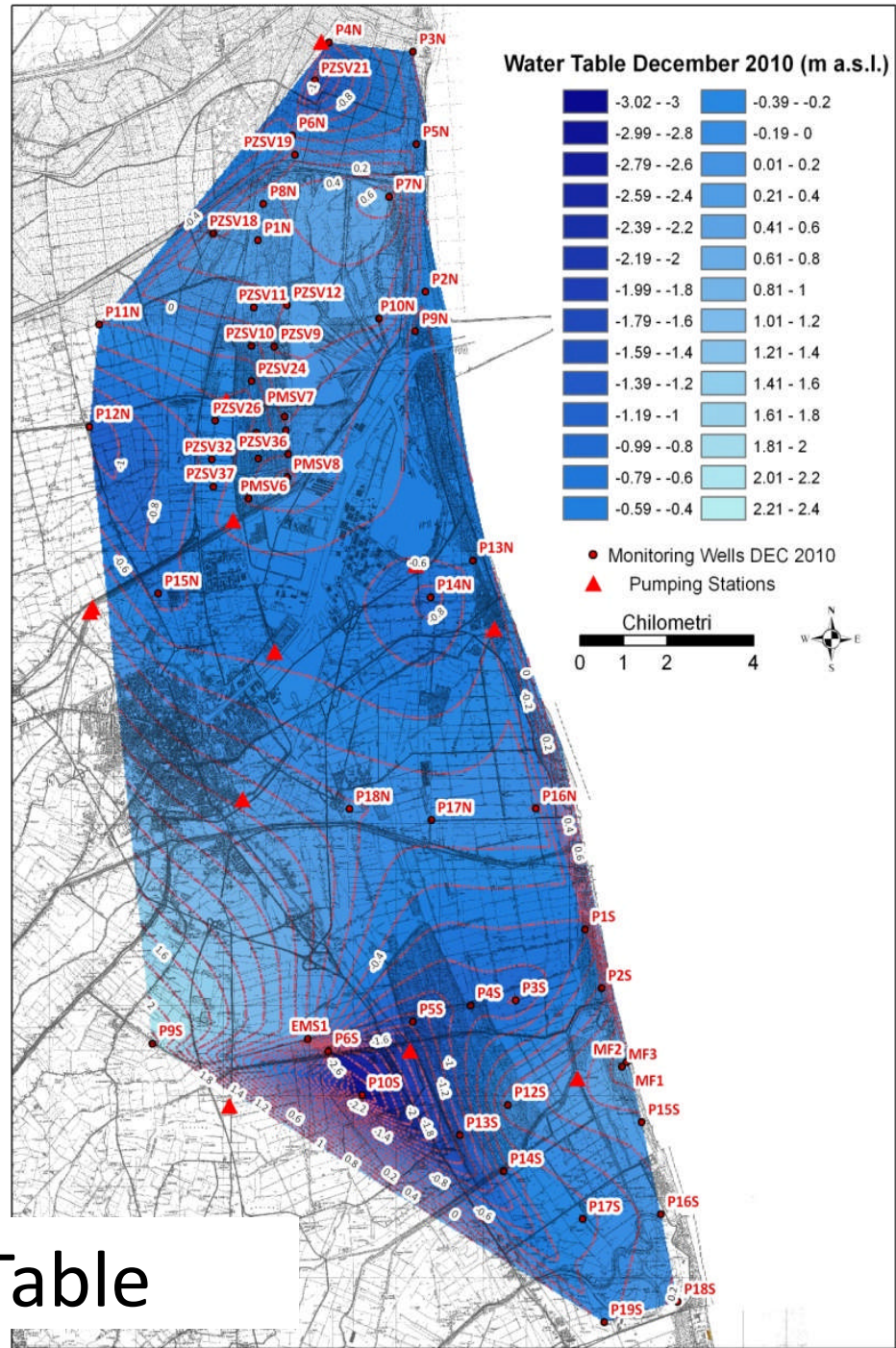
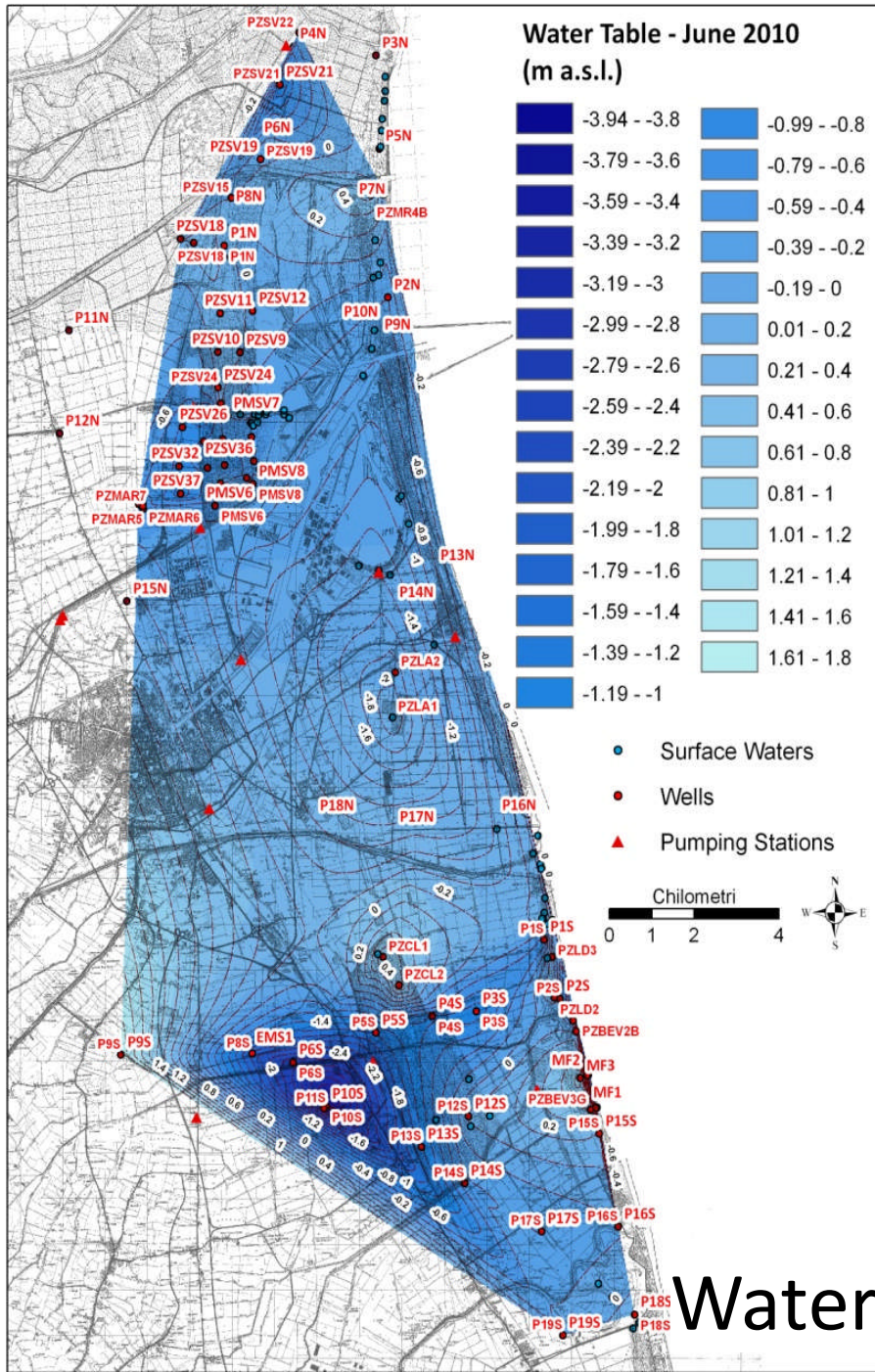
Number of Plant Species vs. Salinity

