Interreg
Italy - Croatia
SeCure

EUROPEAN UNION

SeCure

Saltwater intrusion and climate change: monitoring, countermeasures and informed governance

Deliverable 2.1.1 Kick-off event report

June 2022 - Final version

Contributing partners:
LP – UNIPD , PP1 – CNR-IGG , PP2 – REGVEN ,
PP5 – PIDNC

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1. SeCure Kick-off conference

The Kick-off event of the SeCure project was organized on 22 June 2022 by Veneto Region (PP2) in Venice at Palazzo Grandi Stazioni, as planned in the AF of the SeCure Project and in the WP2 Communication Plan. It was mainly addressed to the Public Authorities (Local, Regional, and National) and also to Universities, Research institutes, and General Public.

The link to participate in the live-streaming event was https://call.lifesizecloud.com/5452472. The English-Italian translation was provided. The event was recorded and the video is available at the link https://www.youtube.com/watch?v=R4DIgEUww6M ().

Fig. 1 – Print-screen of the website with the event video.

A number of 48 participants attended the event: 35 on-site and 13 online. The signature list of the on-site participants is provided Appendix A. A few photos of the event are shown in Fig. 2, Fig. 3 and Fig. 4.

Fig. 2 – The conference room with some of the attendees just before the start of the event.

Fig. 3 – The conference room with some of the attendees just before the start of the event.

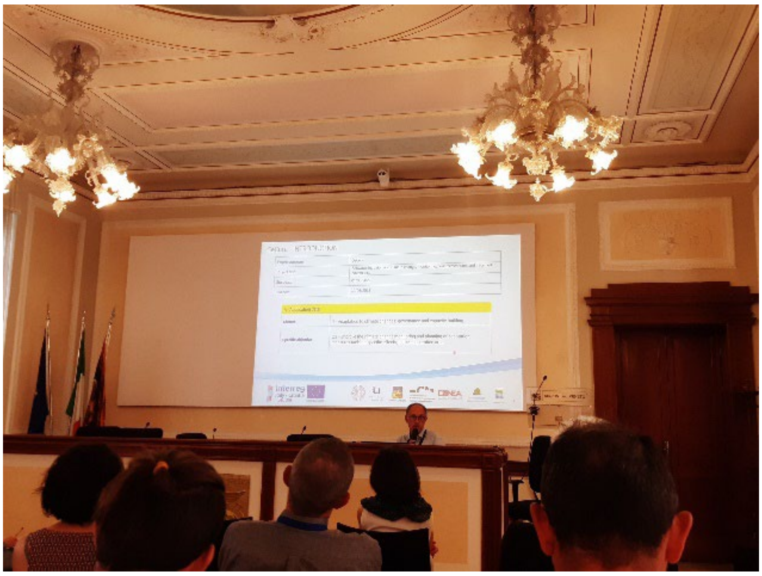


Fig. 4 – Speaker presentation and event attendees view.

2. Agenda

The agenda of the event was finalized after an intensive work carried out by REGVEN, supported mainly by UNIPD and CNR-IGG for the scientific interventions.

- 14:15 – 14:30 Registration of participants
- 14:30 – 14:45 Greetings by Managing Authority Italy Croatia 2014-2020

  Anna Flavia Zuccon*, Directorate for Unitary Programming, Veneto Region*
- 14:45 – 15:00 Introduction of the SeCure Project by the Project Manager

  Pietro Teatini*, Department of Civil, Environmental and Architectural Engineering, University of Padova*

- 15:00 – 15:15 MAC IT_HR projects outcomes: short videos summarizing the main outcomes

- 15:15 – 16:15 Relevant thematic experts – International Experts from specific pilot sites

  - Near-ground and Remote Sensing of Soil Salinity in California Farmland
    ***Elia Scudiero**, University of California, Riverside*
  - Role of the hydro-stratigraphical setting in controlling fresh-saltwater interface in the Rio de La Plata coastal plain, Argentina
    ***Francisco Celdone**, University of la Plata, Argentina*
  - Freshwater groundwater under tress; the case of the Mekong Delta, Vietnam
    ***Gualbert Oude Essink**, Deltares, The Netherlands*
  - Mapping seawater intrusion with Airborne E.M.
    ***Antonio Menghini**, Aarhus Geophysics ApS, Denmark*

- 16:15 – 16:30 Program expectations from Cluster communication
  ***Tea Ivanisevic**, Programme Communication Manager – Interreg V A Italy-Croatia 2014-2020, Veneto Region*
- 16-30 – 16:45 Conclusions

2.1 Greetings by the Managing Authority Italy-Croatia 2014-2020

Anna Flavia Zuccon, *Directorate for Unitary Programming, Veneto Region*

Fig. 5 - Dr. Anna Flavia Zuccon during her speech.

Anna Flavia Zuccon presented the steps toward the experimental initiative called "restrictive call for project proposal" that leaded to the cluster projects (Fig. 5). The call had four main objectives: (i) maximize the experiences of the partners who already participate in other projects of the program; (ii) fully exploit and consolidate the results; (iii) increase the knowledge on the addressed topics in preparation to the next programming period; (iv) allow synergies among the projects. With these aims, the program identified five thematic areas. The main expected achievements are: innovative schemes for the sustainability of results; transferability of results beyond the IT-HR Programme Area; activation of coordination processes with other Interreg and EU initiatives; involvement in communication and dissemination activities of other Standard and Strategic IT-HR projects operating in the same thematic area; the development of project ideas for the Interreg IT-HR Programme 2021-2027; share the results of the project with the policy makers who are thinking about the next programming period. The SeCure project belong to the cluster "Adaptation to climate changes" and is rooted in the three projects Asteris, MoST, and Change we Care. Looking at the next programming period, SeCure is coherent to the new specific objective 2.4 (i.e., climate change adaptation and disaster risk prevention) that is part of the Policy Objective

2 (i.e., a greener Europe – green and resilient shared environment) of the IT-HR draft proposal for the period 2021-2027.

2.2 Introduction of the SeCure Project by the Project Manager

Pietro Teatini, *Department of Civil, Environmental and Architectural Engineering, University of Padova*

Pietro Teatini introduced SeCure project (Fig. 6). The project acronym means "Saltwater intrusion and climate change: monitoring, countermeasures and informed governance". Starting date is 1 May 2022 and the ending date is 30 June 2023. The partners are:

Fig. 6 - Prof. Pietro Teatini during his speech.

- **LP UNIPD**: University of Padova (UNIPD), Dept. ICEA (S+ project: MoST)
- **PP1 CNR-IGG**: Institute of Geosciences and Earth Resources of the Italian Research Council (S+ project: MoST and Asteris)
- **PP2 REGVEN**: Veneto Region, Soil and Coast Defence Directorate (S+ project: MoST)
- **PP3 UNIST**: University of Split, Faculty of Civil Engineering (S+ project: MoST)
- **PP4 DUNEA**: Regional Development Agency of Dubrovnik Neretva Region (S+ project: MoST)
- **PP5 PIDNC**: Public Institution for the Management of Protected Natural Areas of Dubrovnik-Neretva County (S+ project: Change We Care)

- **PP6 CW**: Croatian Waters, Dept. of Water Resources (S+ project: MoST and Asteris)

The main objectives of SeCure project are: (i) take advantage of a further year to continue the monitoring activities started during the S+ projects; (ii) test the countermeasures that we plan during the S+ project; (iii) integrate the experiences coming from the S+ projects in order to upscale the guidelines developed at local scale focusing on the Adriatic basin. The SeCure project communication aims to reach different target groups (general public, local, regional, and national authorities, education and training centers, and universities and research institutes) through different communication tools adequate to each target group.

2.3 MAC IT_HR projects outcomes

The results of the S+ projects MoST, Asteris, and Change We Care WERE presented using three short videos that each project developed.

MoST Monitoring Sea-water intrusion in coastal aquifers and Testing pilot projects for its mitigation.

The video is available at the following link: *https://www.italy-croatia.eu/web/most*

ASTERIS Adaptation to Saltwater intrusion in sEa level Rise Scenarios.

The video is available at the following link: *https://www.italy-croatia.eu/web/asteris*

CHANGE WE CARE Climate cHallenges on coastal and transitional changing arEas: Weaving a Cross-Adriatic Response.

The video is available at the following link: *https://www.italy-croatia.eu/web/changewecare*

2.4 Relevant thematic experts – Experts from specific pilot sites

The topic of saltwater contamination was addressed by four international scientists that participated to the conference on-line (Scudiero and Essink) and on-site (Cellone and Menghini). A summary of their intervention is provided in the following. The slides of the presentation by Scudiero, Cellone and Essink are provided in the Appendices.

Near-ground and Remote Sensing of Soil Salinity in California Farmland

Elia Scudiero, *University of California, Riverside (Fig. 7)*

Fig. 7 - Dr. Elia Scudiero during his speech.

Agricultural soil salinity in California is mainly assessed by means of saturated soil water extract analyses. Depending on the electrical conductivity (ECe), the soil is classified into five categories from non-saline to extremely saline where most of the crops are not able to grow. Traditional soil sampling is combined with high-resolution geophysical measurements to map field-scale soil salinity. The main field scale technology is the assessment of soil apparent electrical conductivity (ECa) through electrical resistivity or electromagnetic induction measurements. The measurements follow the protocol developed by the U.S. Salinity Lab: (i) soil sensor measurements and statistical analysis to define the sampling scheme, (ii) soil sampling and analyses, (iii) site-specific calibration, and (iv) salinity mapping. Another technology for the assessment of soil salinity is the use of high-resolution remote sensing to capture short-scale changes. This is performed using reflectance products from satellite sensors (visible and NIR bands) to calculate vegetative indexes and study the crop status. As this is not a direct measurement of soil salinity, multiyear analyses are performed to assess the salinity stress. The final aim is to develop regional maps of soil salinity that may be used for further studies such as yield projection or the definition of the additional water required to leach the excess salts.

The slides of the presentation are available in Appendix B.

Role of the hydro-stratigraphical setting in controlling fresh-saltwater interface in the Rio de La Plata coastal plain, Argentina

Francisco Celdone, *University of la Plata, Argentina (Fig. 8)*

Fig. 8 - Dr. Francisco Cellone during his speech.

The investigated area is located in the marshes of the Rio de La Plata estuary. The Río de la Plata littoral is characterized by extensive and low-relief coastal plains with an extension of approximately 400 km. The estuary has a mixed semi-diurnal micro-tidal regime characterized by a mean range of 0.7 m. Salinity ranges from 0.5 g/L in the upper estuary to 20 g/L in the lower estuary. The geomorphology consists of the alternation and lateral migration of tidal flats, beach ridges, and sandy spits. Freshwater lenses are stored in the most permeable units and exploited for human consumption worsening the natural phenomenon of coastal aquifers salinization. The aim of the study is the investigation of the role of the hydro-stratigraphic and geomorphological setting in the freshwater-saltwater interface shape and in the distribution of freshwater lenses. The study was carried out using satellite imagery, installing groundwater wells and sediment sampling, analyzing the water electrical conductivity (EC), and performing Vertical Electrical Soundings (VES). Four zones were identified. (i) Zone 1 is characterized by sand and shelly beach ridge deposits lying above silty deposits that correspond to the Pleistocene loessic plain and in which the main freshwater reserves are stored. (ii) Zone 2 is characterized by beach ridges deposits above a bioturbated clayey layer close to 2 m thick and that decreases permeability and rainwater infiltration. (iii) Zone 3 is characterized by dune systems and aeolian sheets above sandy deposits of beach ridges associated with the migration of a spit. (iv) Zone 4 is characterized by aeolian sand sheets deposited above a thin layer of sand on beach ridges. Freshwater lenses of Zones 3 and 4 are associated with sandy beach ridges overlaid by sand sheets and dune systems and their thickness is related to both topography and low-permeability facies. When aeolian sand sheets and dunes develop on beach ridge deposits freshwater lenses can develop reaching thicknesses of 20 m.

The slides of the presentation are available in Appendix C.

Fresh groundwater under tress; the case of the Mekong Delta, Vietnam

Gualbert Oude Essink, *Deltares, The Netherlands (Fig. 9)*

The Mekong Delta is the "rice bowl" of South East Asia and more than 20 million people leave in the area. Saltwater intrusion seriously threatens agricultural activities and is worsened by groundwater extraction, land subsidence, and sea-level rise that cause also flooding and coastal erosion. Thanks to the data collected by different authorities, toolboxes can be used to understand processes and create projections on land subsidence (iMOD SUB-CR: Modeling subsidence), groundwater salinity (iMOD WQ-SEAWAT: Modeling salt transport and groundwater flow), and surface water salinity (Delft3D-FM: Modeling fresh and saline surface water). Moreover, the volume of freshwater per province per

Fig. 9 - Dr. Gualbert Oude Essink during his speech.

aquifer and the distribution of fresh-saline groundwater both in the present and in the past were estimated. The groundwater salinity in the past was modeled over 40kyr and the results show that most fresh groundwater was recharged 60-12kyr ago. Presently, groundwater is hardly being recharged due to the high resistance top layer. Moreover, when fresh groundwater is extracted, the fresh groundwater volume decreases much faster due to natural saltwater intrusion and mixing with brackish groundwater. Those issues may be mitigated by the combination of smart freshwater practices such as the extraction of brackish water and its desalinization, reduction of groundwater extraction, and freshwater storage during the wet season (Aquifer Storage).

The slides of the presentation are available in Appendix D.

Mapping seawater intrusion with Airborne E.M.

Antonio Menghini, *Aarhus Geophysics ApS, Denmark (Fig. 10)*

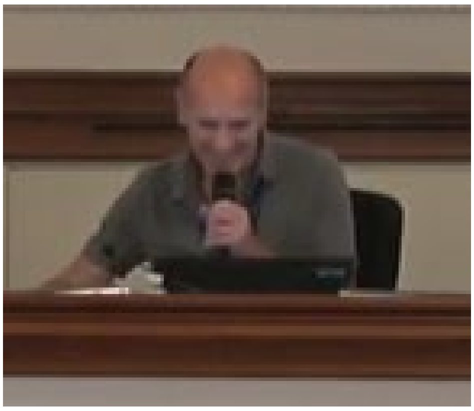


Fig. 10 - Dr. Antonio Menghini during his speech.

The airborne E.M. is a useful tool for hydrogeologists because of the following advantages: it is able to cover large areas (around 300 linear km per day), achieve a great data density and a good penetration depth (around 500 m), it is cost-effective (100-200 euros per km), and it produces qualitative results. Airborne E.M. consists of a transmitter (a loop with a 20 m diameter) mounted on a helicopter. An electromagnetic signal induces eddy currents in the ground which are detected by the receiver mounted in the same frame as the transmitter. The second step consists in modeling the ground response to produce a 3D resistivity or conductivity map. This method can easily detect seawater encroachment in coastal areas and particularly the freshwater saltwater interface depth.

2.5 Program expectations from Cluster communication

Tea Ivanisevic, *Programme Communication Manager – Interreg V A Italy-Croatia 2014-2020, Veneto Region (Fig. 11)*

The SeCure project is much about communication (work package 2). The cluster communication is expected to be focused on a common thematic aspect of the Italy-Croatia program with the final aim to be the reference point of that theme in the area. The communication activities should be accessible, transferable, visible, and are expected from the beginning of the cluster project. Moreover, other mandatory tasks are a digital editorial plan for each semester, website publications and updates, and the preparation of project posters placed in a location visible to the public.

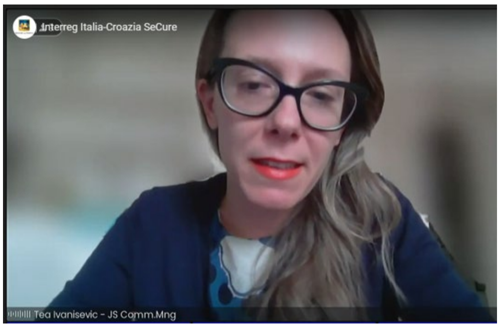


Fig. 11 - Dr. Tea Ivanisevic during her speech.

UC RIVERSIDE
Environmental Sciences Department

Agricultural Research Service
U.S. Salinity Laboratory

Near-ground and Remote Sensing of Soil Salinity in California Farmland

Elia Scudiero

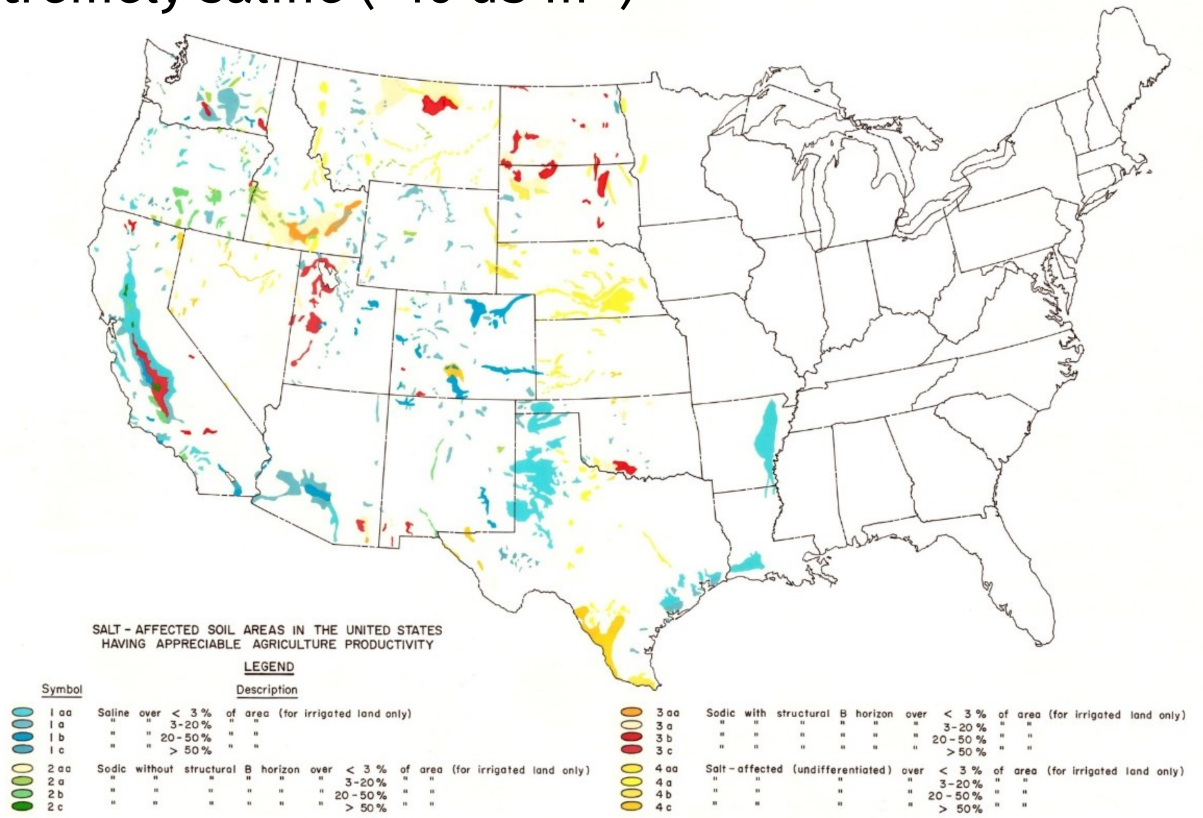
SeCure Project Meeting
Veneto Region - Soil and Coast Defense Department
Wednesday, 22nd June 2022 – Palazzo Grandi Stazioni, Venezia

Agricultural soil salinity

- Salinity refers to the presence of Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, SO_4^{2-}, HCO_3^-, NO_3^-, CO_3^{2-} in the soil solution.
- **Usually measured as electrical conductivity of saturated soil extract (EC_e, dS m^{-1})**

  Non-saline (0-2 dS m^{-1})
  Slightly saline (2-4 dS m^{-1})
  Moderately saline (4-8 dS m^{-1})
  Strongly saline (8-16 dS m^{-1})
  Extremely saline (>16 dS m^{-1})

- **Salinity in the world** (ITPS, 2015)
  - 1 billion ha of land is salt-affected
  - **20%** of the ~300 million ha of **irrigated farmland** is estimated to be affected by salinity.
    - >50% found in four countries: China, India, Pakistan, and **United States**



USDA-ARS US Salinity Laboratory (ca. 1970)

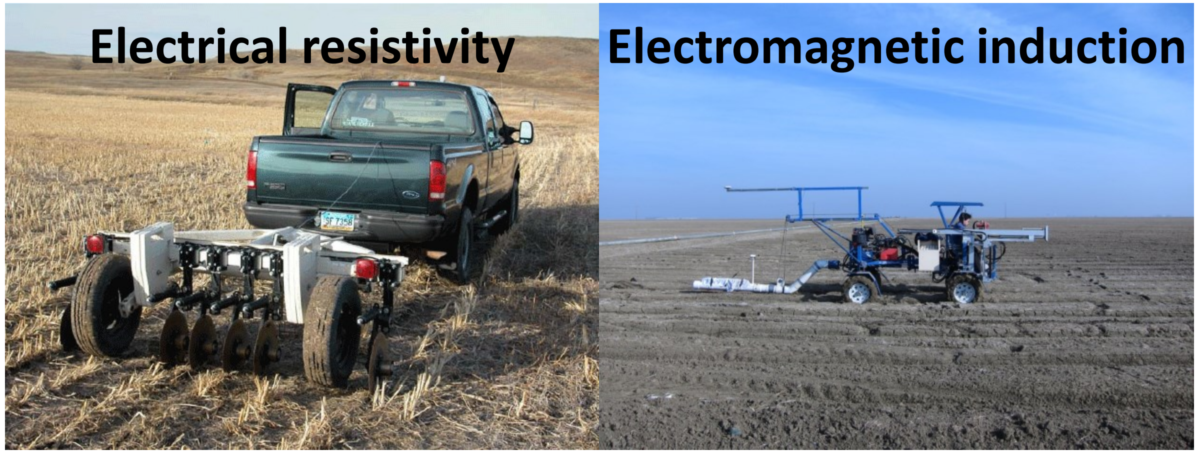
Short-scale spatial variability/heterogeneity at the field scale

- Spatial variability of salinity influenced by multiple factors (e.g., soil texture, soil type, irrigation management).
  Often resulting to high short-range variability at the field scale

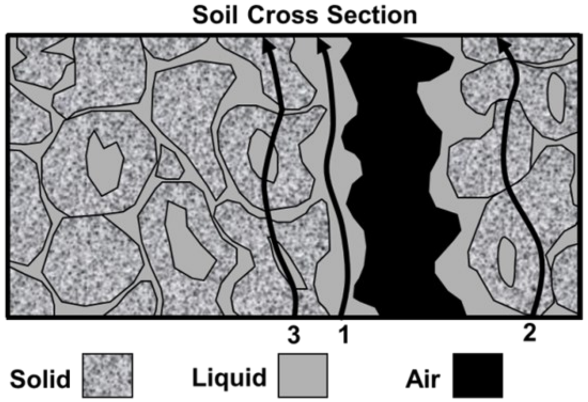
- In irrigated soils, most of salts accumulate below the soil surface, throughout the root-zone (0 to ~1 m)

We use a combination of traditional soil sampling and high-resolution geophysical measurements to map monitor field-scale soil salinity

Soil apparent electrical conductivity (EC_a)



Several depths of penetration: 0-30, 0-75 cm, 0-150 cm



Rhoades et al., 1989

EC_a complex measurement:

- Salinity ↑ ← Transient
- Water Content ↑ ← Transient
- Texture (Sand ↓; Clay ↑)
- Gravel (↓)
- ....

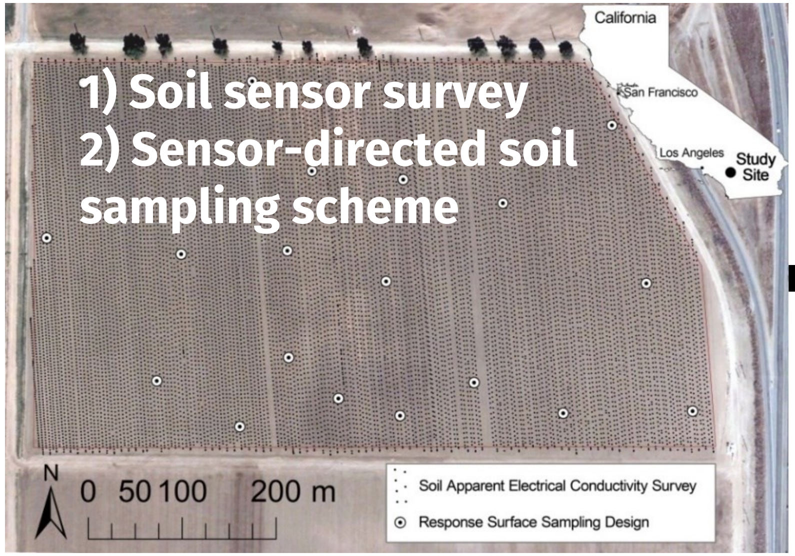
Flood, sprinkling irrigation (horizontally homogeneous)

- ECa survey best when done at field capacity (or slightly drier soil)

Ongoing research: ECa measurements in drip irrigated soil profiles

FIELD SCALE: From EC_a measurement to salinity maps

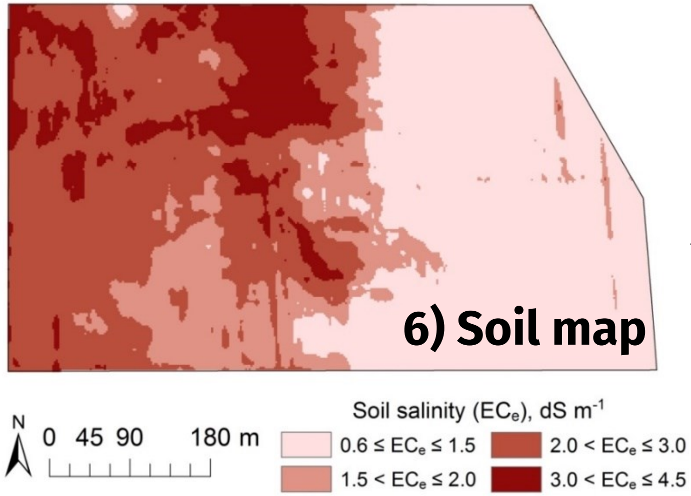
We use the protocols for field-scale salinity mapping developed by Dr. Corwin and other U.S. Salinity Lab colleagues



3) Soil sampling 4)laboratory analyses

5) A site-specific calibration is needed!

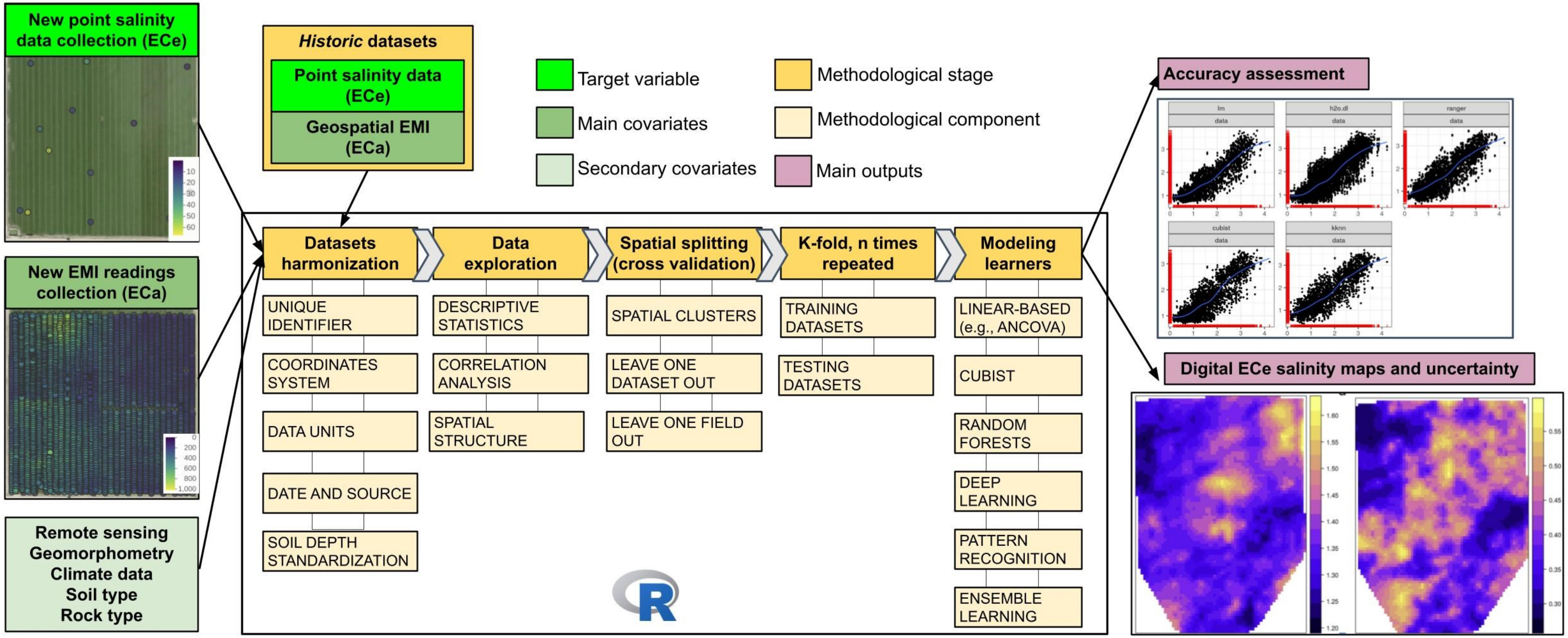
- Machine learning
- Geostatistics (co-Kriging)
- Regression modeling



Workflow for automated sensor calibration and soil mapping

When large datasets (hundreds of agricultural fields) are available,
e.g., federal agencies, soil mapping businesses, …

Mario Guevara
Postdoc



Use high-res soil maps to, e.g., inform regional scale models, direct field-scale management, …

Short-scale spatial variability/heterogeneity across scales

- Spatial variability of salinity influenced by multiple factors which result in high short-range variability at the field scale

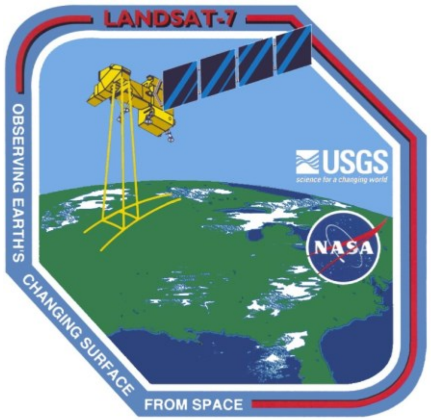
- Often, because of different management (irrigation water quality) neighboring fields are characterized by dramatically different salinity levels

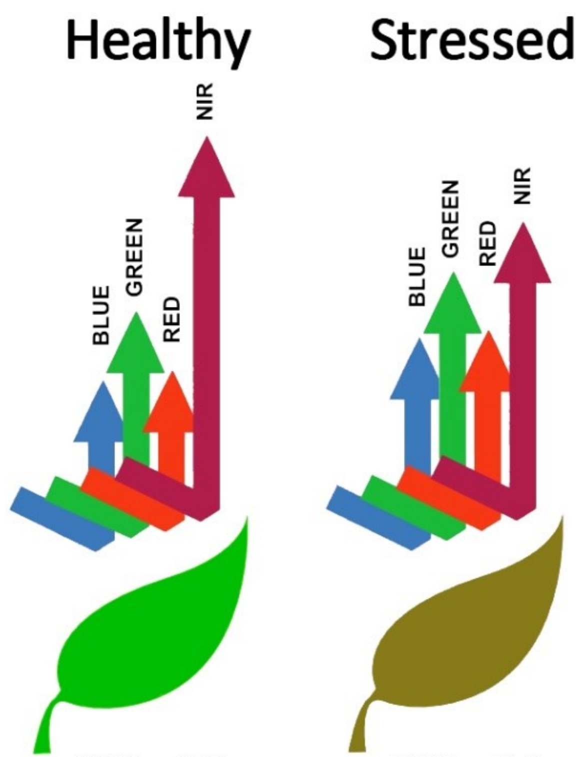
We use high-resolution remote sensing to capture such short-scale changes

REGIONAL SCALE salinity assessment

SURFACE REFLECTANCE OF CROPS

- **VEGETATION INDICES** at **30x30m** resolution
  Blue (450-520 nm)   Green (520-600 nm)
  Red (630-690 nm)   Near-infrared (770-900 nm)





CRSI = 0.9   CRSI = 0.6

$$CRSI=\sqrt{\frac{(NIR\times R)-(G\times B)}{(NIR\times R)+(G\times B)}}$$

Surface reflectance is influenced by:

- Relative crop status
  → **stressed vs. non-stressed**
  (e.g., B,G,R → photosynthesis activity; NIR → turgor)
- Crop type / phenological stage
- Soil type (texture, SOC, iron, <u>salt crust</u>, …)

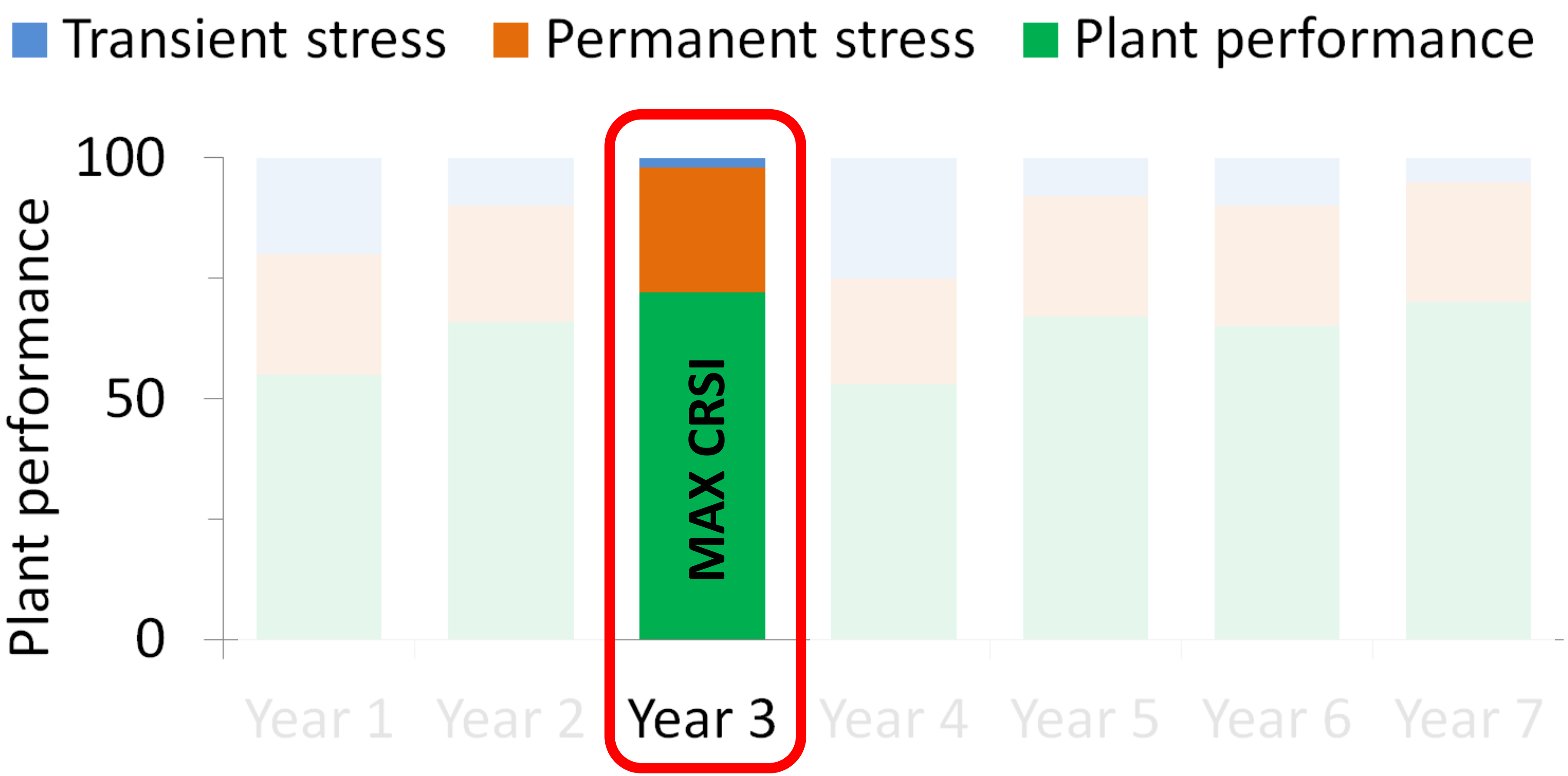
Thermal imagery can be used too

Ivushkin et al. (2017). Satellite Thermography for Soil Salinity Assessment of Cropped Areas in Uzbekistan. Land Degradation & Development, 28, 870-877

<u>**This is not a direct indicator of soil salinity.**</u>
<u>**Ground-truth sampling is needed**</u>

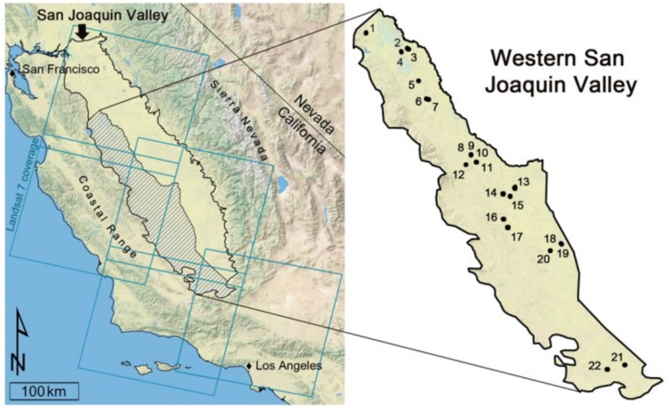
Multiyear max CRSI and soil salinity

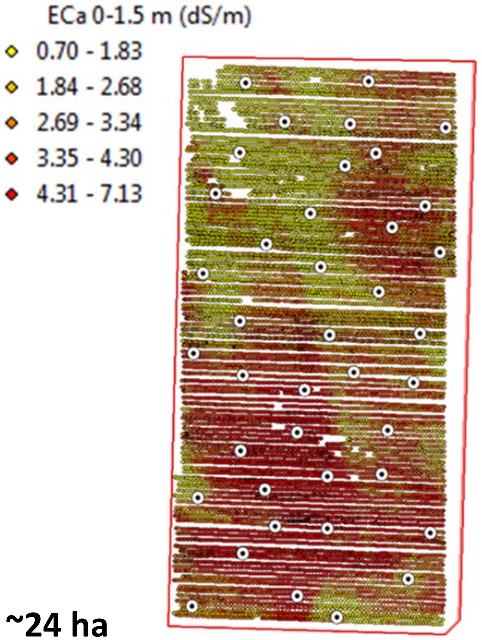
- Under similar management, **salinity stress (*permanent* stress)** is fairly constant in the root-zone through a limited amount of time
- Plant performance (measured with CRSI) is maximum when transient stress sources are at minimum→ **salinity effect on plant growth is highlighted**



Ground-truth measurements

- 22 fields sampled in 2013 (ca. 550 ha) in western San Joaquin Valley,
- ~42,000 APPARENT ELECTRICAL CONDUCTIVITY (**EC_a**) measurement at 0-0.75 & 0-1.5 m (with EM38 Dual Dipole)
- 267 soil samples (0.3 m intervals, down to 1.5 m): Salinity (**EC_e**), pH, SP, WC … → **focus on 0-1.2 m aggregate: "root-zone"**
- **~6000 ground truth cells.** Overall accuracy R^2 = 0.93





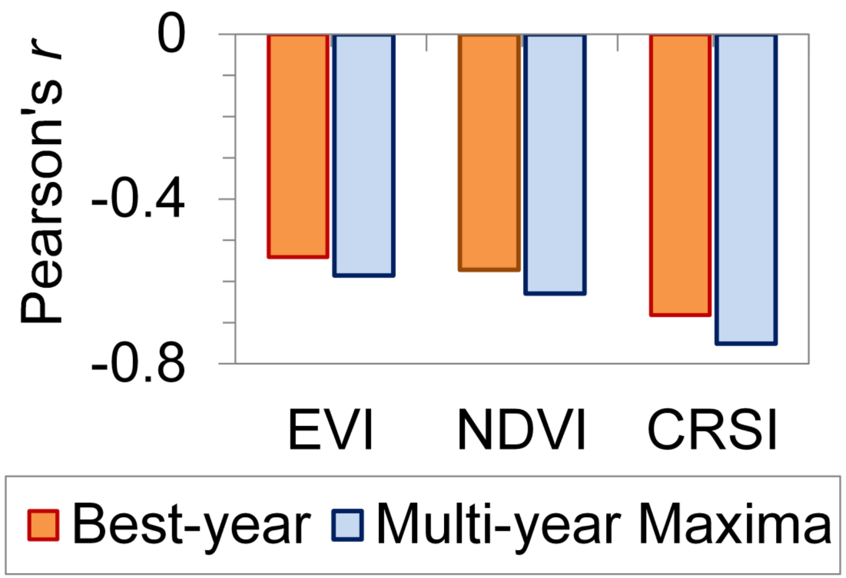
~24 ha

EC_a depends on several soil properties:

- **Salinity** (**EC_e**) ↑
- Texture (Sand ↓; Clay ↑)
- Water Content ↑
- …

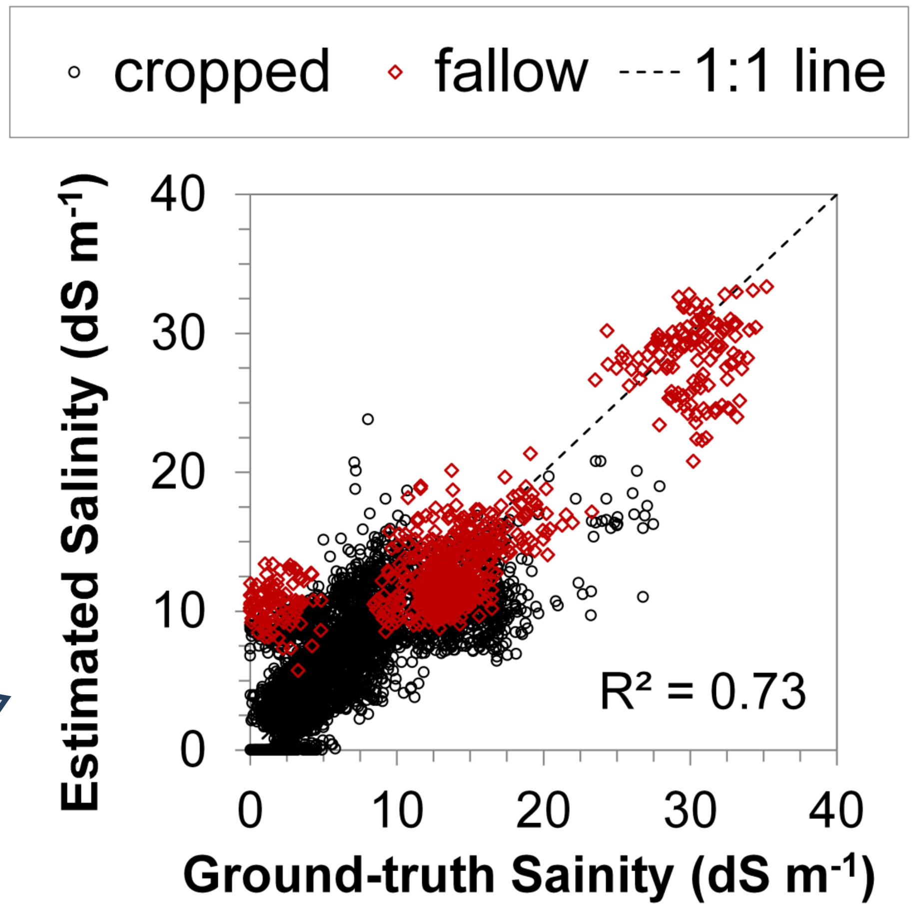
A calibration is needed to co

Soil salinity Vs. multiyear max CRSI (and additional covatiates)



Scudiero et al. (2015). *Remote Sensing of Environment*

MAX CRSI as main explanatory variable.
Other covariates?
-Crop type?
-Meteorology?
-Soil information (texture, elevation, …)?
-Management?

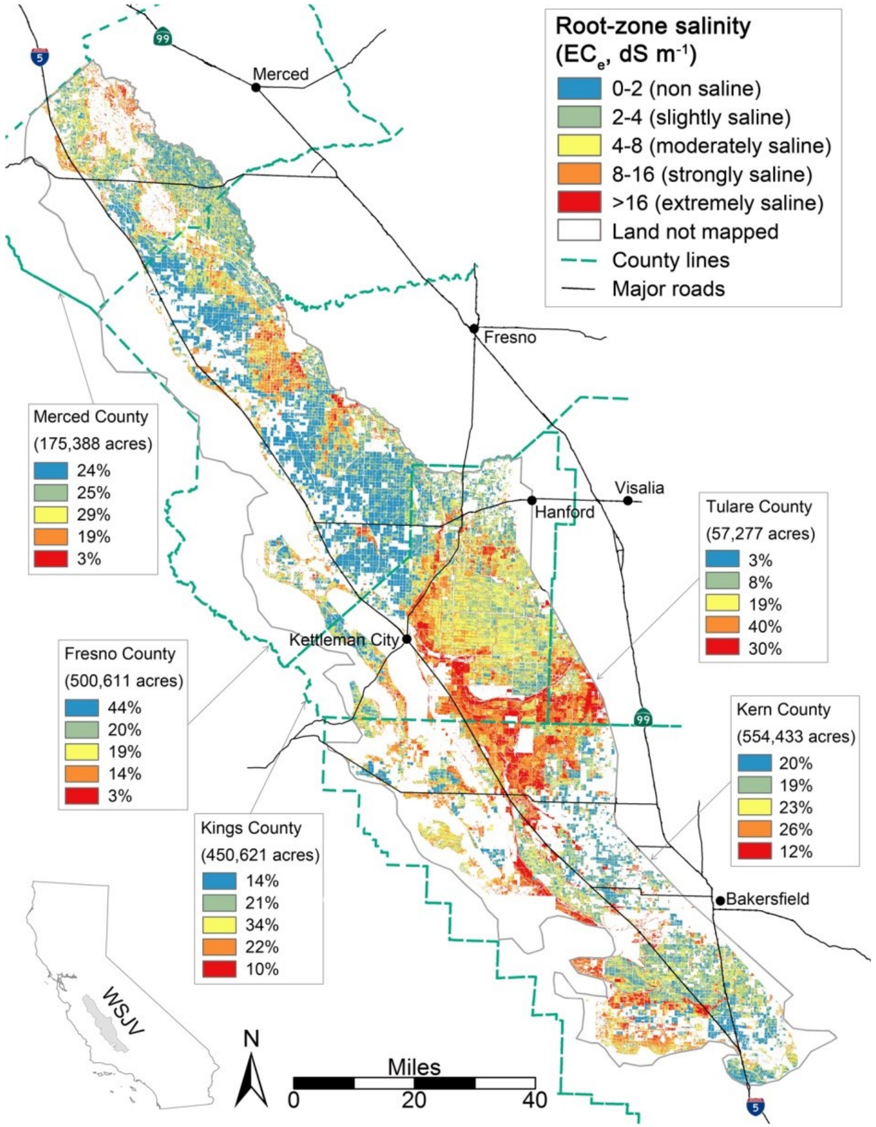


Scudiero et al. (2015). *Remote Sens Environ*

Model evaluation satisfactory?

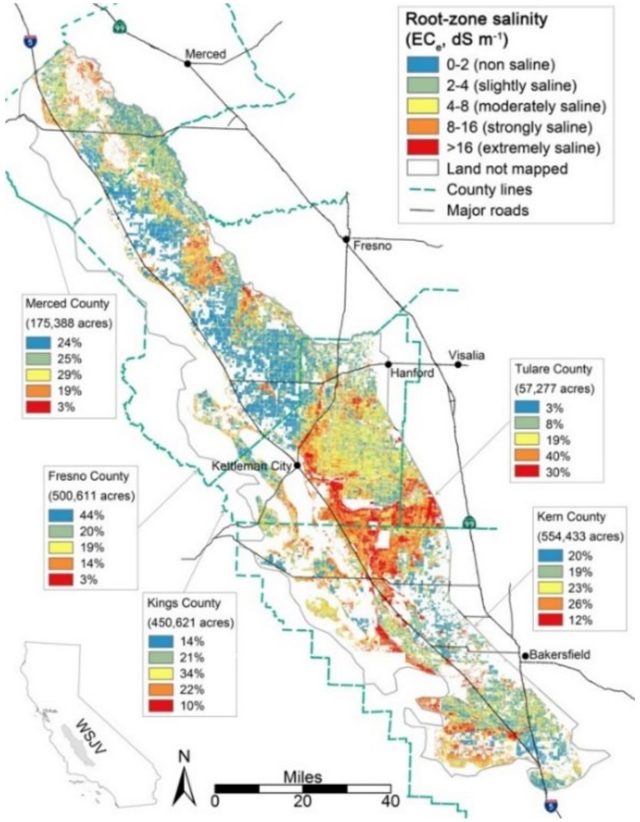
- **Spatially-independent cross-validation**
  (e.g., leave-one-field-out)
- Independent data
- Ask a farmer!