thresholds

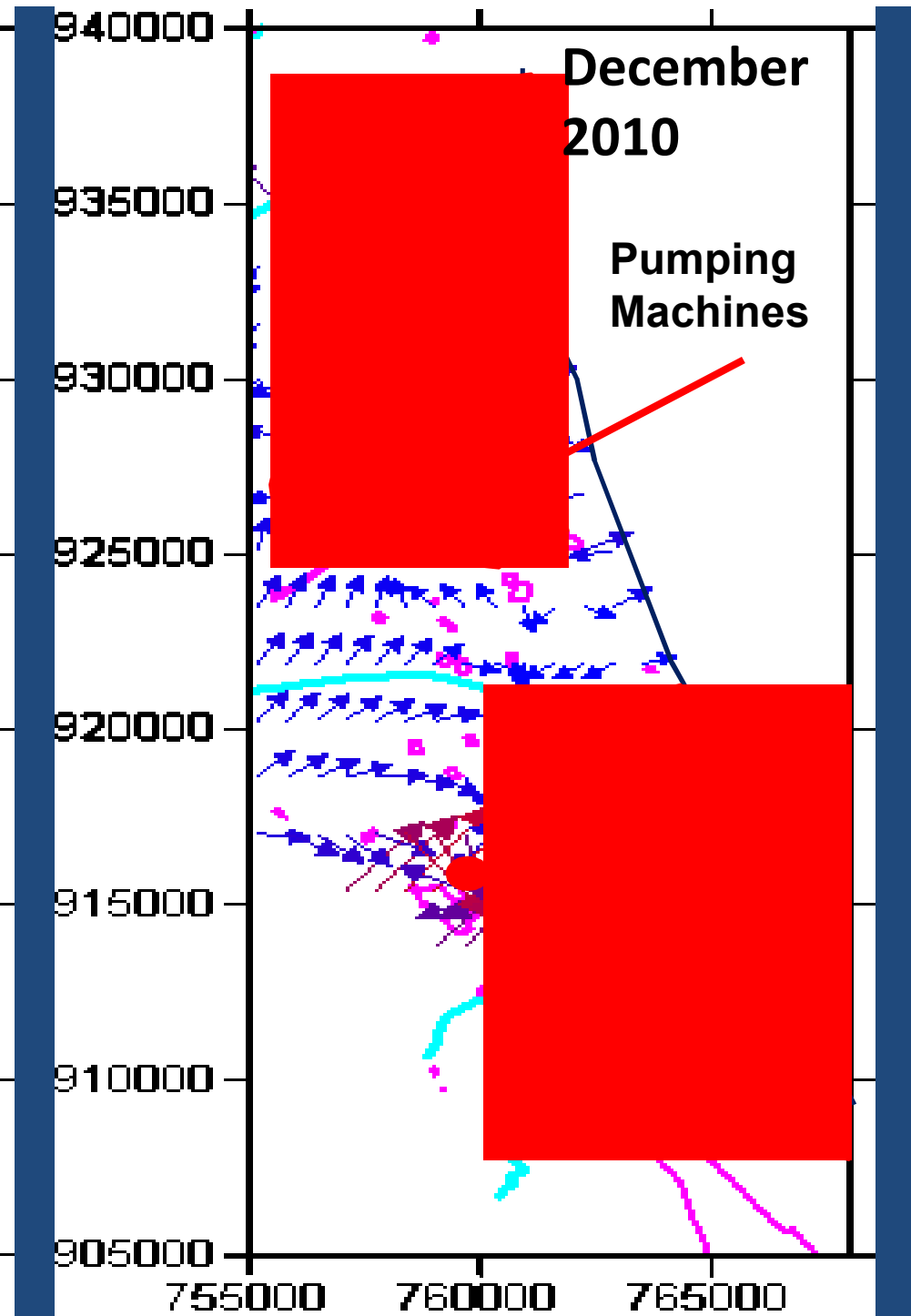
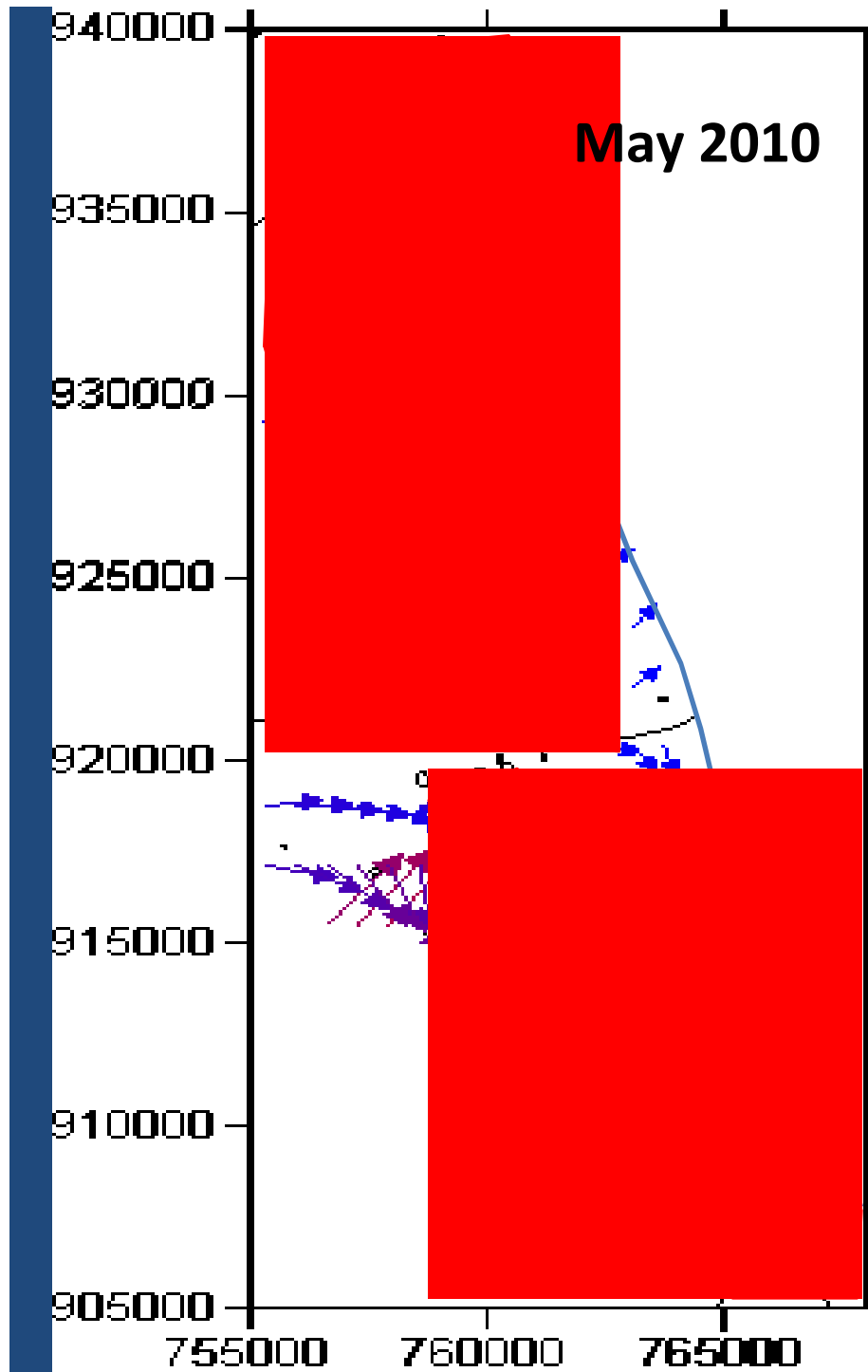