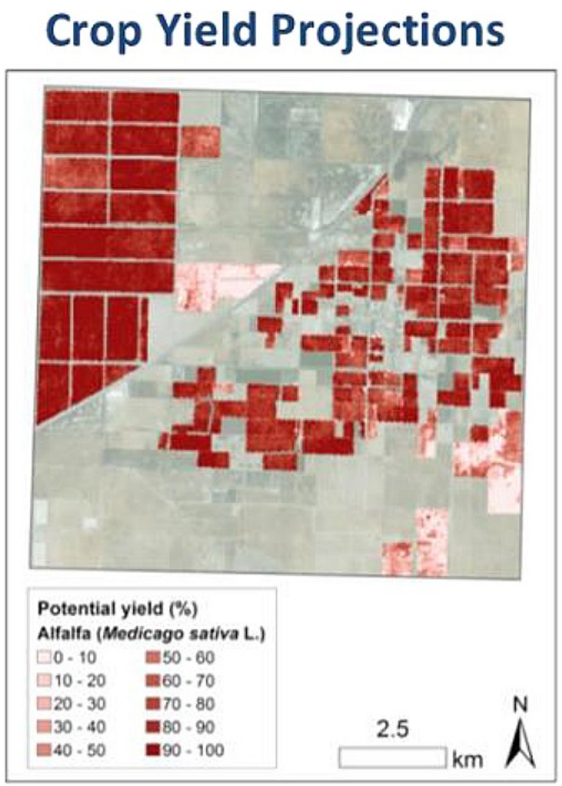
Extrapolate to whole region

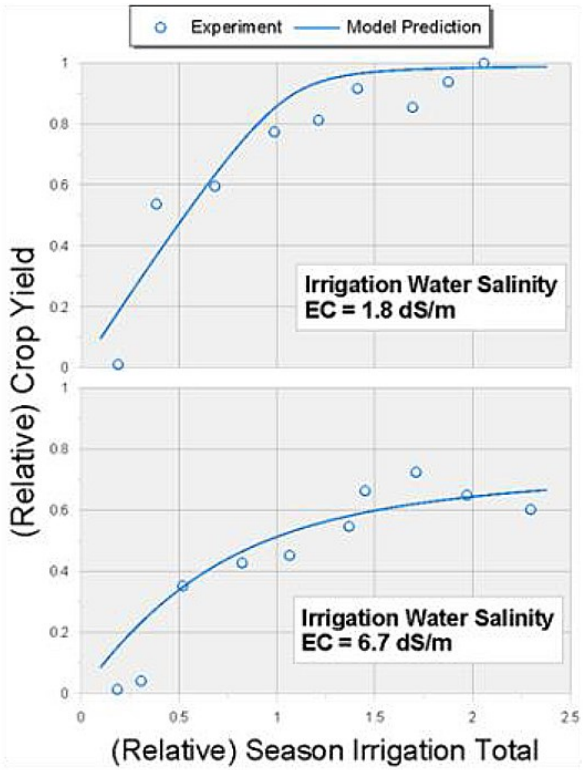


Scudiero et al. (2017). *California Agriculture*

How do natural resource managers use the salinity maps?







Regional scale econometrics (e.g., Stanford University)

Farm scale irrigation decision support

UC ANR

CropManage

Thanks for your attention

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Funding:

NIFA (Grant Number: 2019-67022-29696)

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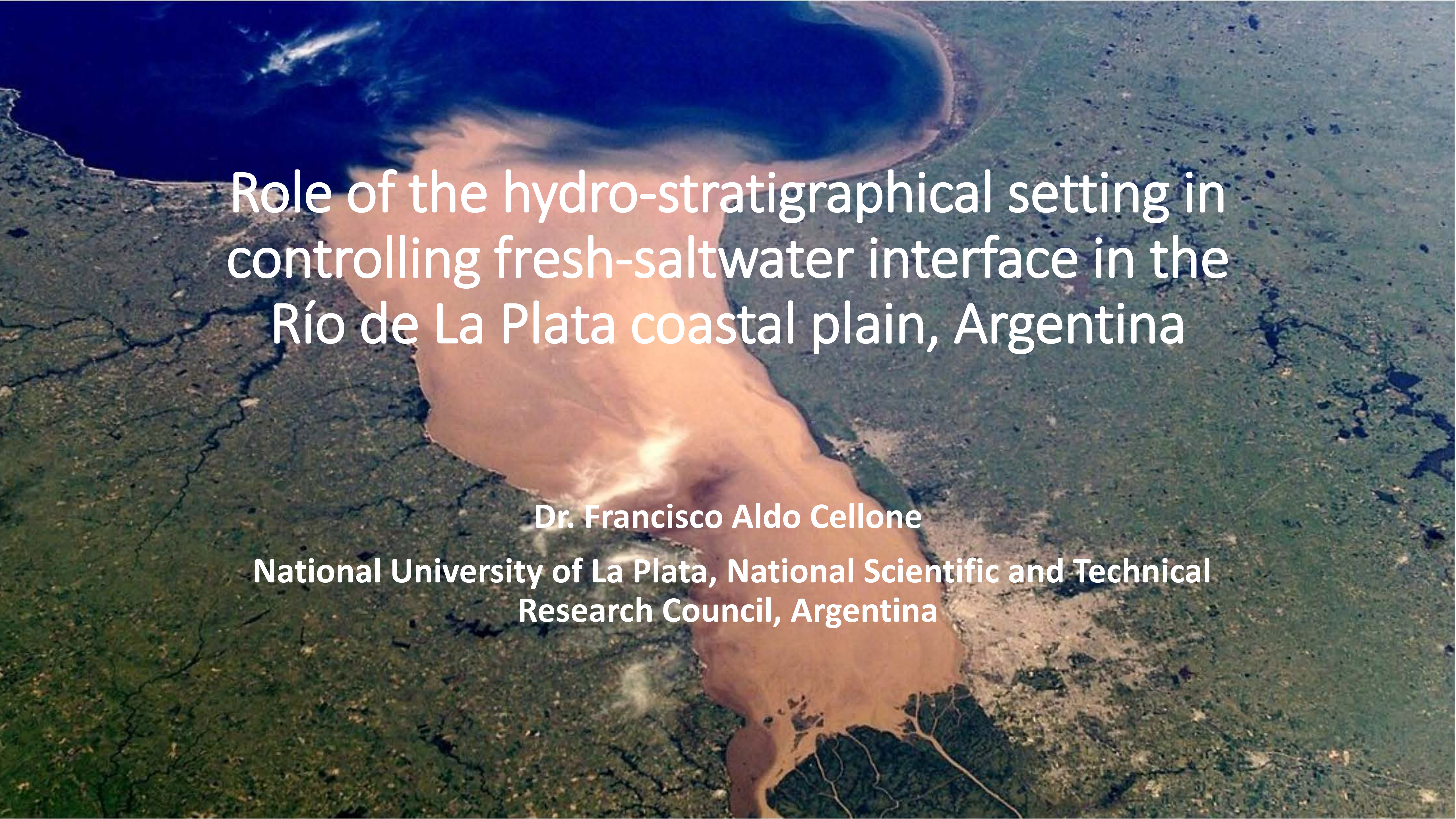
Digital Agronomy Lab.

Scudiero et al., 2015. Regional-scale soil salinity assessment using Landsat ETM plus canopy reflectance. Remote Sensing of Environment 169, 335-343. doi: 10.1016/j.rse.2015.08.026

Scudiero et al., 2017. Remote sensing is a viable tool for mapping soil salinity in agricultural lands. California Agriculture 71, 231-238. doi: 10.3733/ca.2017a0009

Do not hesitate to contact me to get copies of these research articles!

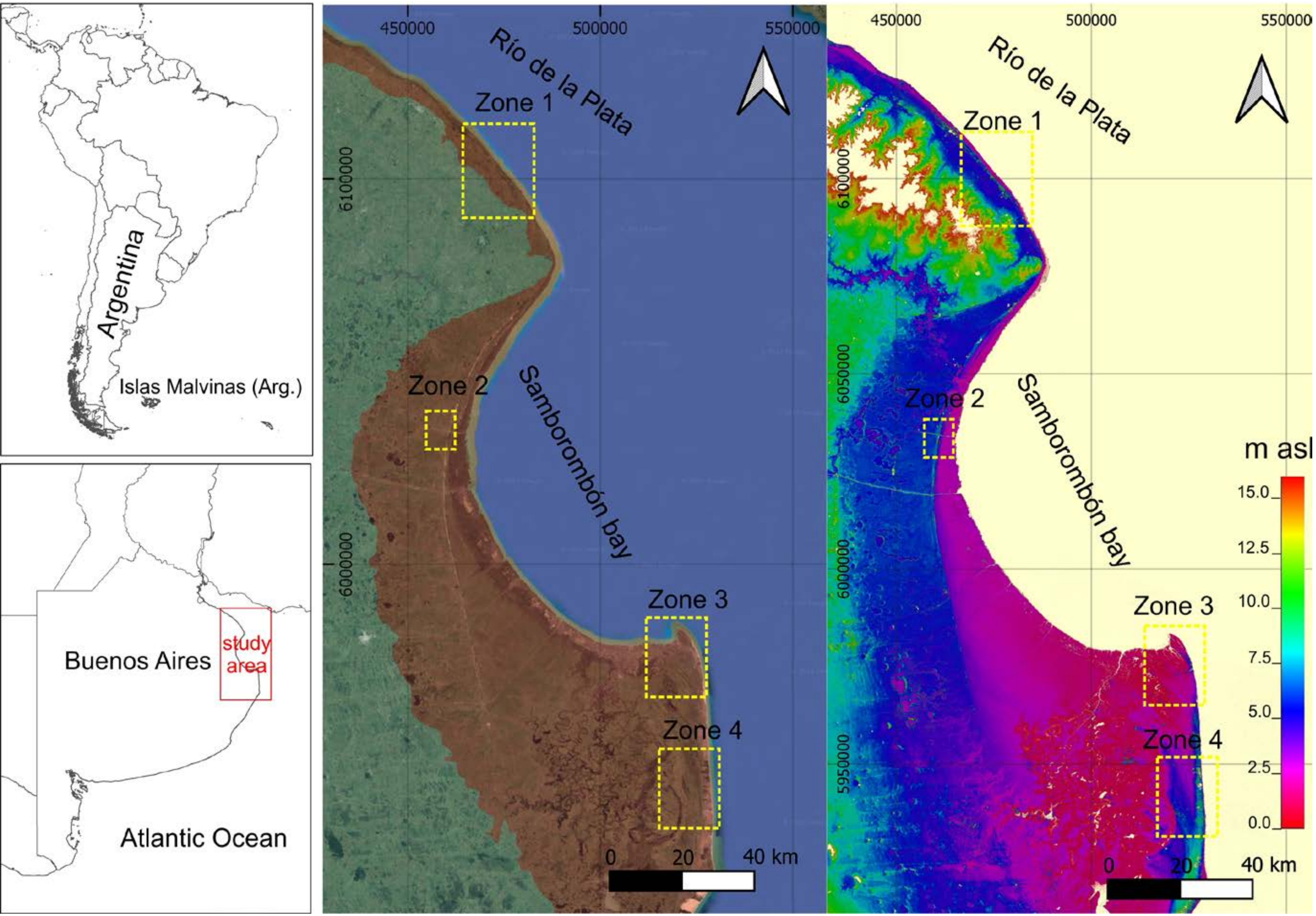
Appendix C – Slides by Francisco Cellone



Role of the hydro-stratigraphical setting in controlling fresh-saltwater interface in the Río de La Plata coastal plain, Argentina

Dr. Francisco Aldo Cellone

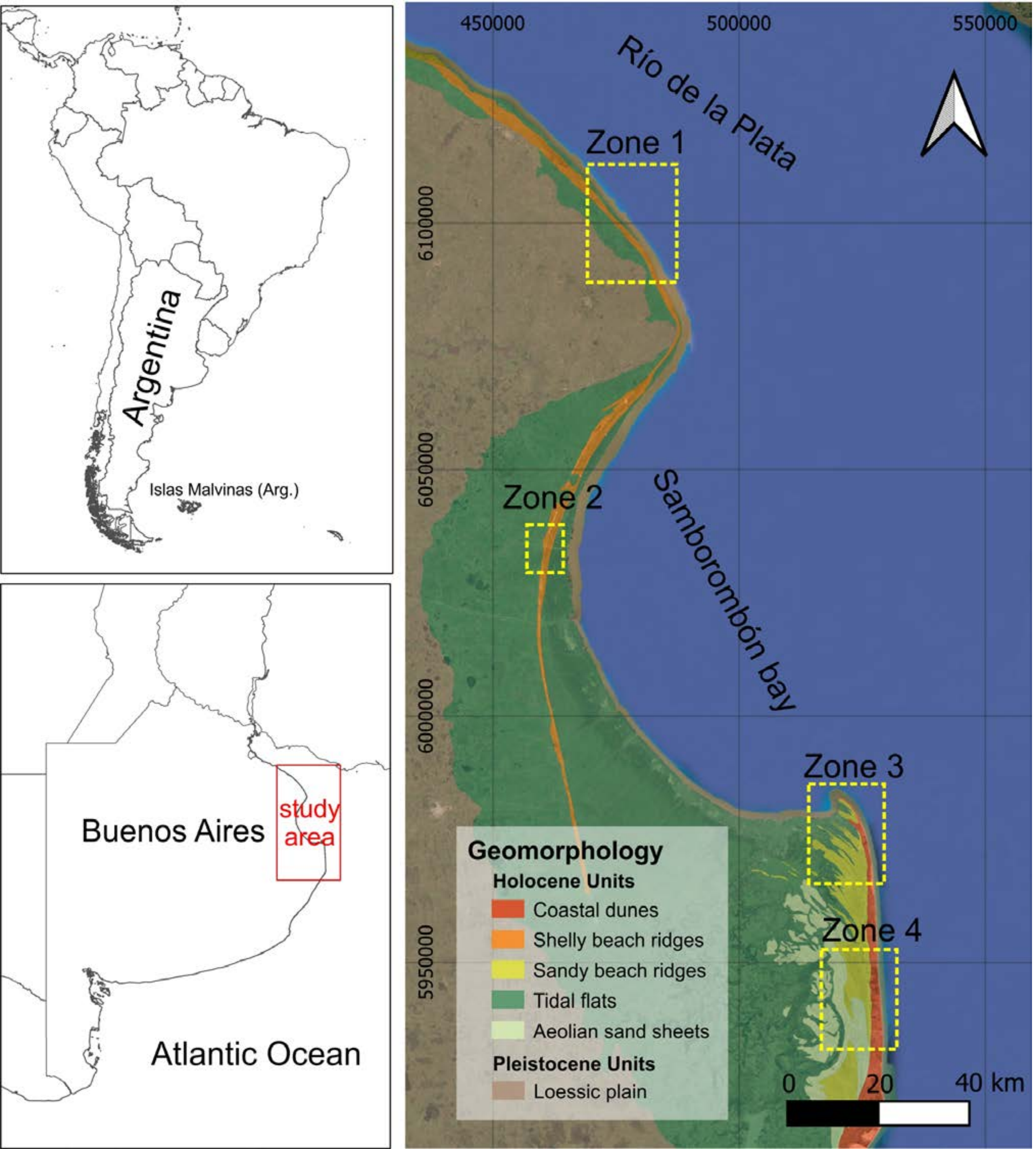
National University of La Plata, National Scientific and Technical Research Council, Argentina



The Río de la Plata littoral is characterized by extensive, and low -relief coastal plains with an extension of approximately 400 km. These coastal plains were formed during the sea-level fluctuations during the post-LGM

The Río de la Plata estuary has a mixed semi-diurnal micro-tidal regime characterized by a mean range of 0.7 m. Salinity ranges from 0,5 g/L in the upper estuary to 20 g/L in the lower estuary

Location of the study area; geomorphological map; DEM. The yellow line in indicates the position of the different studied zones.