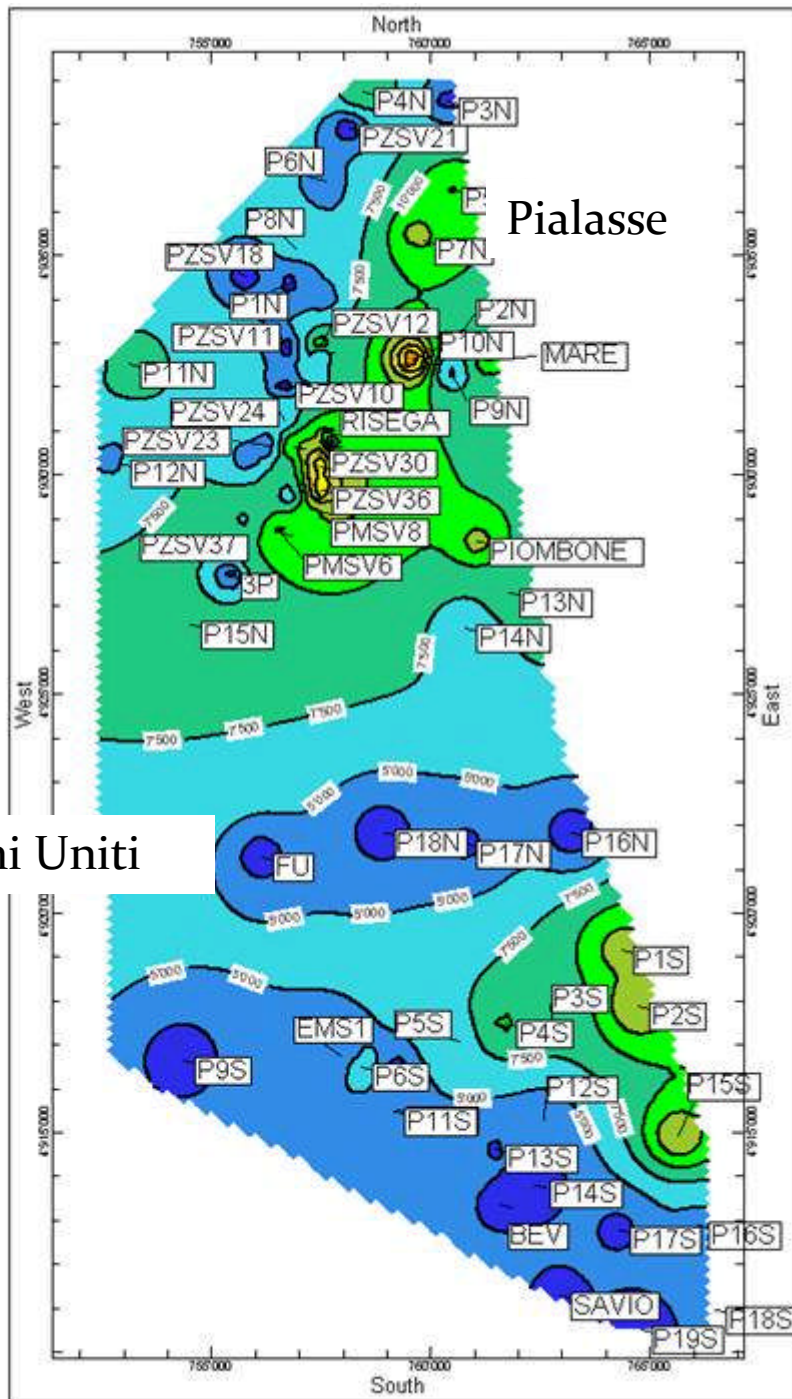
Soil Salinization and Loss of Farmland





Water Table

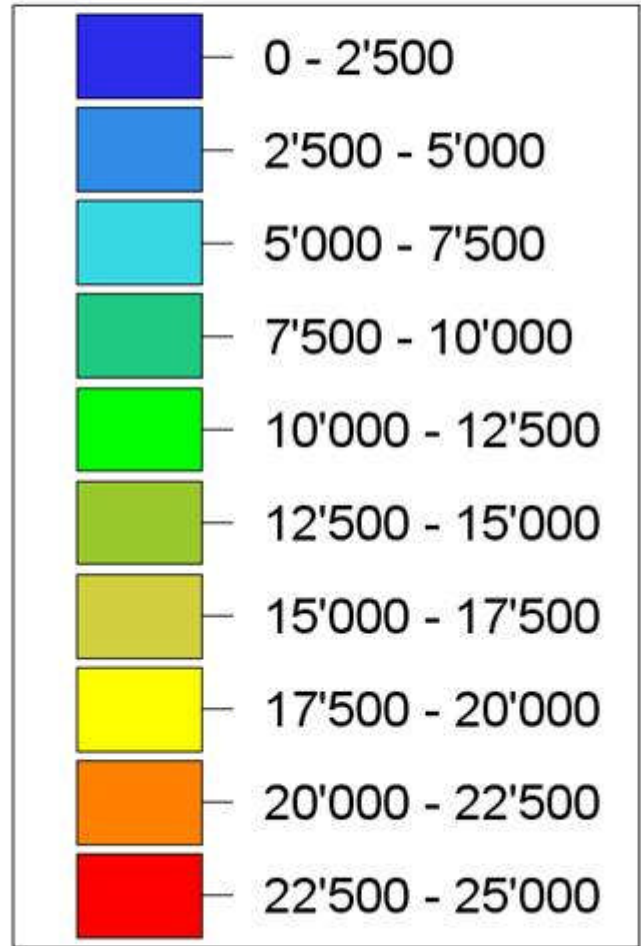




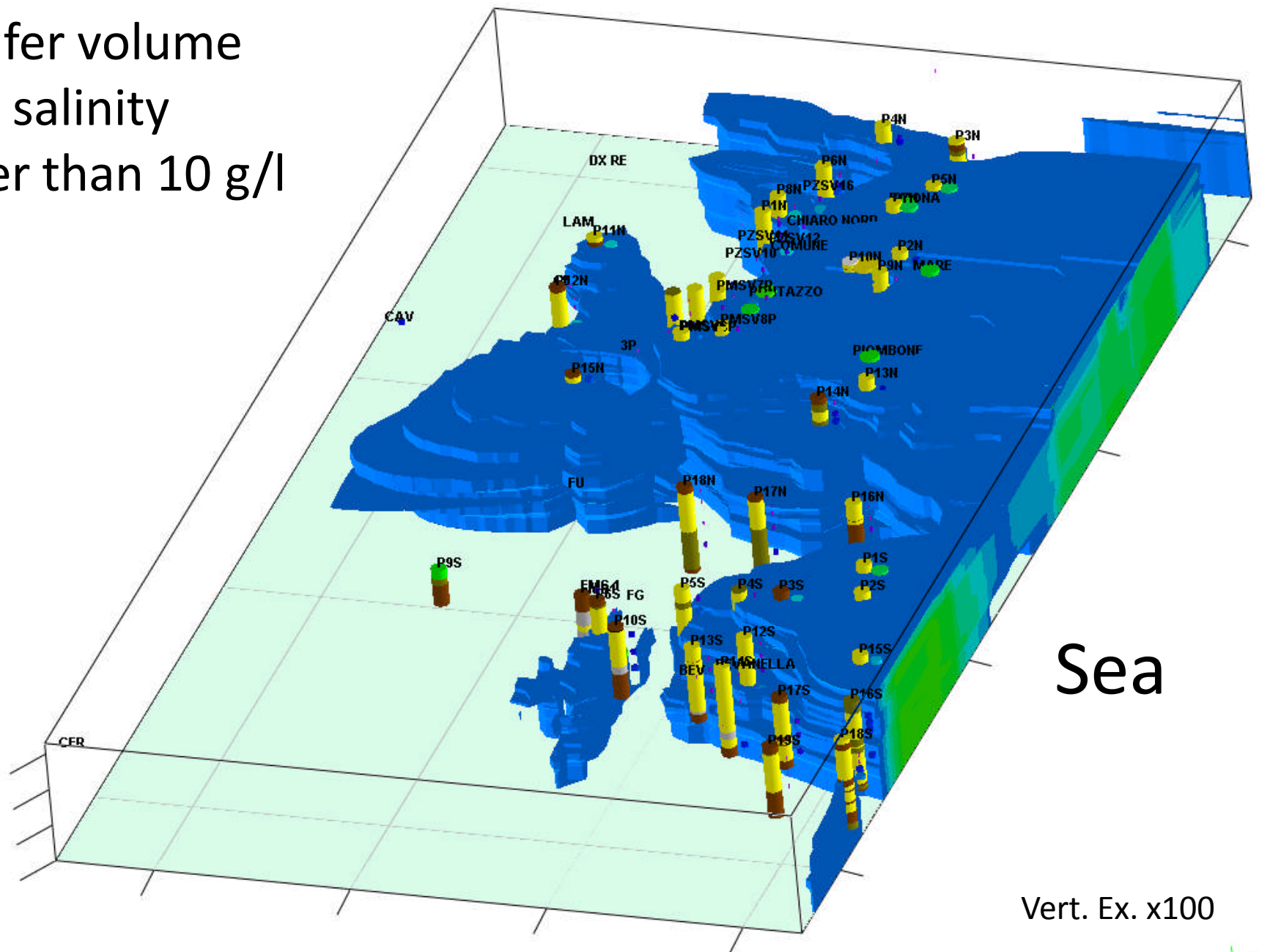
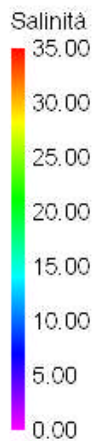
Pialasse

Fiumi Uniti

Cl⁻ [mg/l]