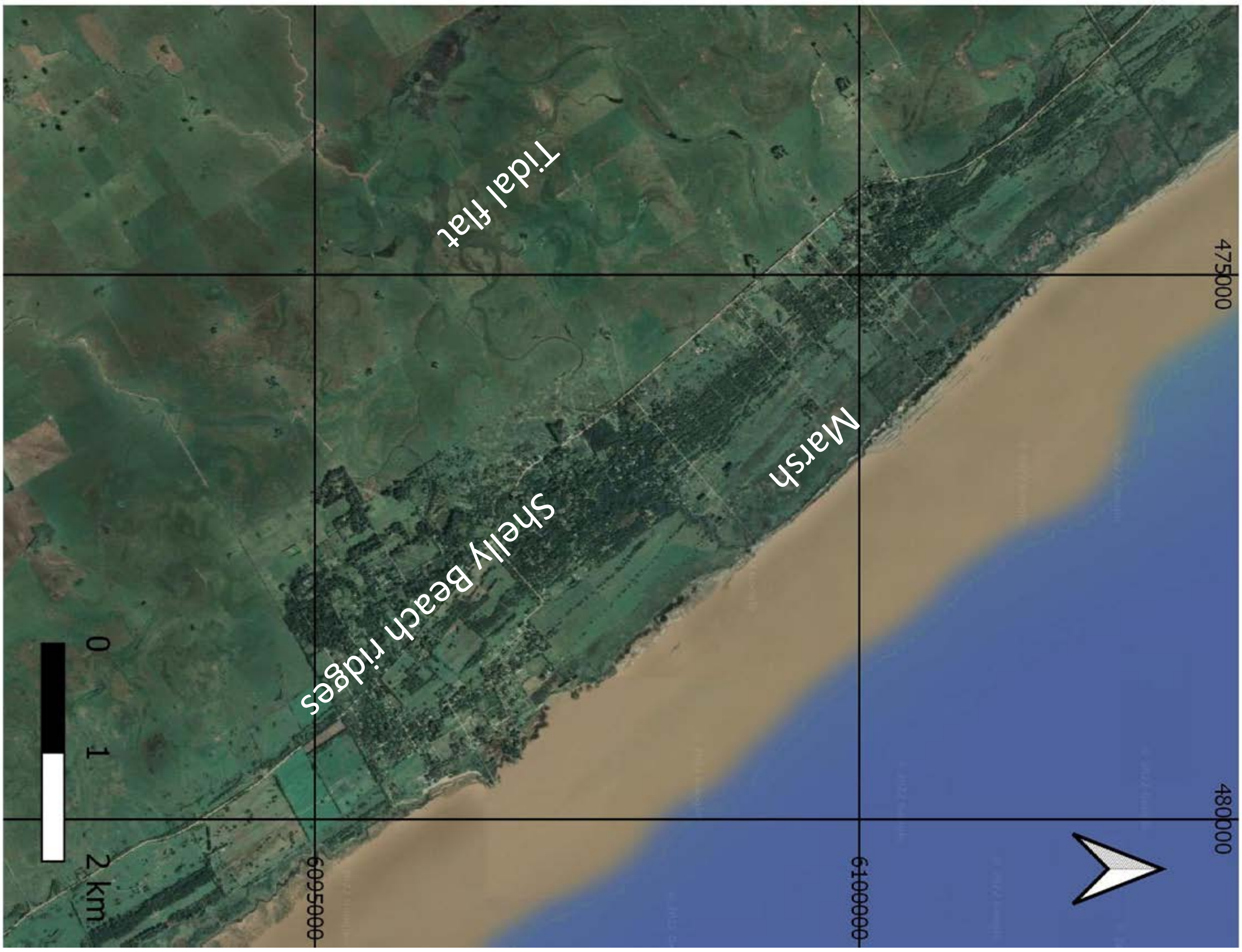
Sea level fluctuations during the Holocene have given rise to the deposition of different sedimentary facies.

The alternation and lateral migration of environments of **tidal flats**, **beach ridges**, and **sandy spits** characterize the geomorphology of this coastal sector

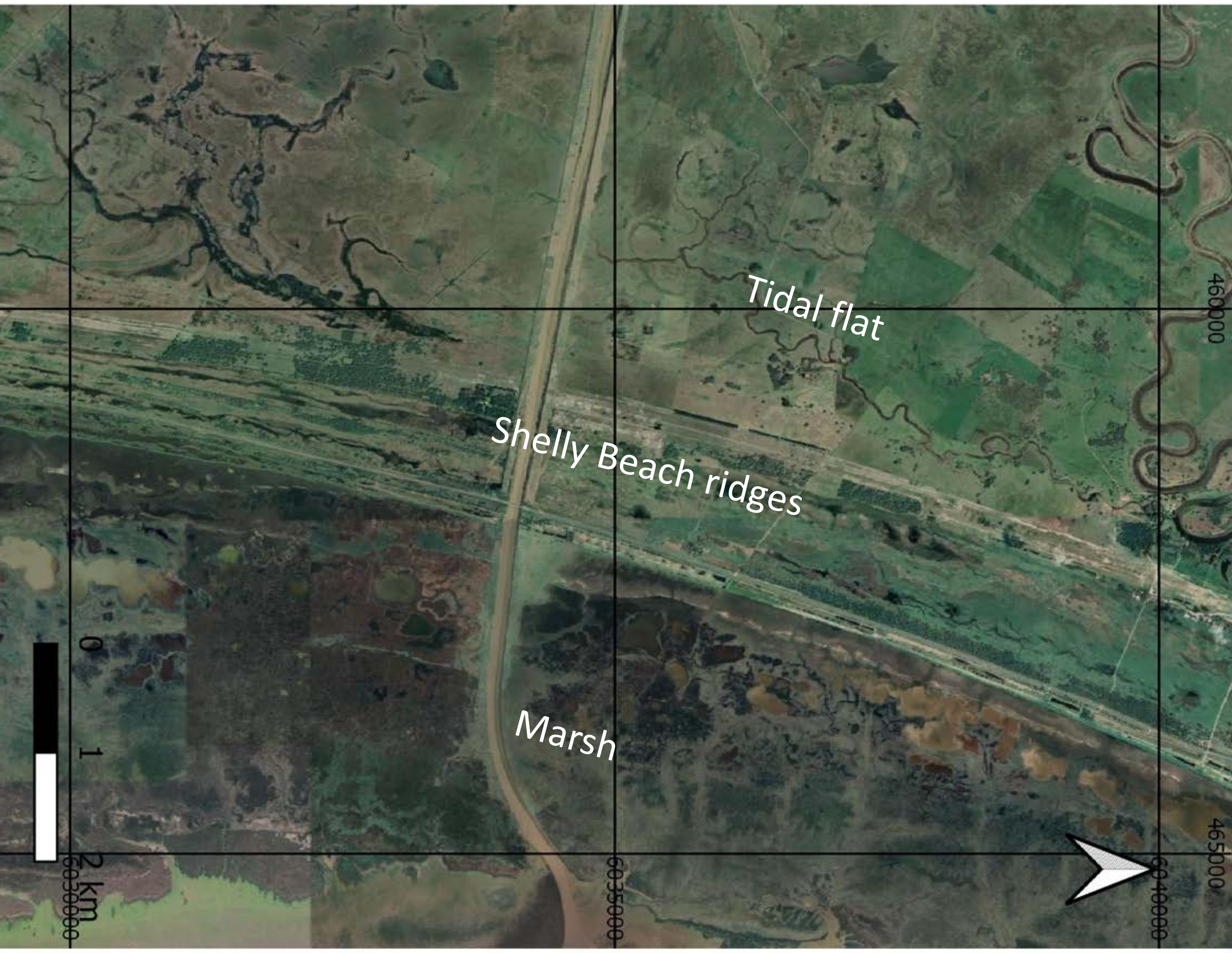
In this region, **freshwater supply** for human consumption is one of the main problems for socioeconomic development, being **freshwater lenses** the primary or only source.

Freshwater lenses are mainly stored in the most permeable units such as **beach ridges, sandy spits and coastal dunes**. But their shape and distribution and the saltwater-freshwater interface are still not well known

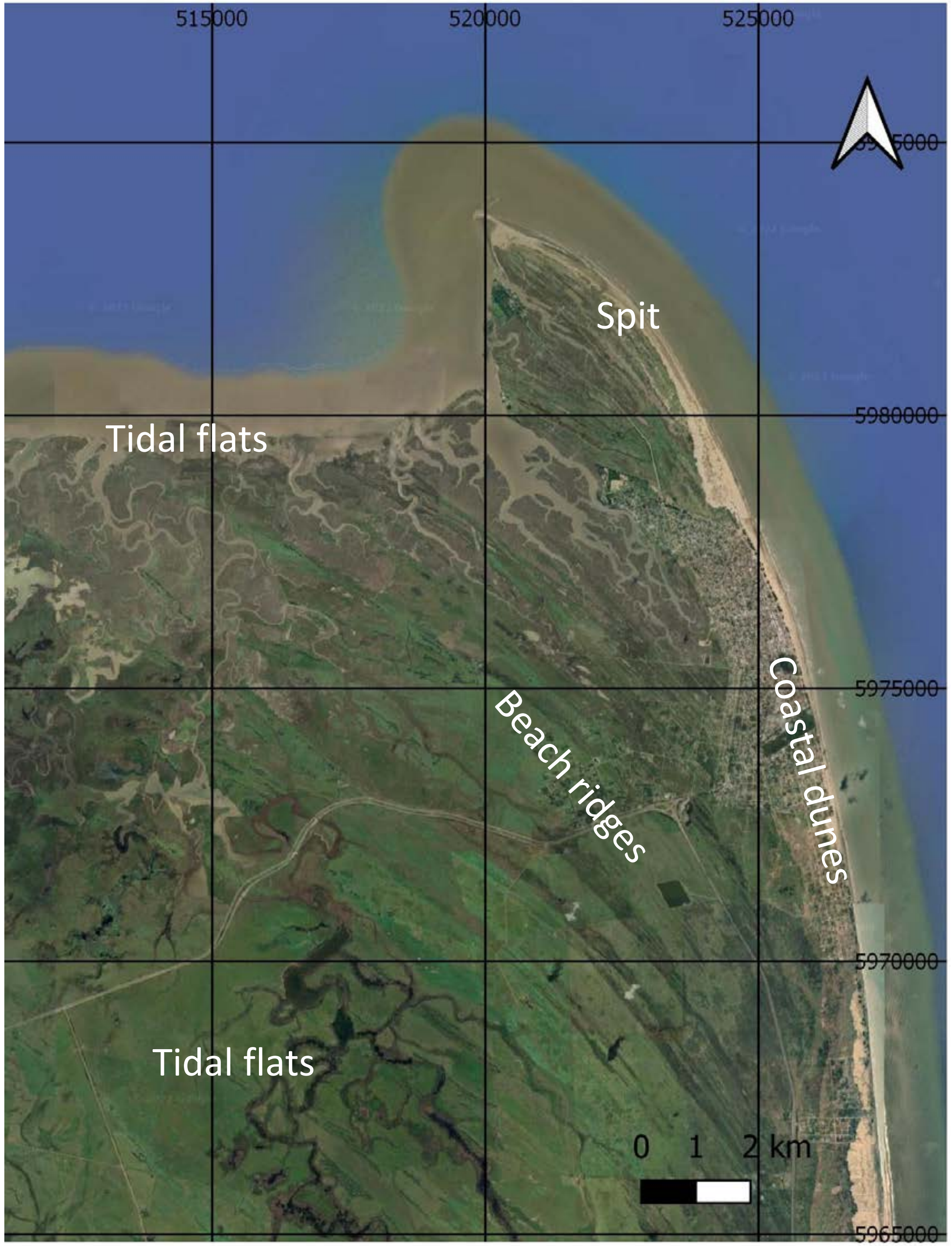
ZONE 1


Tidal flat
Marsh
Shelly Beach ridges
0
1
2 km
475000
480000
6095000
6100000

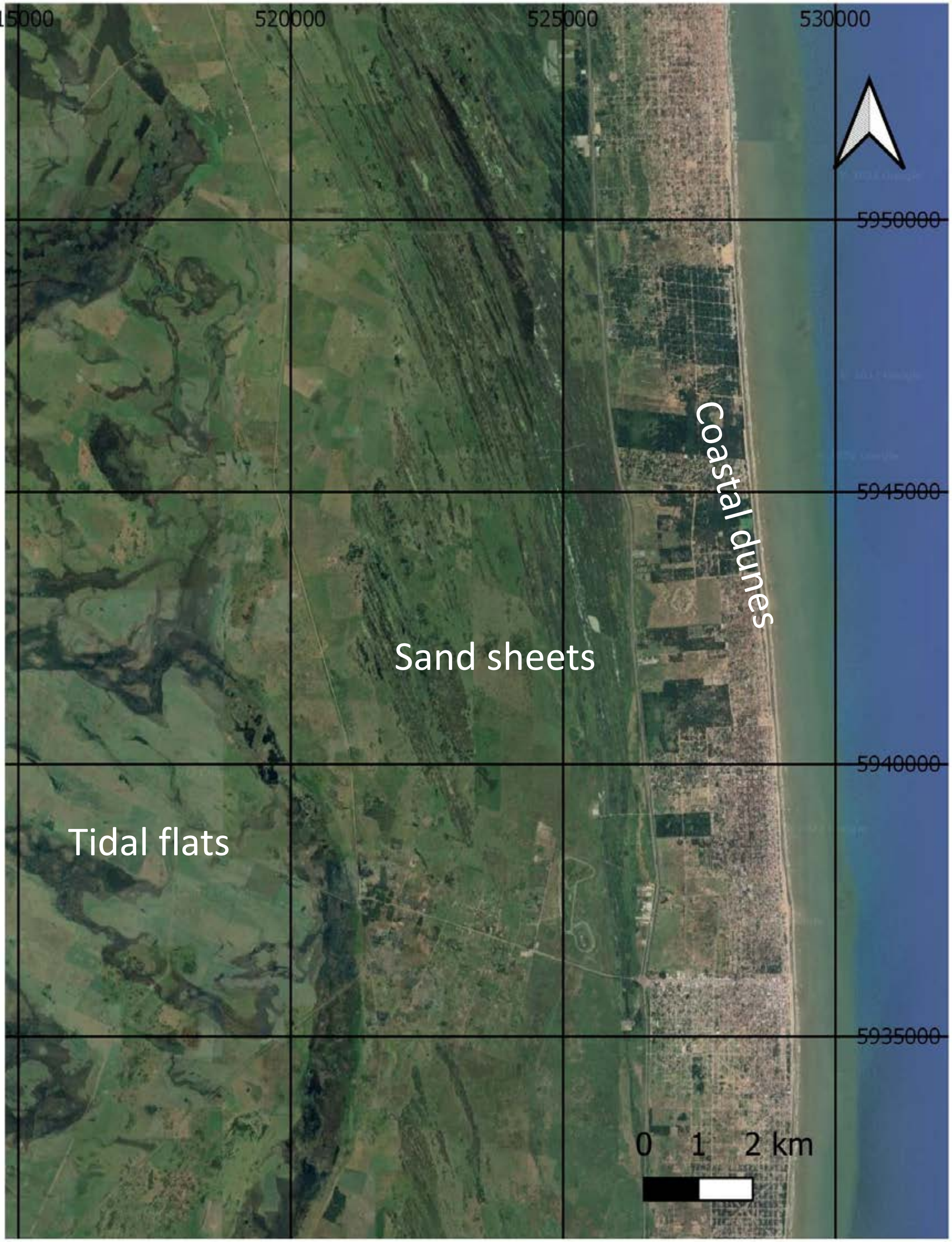
ZONE 2


Tidal flat
Shelly Beach ridges
Marsh
0
1
2 km
460000
465000
6030000
6035000
6040000

ZONE 3

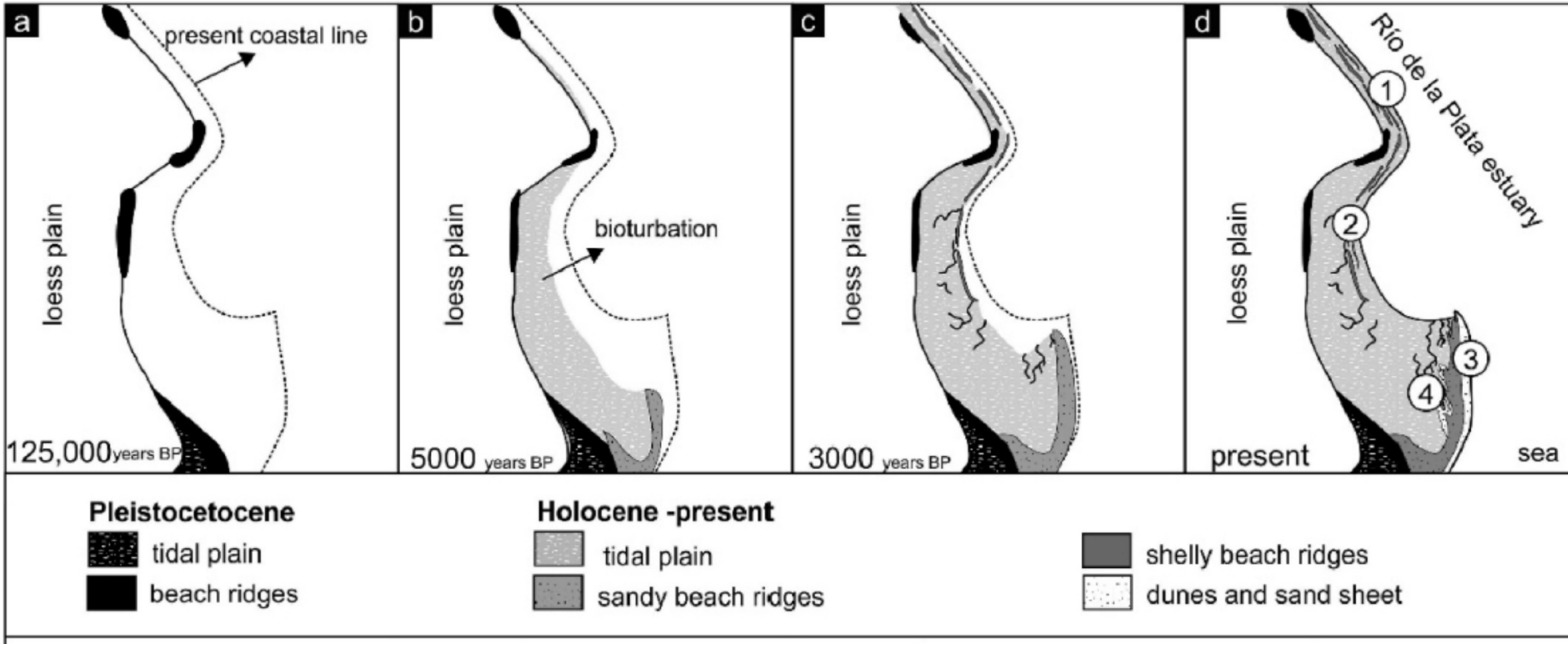

515000
520000
525000
5985000
5980000
5975000
5970000
5965000
Spit
Tidal flats
Beach ridges
Coastal dunes
Tidal flats
0 1 2 km

ZONE 4


515000
520000
525000
530000
5950000
5945000
5940000
5935000
Coastal dunes
Sand sheets
Tidal flats
0 1 2 km


canal
llanura de marea
a
cordón
intercordón
cordón
b
cordón
cordón
intercordón
c
marisma
médano
d

Evolution of the Argentinian littoral of the Río de la Plata estuary and adjacent sea area



.

The **aim** is to analyze the role of the **hydro-stratigraphic** and geomorphological setting related to the Holocene evolution of the Río de la Plata estuary regarding its control on the **freshwater-saltwater interface** and the shape and distribution of **freshwater lenses** for water supply.

This is of vital relevance for the generation of guidelines for the sustainable management of water resources.

These types of coastal aquifers are small and highly vulnerable to **salinization processes** due to anthropogenic factors, such as intensive exploitation, or natural ones, such as those resulting from climate change and sea level rise.

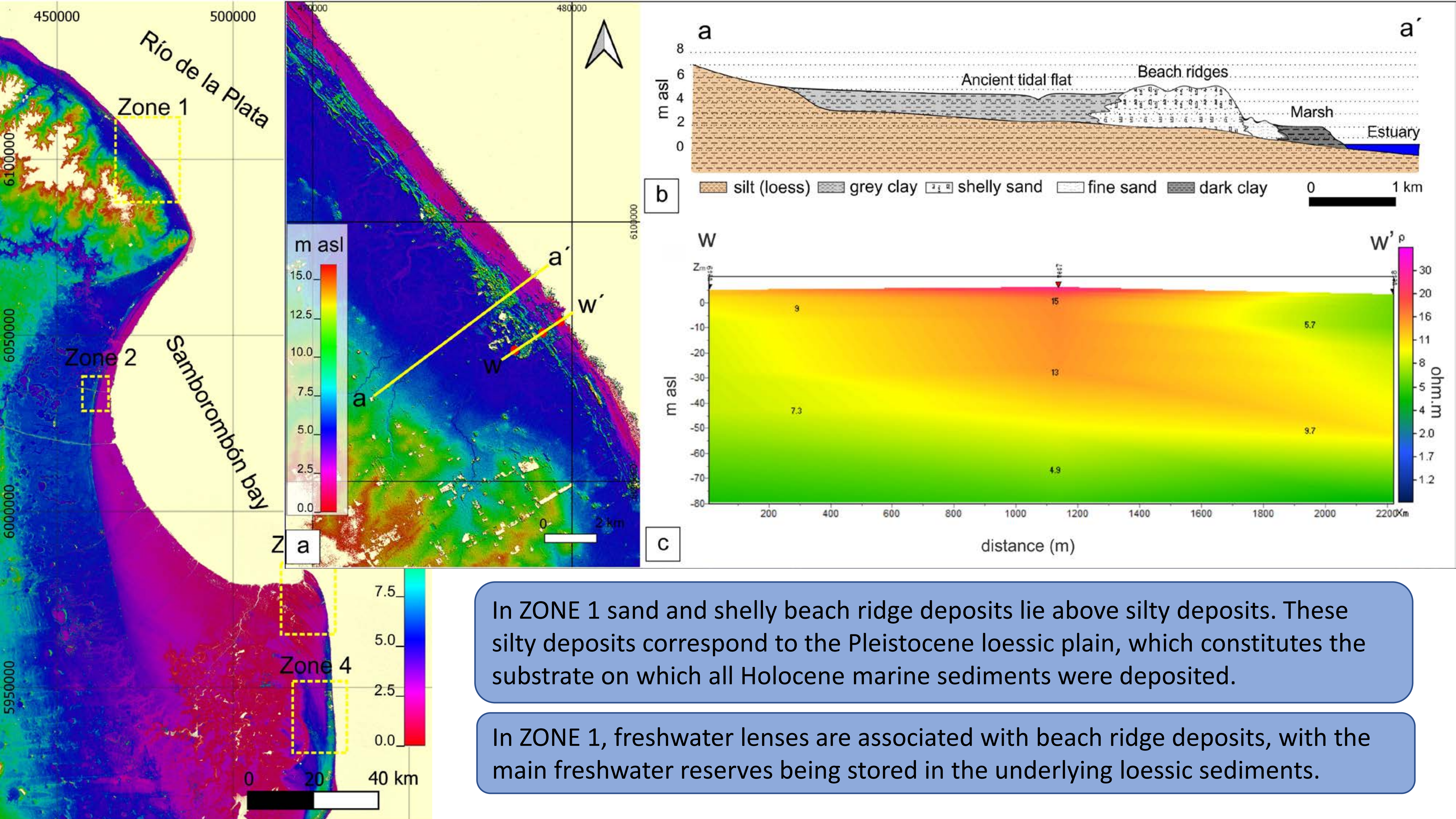
Methodology

Geomorphological characterization using satellite imagery complemented with a Tan-DEM X digital surface model (DSM) with 12 m spatial resolution.

Installation of **groundwater exploration wells and sediment samplings** in transects crossing the coastal plain. Cutting data from drillings deeper than 12 m was also analyzed. Analysis of previous geological profiles was performed.

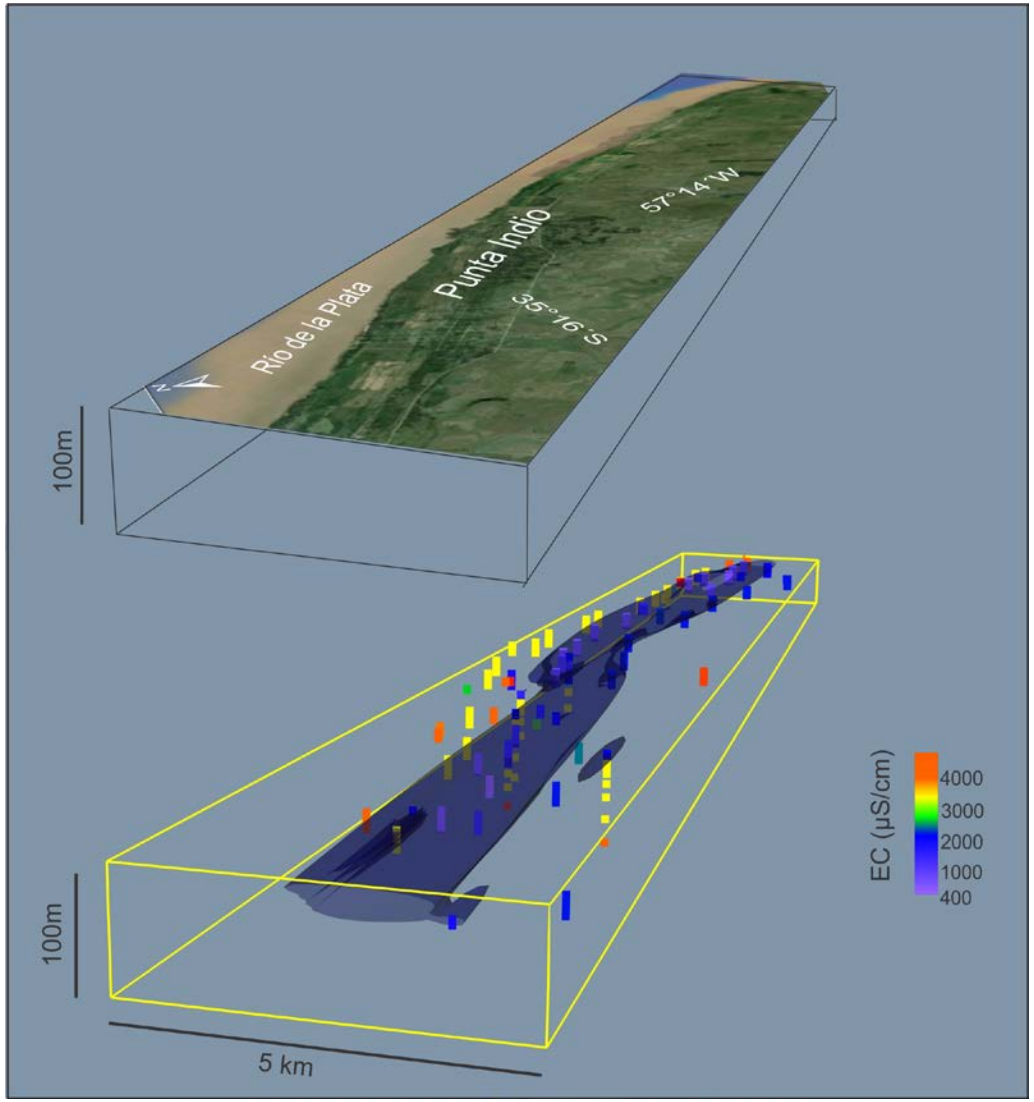
Electrical conductivity (EC) of the water was measured *in situ* with a portable conductivity meter in piezometers and wells.

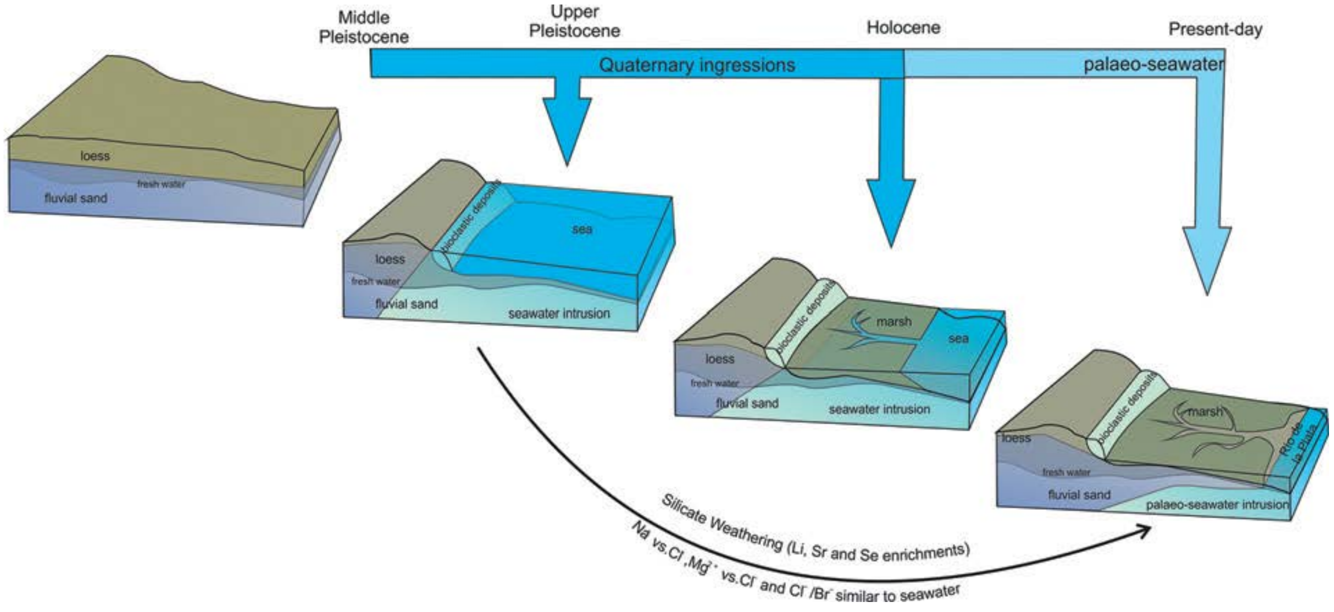
21 Vertical Electrical Soundings (VES) acquired using Schlumberger configuration.



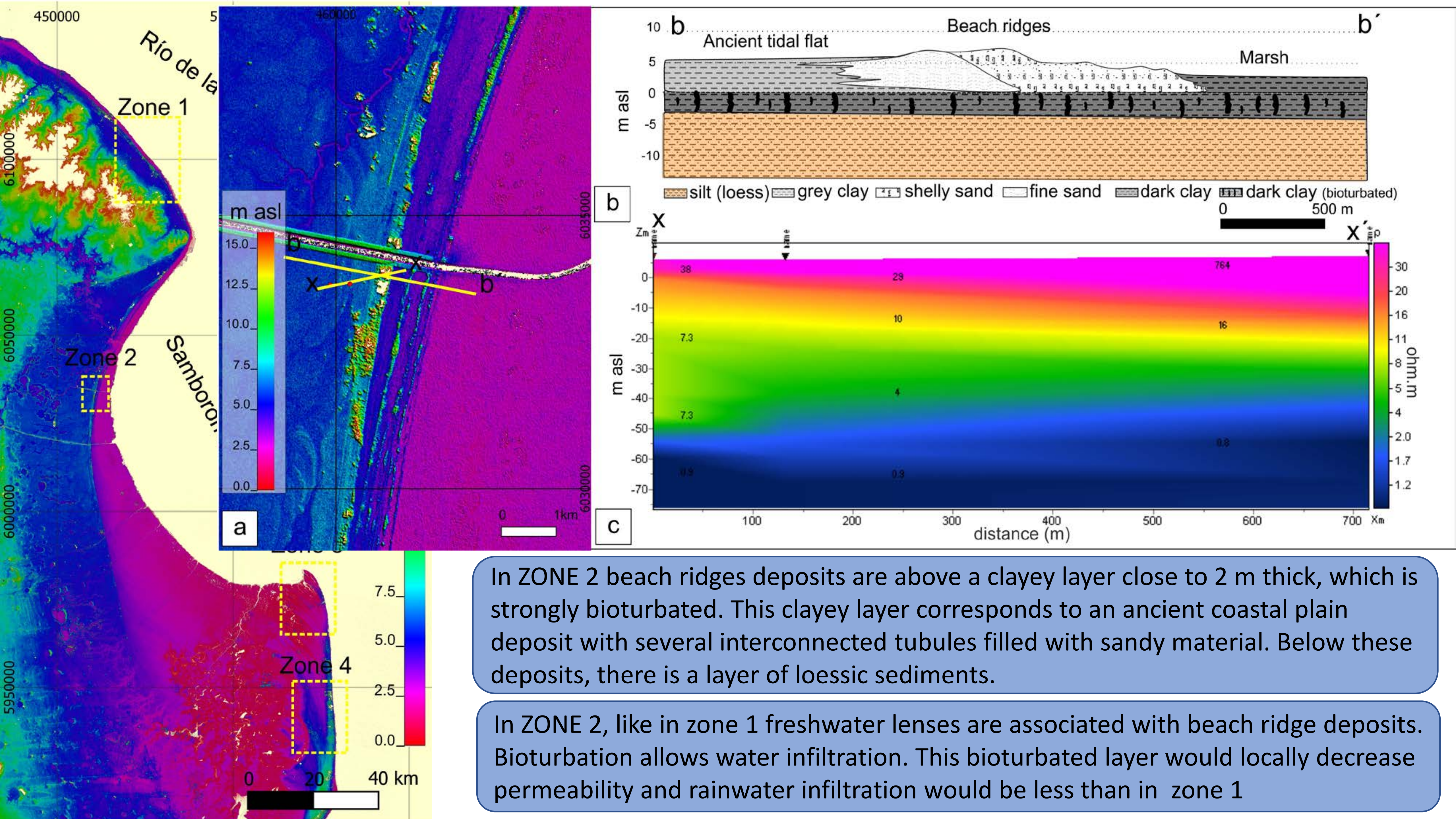
In ZONE 1 sand and shelly beach ridge deposits lie above silty deposits. These silty deposits correspond to the Pleistocene loessic plain, which constitutes the substrate on which all Holocene marine sediments were deposited.