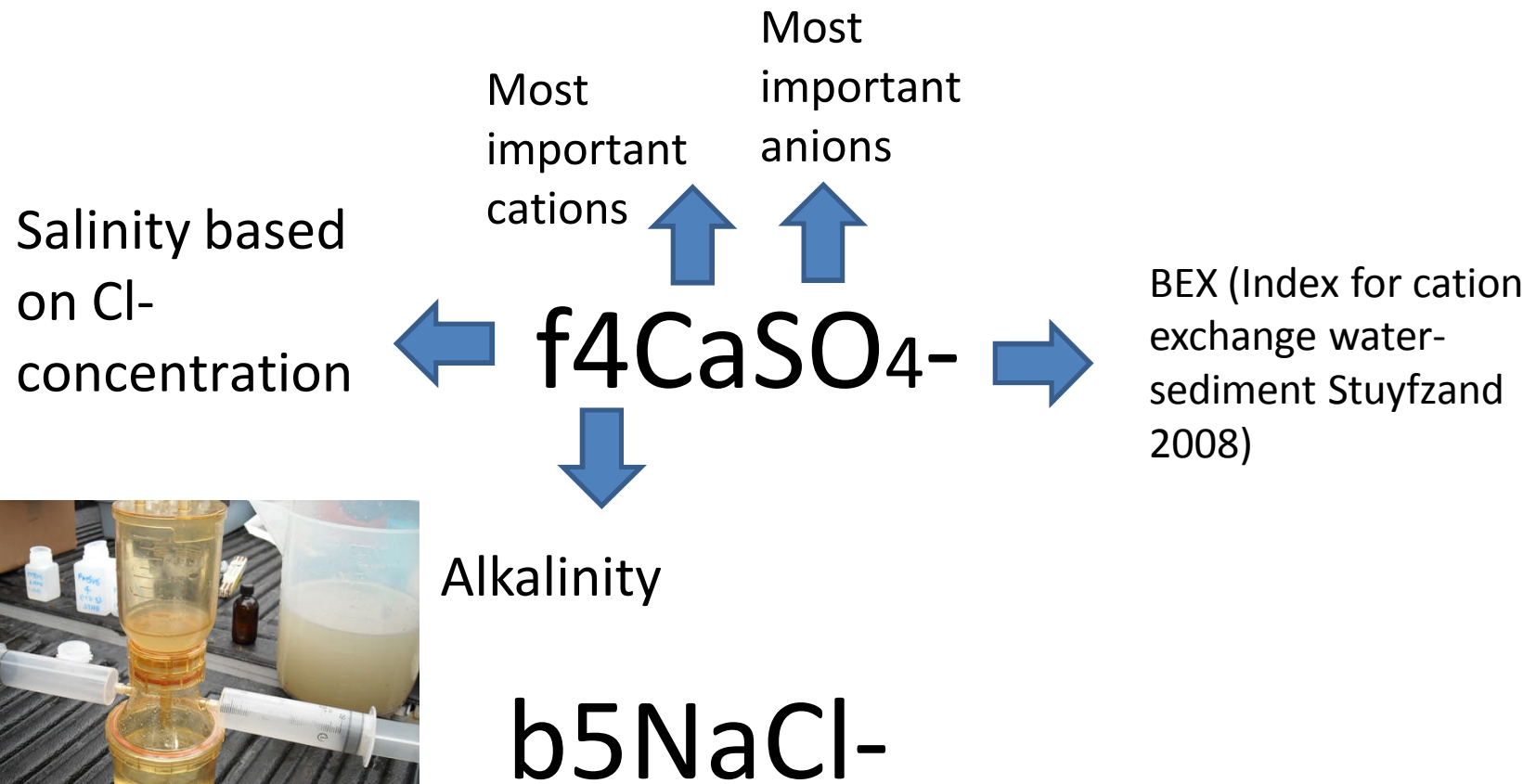
Aquifer volume
with salinity
larger than 10 g/l