In ZONE 1, freshwater lenses are associated with beach ridge deposits, with the main freshwater reserves being stored in the underlying loessic sediments.





In this sector, the freshwater-saltwater interface is related to paleo-saltwater intrusion related to the Pleistocene and Holoce transgressions.



In ZONE 2 beach ridges deposits are above a clayey layer close to 2 m thick, which is strongly bioturbated. This clayey layer corresponds to an ancient coastal plain deposit with several interconnected tubules filled with sandy material. Below these deposits, there is a layer of loessic sediments.

In ZONE 2, like in zone 1 freshwater lenses are associated with beach ridge deposits. Bioturbation allows water infiltration. This bioturbated layer would locally decrease permeability and rainwater infiltration would be less than in zone 1

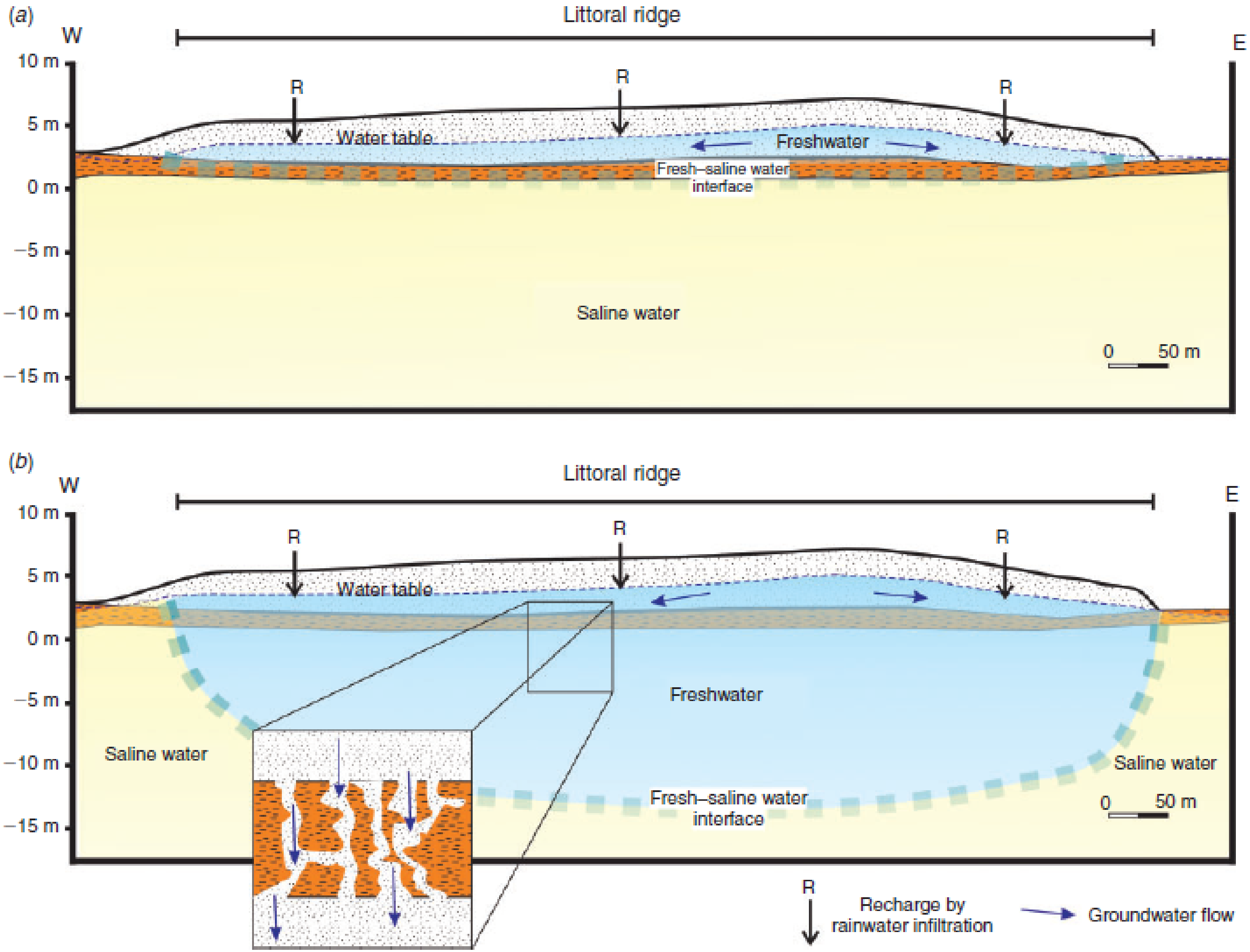
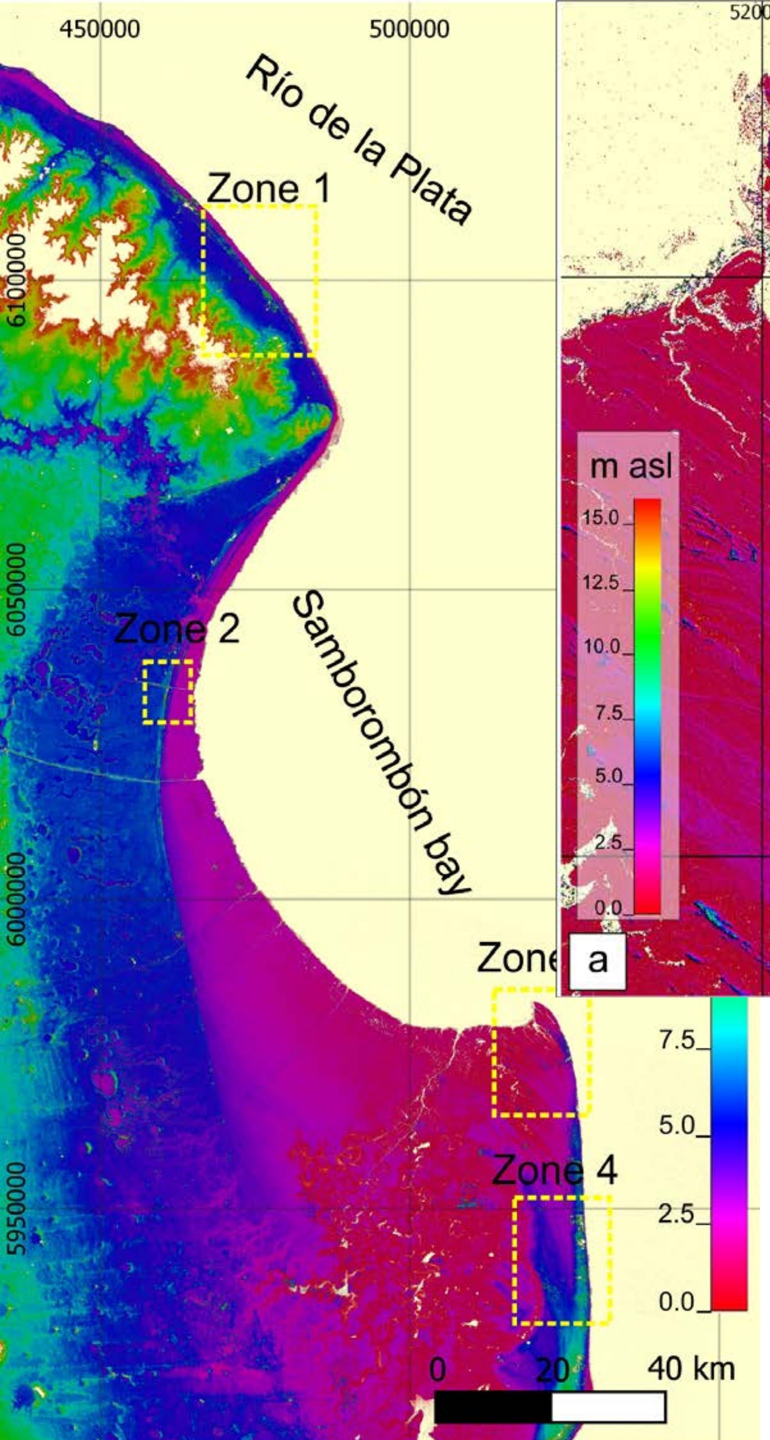
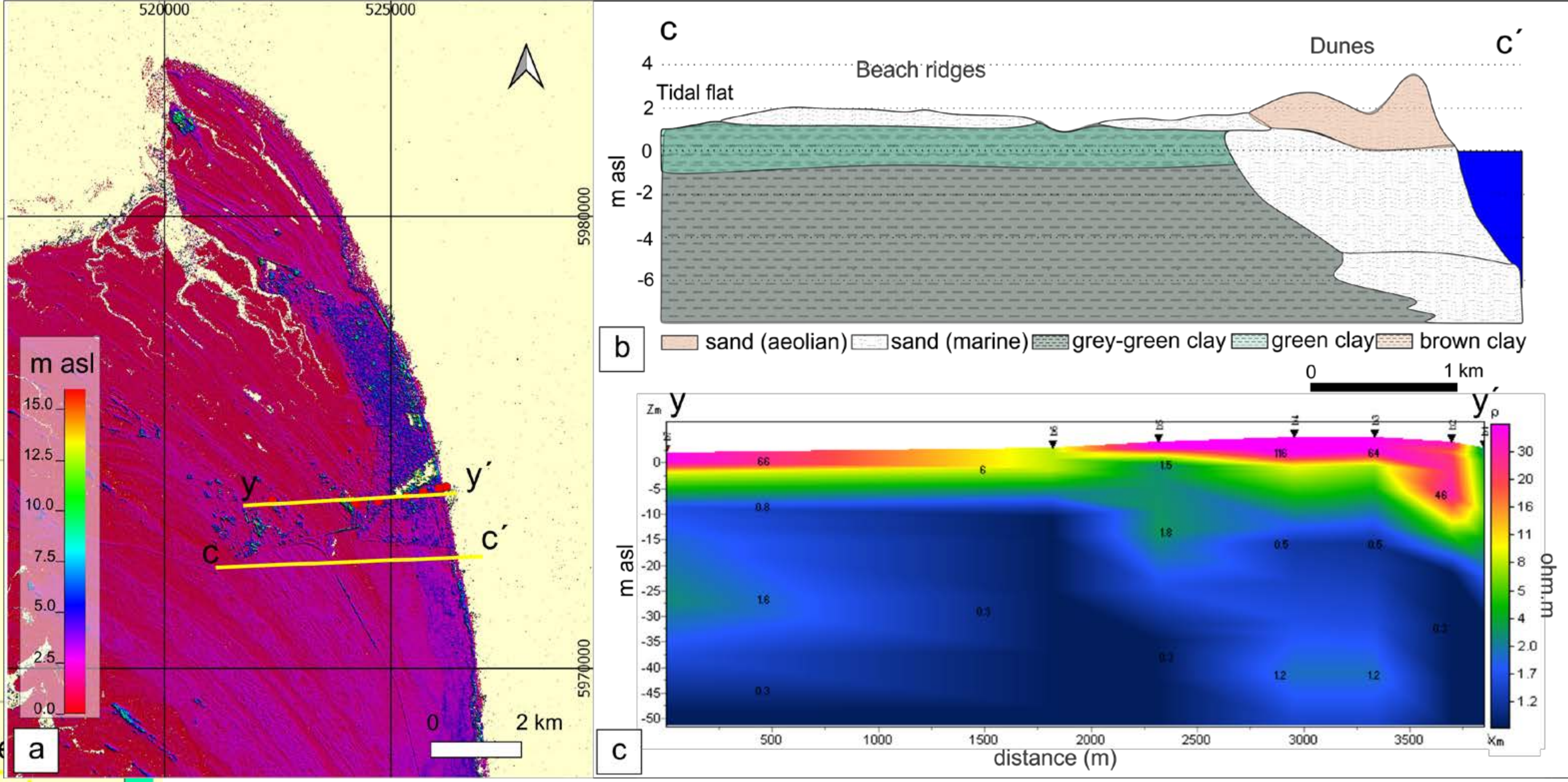
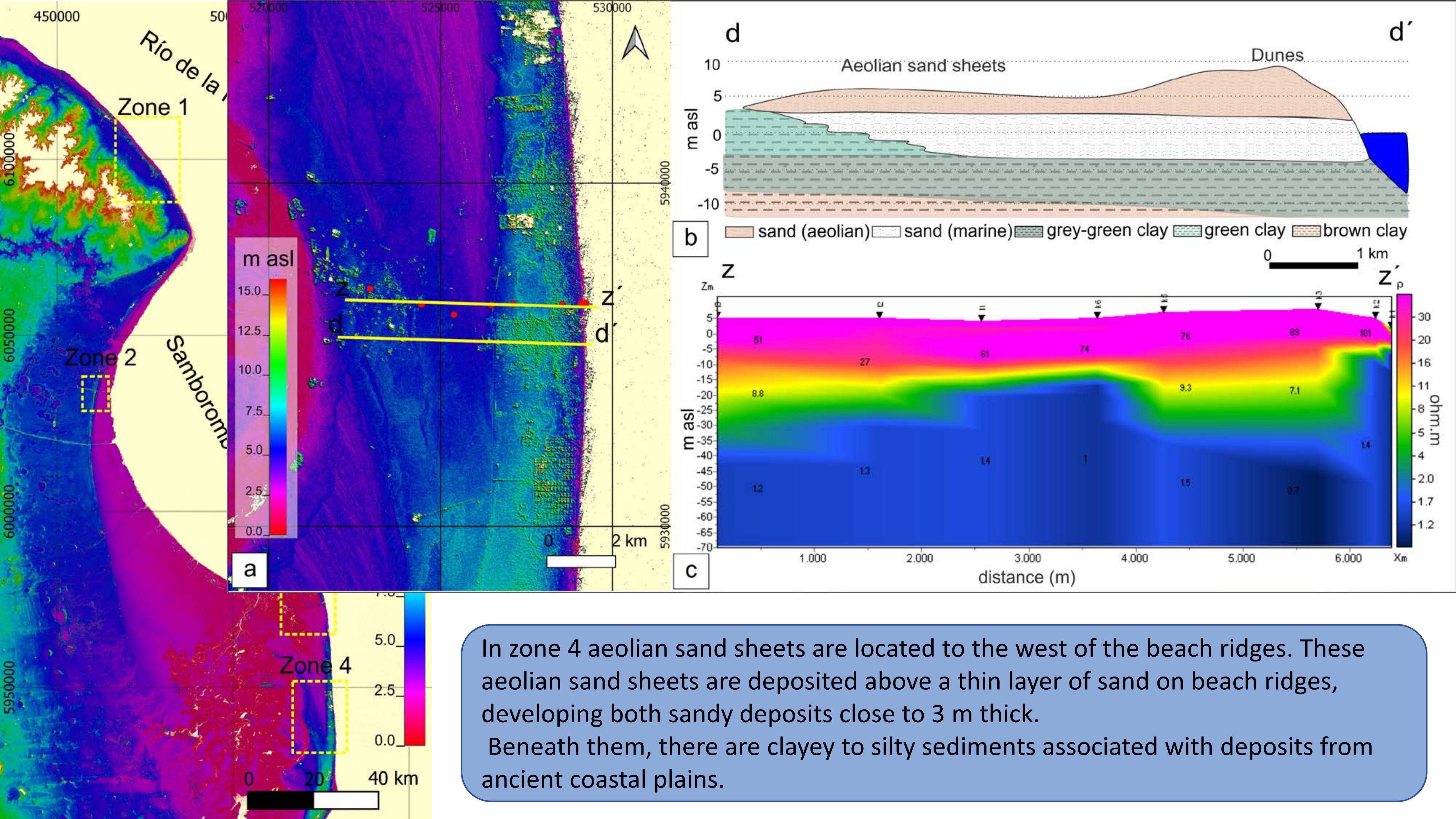


Fig. 6. (*a*) Theoretical *v.* (*b*) real model of freshwater lenses.