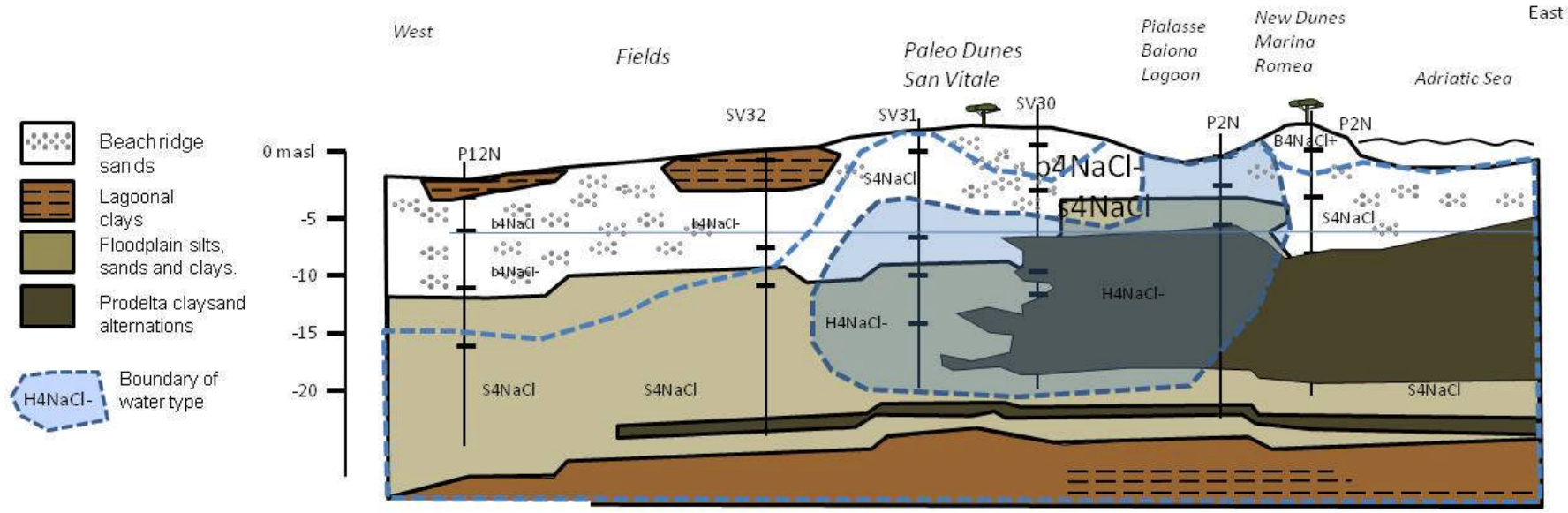
Vert. Ex. x100



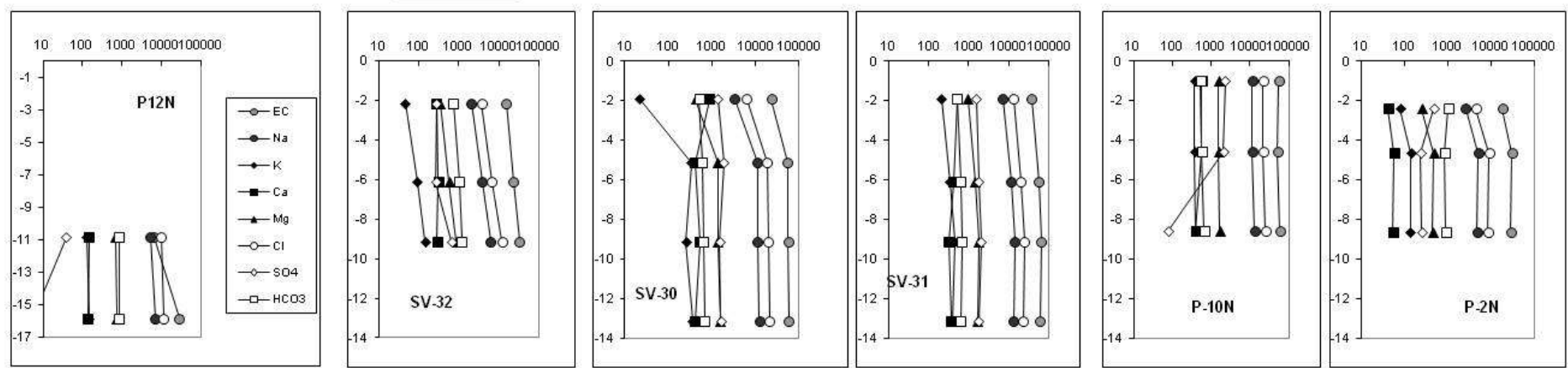
Hydrofacies analysis



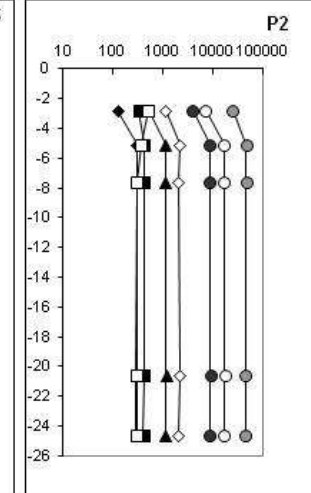
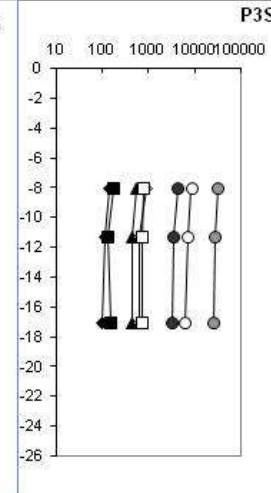
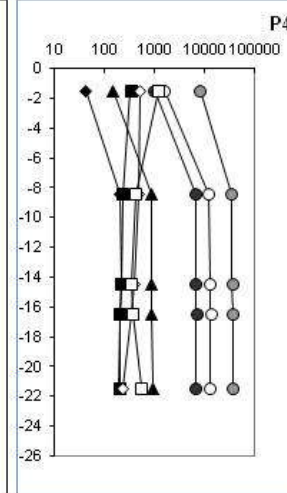
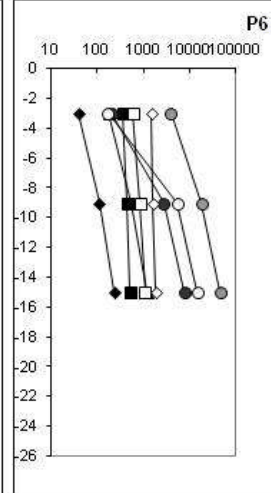
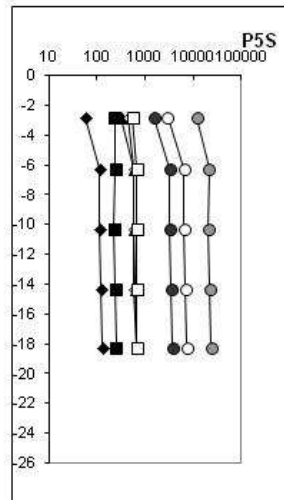
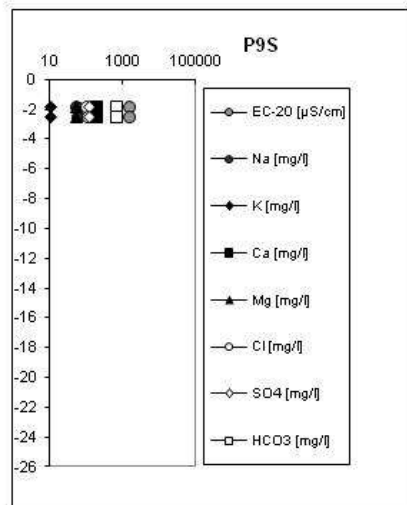
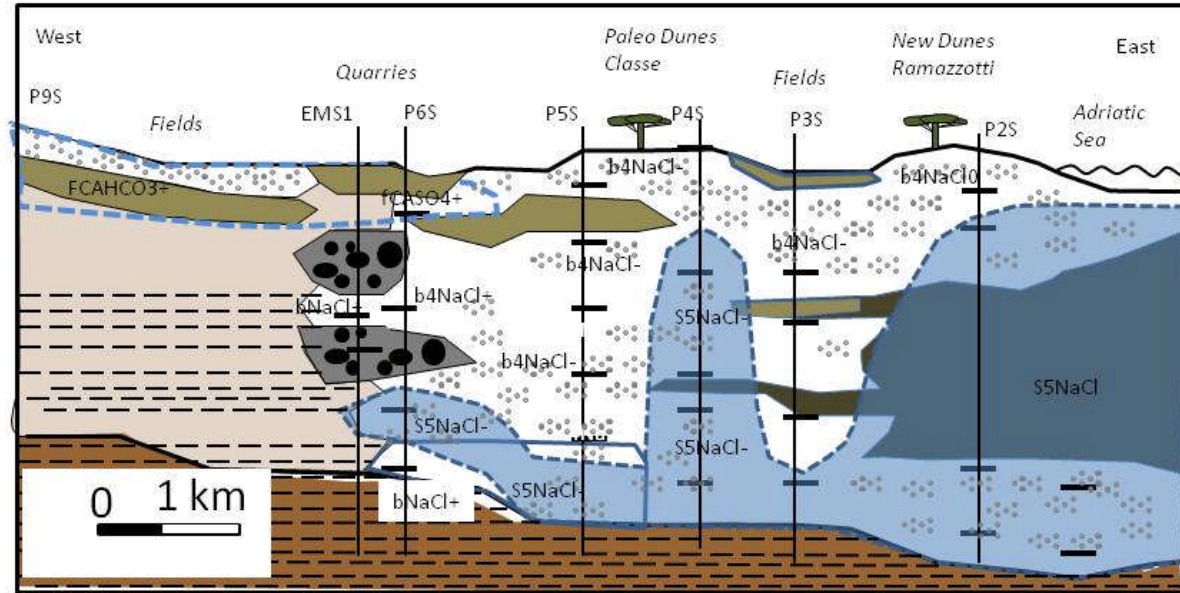
Section Ravenna North

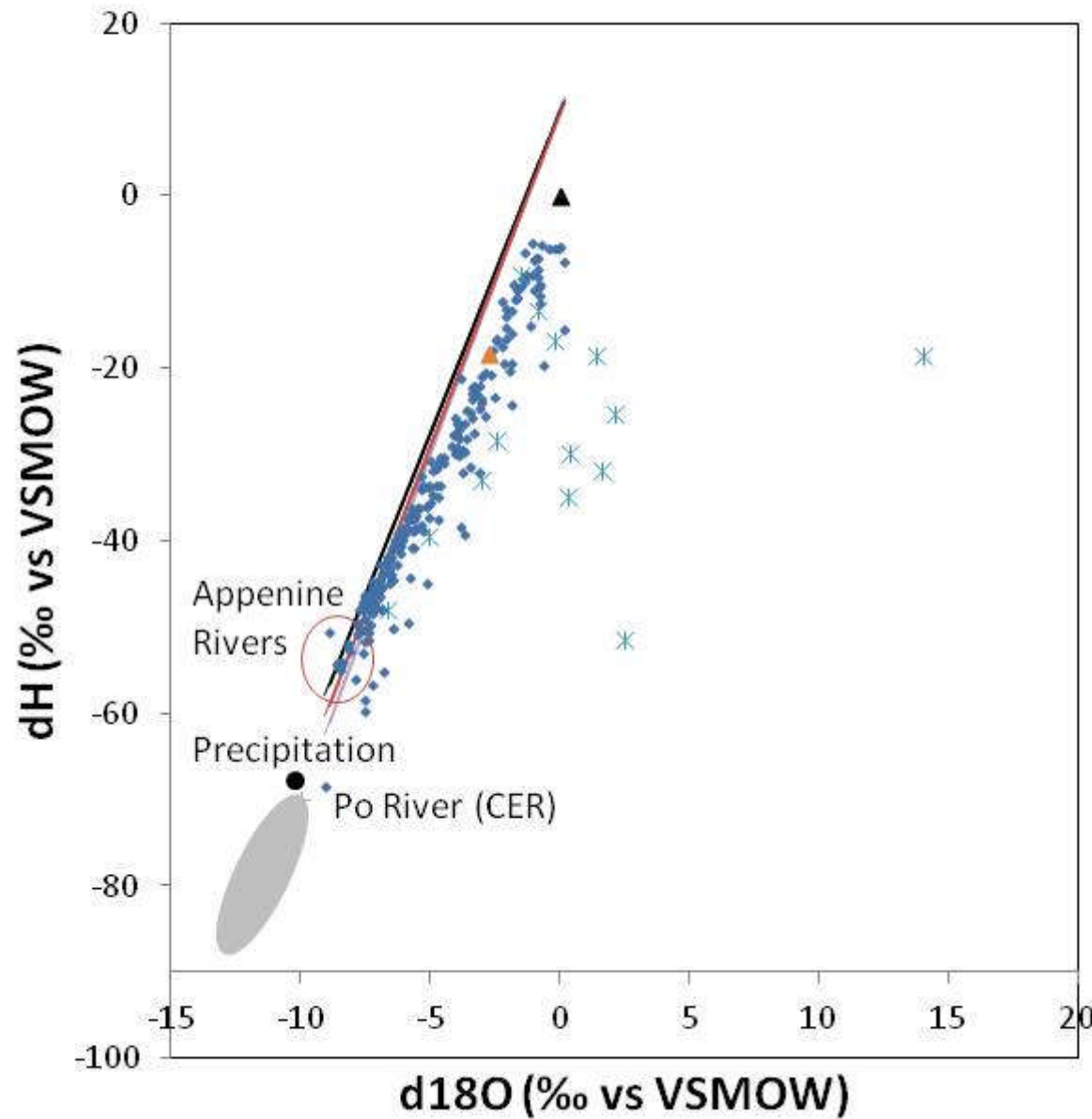


0 1 km

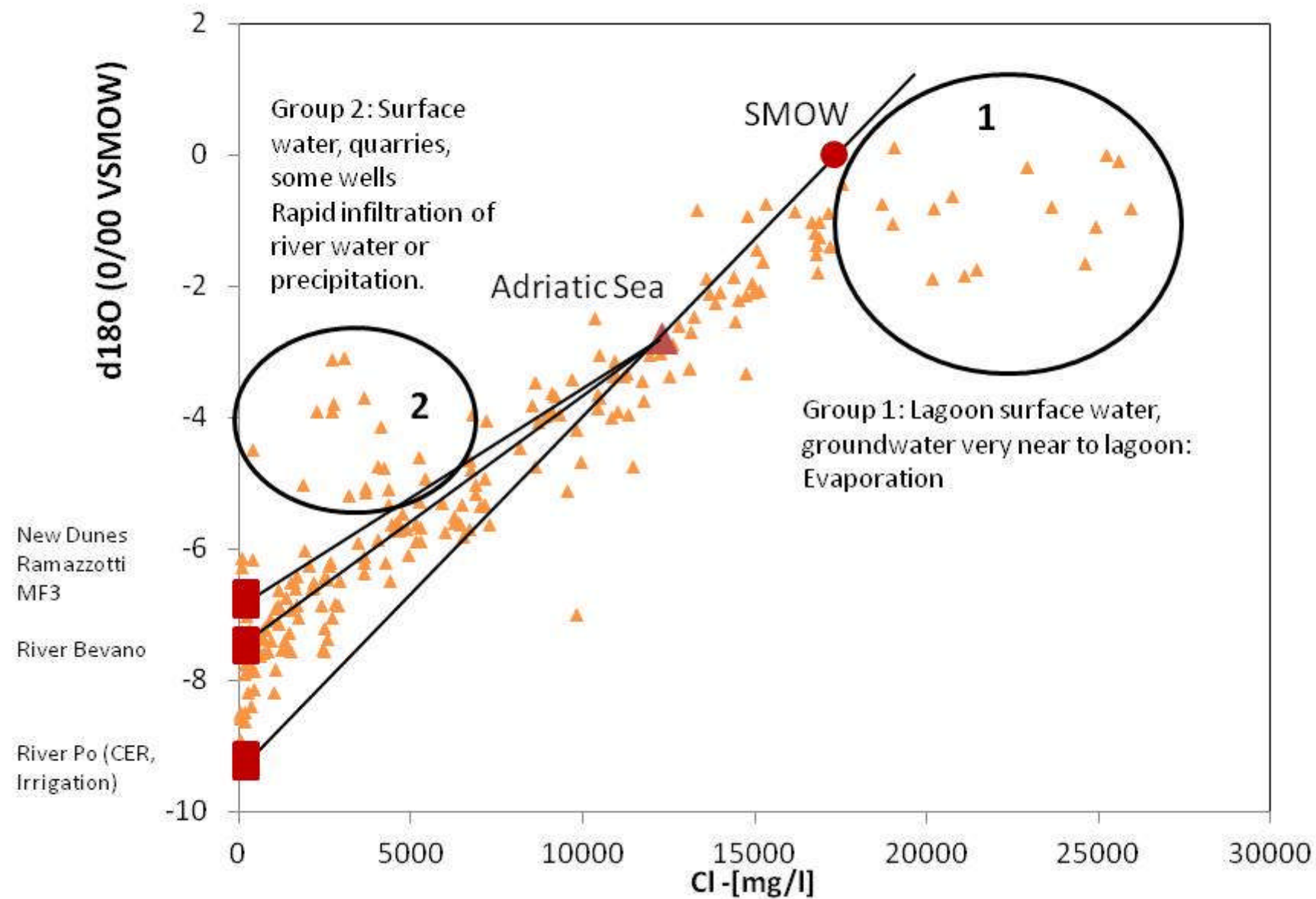


Section Ravenna South





- ◆ This study all samples
- GMWL (CRAIG 1961)
- Local MWL Cidu et al., 2011
- Northern Italy Meteoric Water line (Longinelli and Selmo, 2003)
- * Deep brines Po Plain, Pleistocene aquifers.
- ▲ Adriatic Sea
- Confined Aquifers Venice, after Gattacceca et al. 2009
- ▲ SMOW



W

E

Land subsidence +
Sea level rise



Rainfall

ET

Irrigation

Drainage

Sea level

Sea

Freshwater
lenses

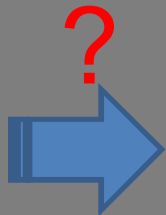
Upwelling

Sea-water
intrusion

Aquifer

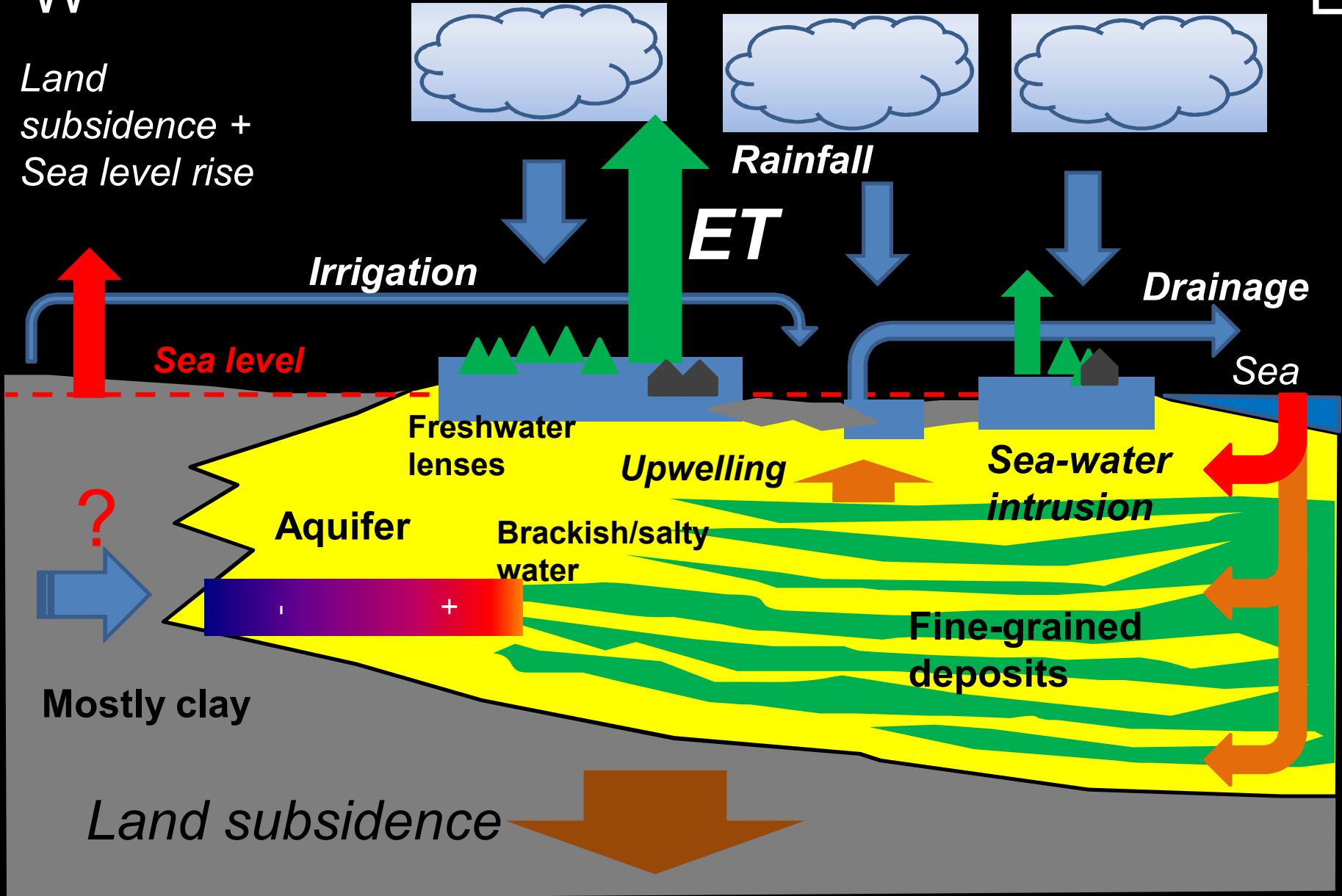
Brackish/salty
water

Fine-grained
deposits



Mostly clay

Land subsidence



Mitigation?

- Drainage network management accounting for canals directly connected to the aquifer. High hydraulic heads during the irrigation period should strongly help contain salinization.
- Move pumping machines towards the coastline.
- Close rivers and canals open to sea at the shoreline.
- Create a ring channel around the drained areas.
- Deep draining.
- Managed Aquifer Recharge.



Thank You
for your attention!