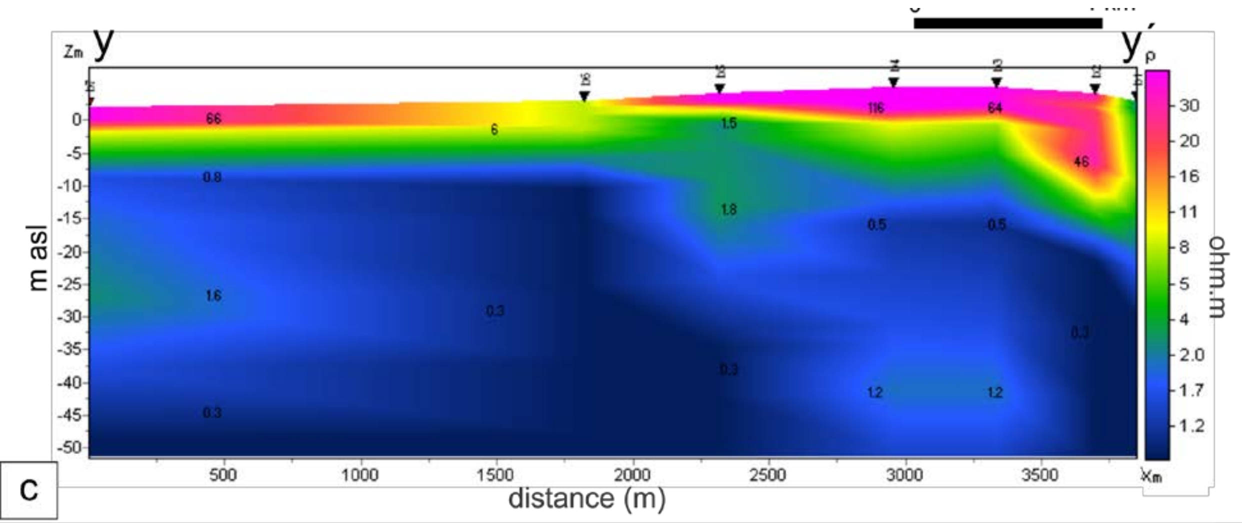


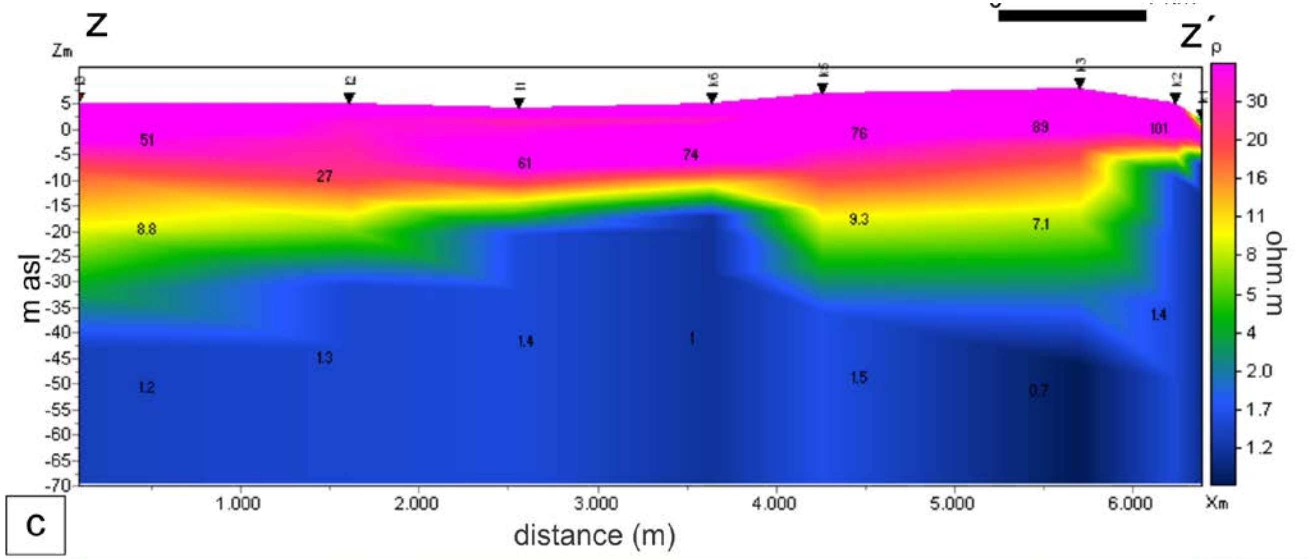
Zone 3 is dominated by sandy deposits of beach ridges associated with the migration of a spit. Dune systems are formed on top of the beach ridges and aeolian sand sheets are deposited on the coastal plain facies located towards the continental sectors to the west of the spit.



In zone 4 aeolian sand sheets are located to the west of the beach ridges. These aeolian sand sheets are deposited above a thin layer of sand on beach ridges, developing both sandy deposits close to 3 m thick.

Beneath them, there are clayey to silty sediments associated with deposits from ancient coastal plains.





- In ZONES 3 and 4 freshwater lenses are associated with **sandy beach ridges** overlaid by **sand sheet and dune systems**. Both topography and the presence of low-permeability facies are the factors that determine the thickness of freshwater lenses.
- Even though **aeolian sand sheets** found in the more continental sectors accumulate rainwater in the shape of lenses they are thin and therefore do not represent relevant water reserves. These landforms are of low topographic height and are deposited on silty clay facies lacking bioturbations that allow rainwater to infiltrate and migrate in depth. The thickness of the lenses is less than 2 m
- In contrast, when **aeolian sand sheets** and **dunes** develop on beach ridge deposits of both greater size and topography, freshwater lenses can develop reaching thicknesses of 20 m on average

Conclusions

The Holocene evolution of the littoral of the Río de la Plata estuary and the adjacent sea area gave rise to the deposition of beach ridges and spits associated with aeolian sand sheets and dunes.

These deposits have higher altitudes than the contiguous tidal flats and are composed of highly permeable sediments, characteristics that favor rainwater infiltration and the development of freshwater lenses

The variability in the dimensions and thickness of the lenses and the position of the freshwater-saltwater interface were explained from detailed lithological studies that showed an interdigitation of ridge and spit deposits with clayey environments of tidal flats as a result of sea level oscillations during the Holocene.

Different architectural arrangements determine the morphology and thickness of the freshwater lenses and the position of the freshwater-saltwater interface.


Thank you for your attention!
Grazie per la vostra attenzione!
Muchas gracias por su atención!

Appendix D – Slides by Gualbert Oude Essink

58

Fresh groundwater under stress; the Mekong Delta case, Vietnam

Gualbert Oude Essink[1,2]

Co-authors, Hung Van Pham[2,5], Philip Minderhoud[1,3,4]

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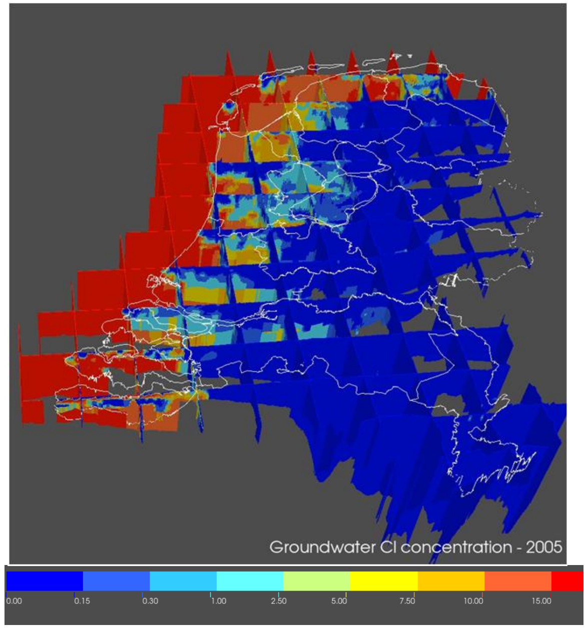
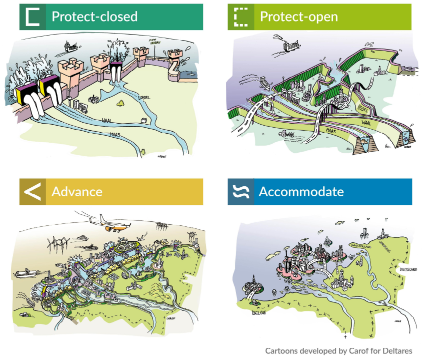
1. Deltares, The Netherlands
2. Utrecht University, The Netherlands
3. Wageningen University, The Netherlands
4. University of Padova, Italia
5. Division of Water Resources and Planning of the South of Viet Nam, Viet Nam

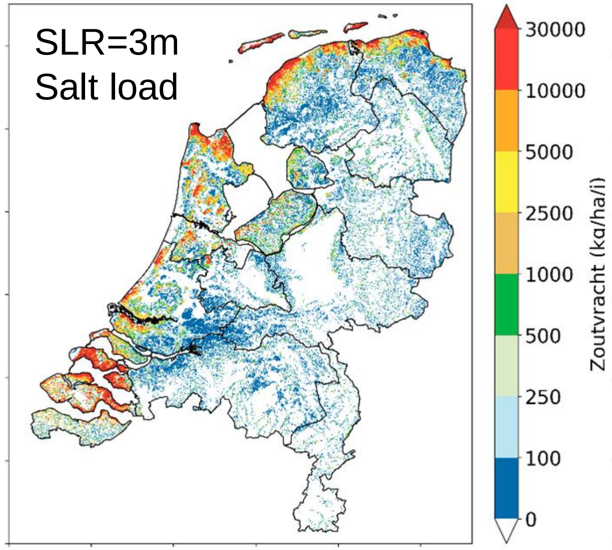
Salt water intrusion NL

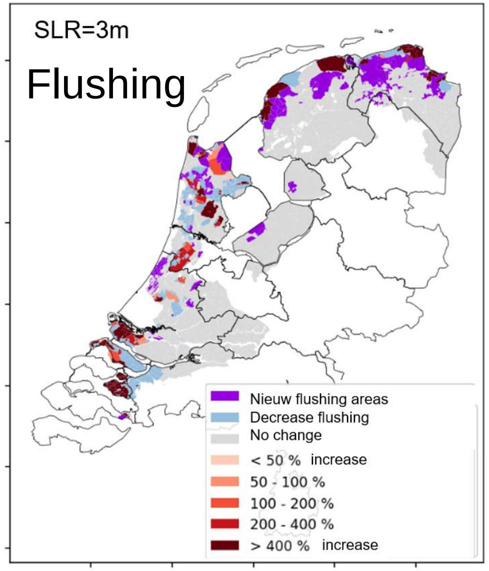


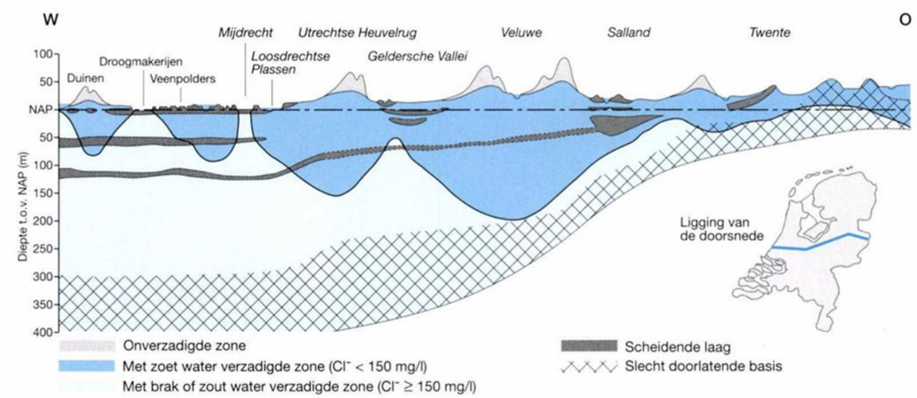
Monitoring AEM
Modelling 3D
Projections SLR on:

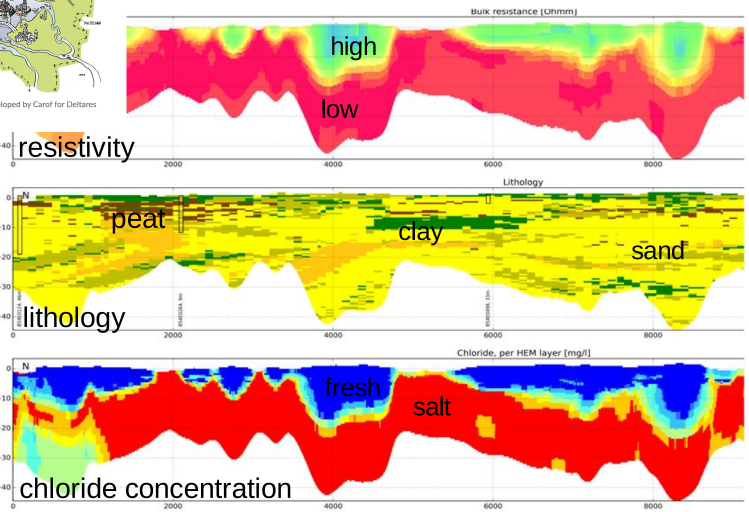
- freshwater volume
- flushing

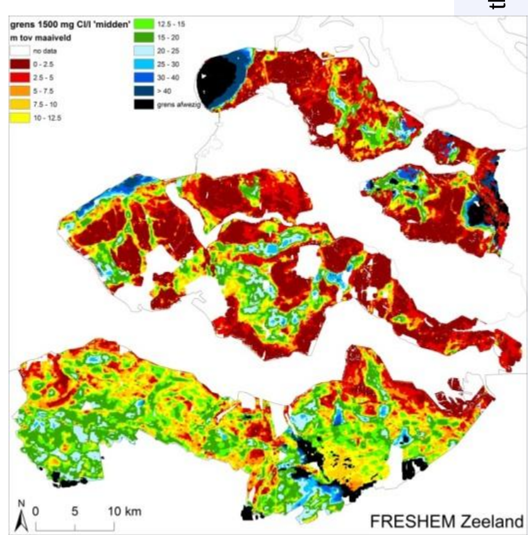












th

Stresses in the Mekong delta, Vietnam

The “*rice bowl*” of South East Asia.

Home to more than 20 million people.

Vietnam+

Mekong Delta attempts to combat saltwater intrusion

Saltwater intrusion in the Mekong Delta is expected to increase between April 28 and May 6 as the volume of water flowing southward from the Mekong River will decline, according to the Ministry of Agriculture and Rural Development's Irrigation Department.

The great salt drought desiccating Vietnam's Mekong Delta (ALJAZEERA)

Farmers suffer huge losses and communities struggle amid high levels of seawater intruding into the freshwater delta.

Nhân Dân ONLINE

Reducing damages caused by salt intrusion in the Mekong Delta

Monday, 2018-04-23 11:12:51

A farmer on his dry rice field in the Mekong Delta province of Long An (Photo: VNA)

Gravest threat to Mekong delta today is sediment starvation not rising seas

East Asia Pacific

Huge Land Loss Predicted for Vietnam's Mekong Delta

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Saline intrusion threatens Delta

Update: January, 25/2019 - 04:00

Việt Nam's Cửu Long (Mekong) Delta region could suffer serious salt intrusion by the end of this month, according to the Southern Irrigation Institute.— Photo phapluatvietnam

CỬU LONG DELTA — Việt Nam's Cửu Long (Mekong) Delta region could suffer serious salt intrusion by the end of this month, according to the Southern Irrigation Institute.

Saltwater could penetrate 40 to 50km inland, the institute said..

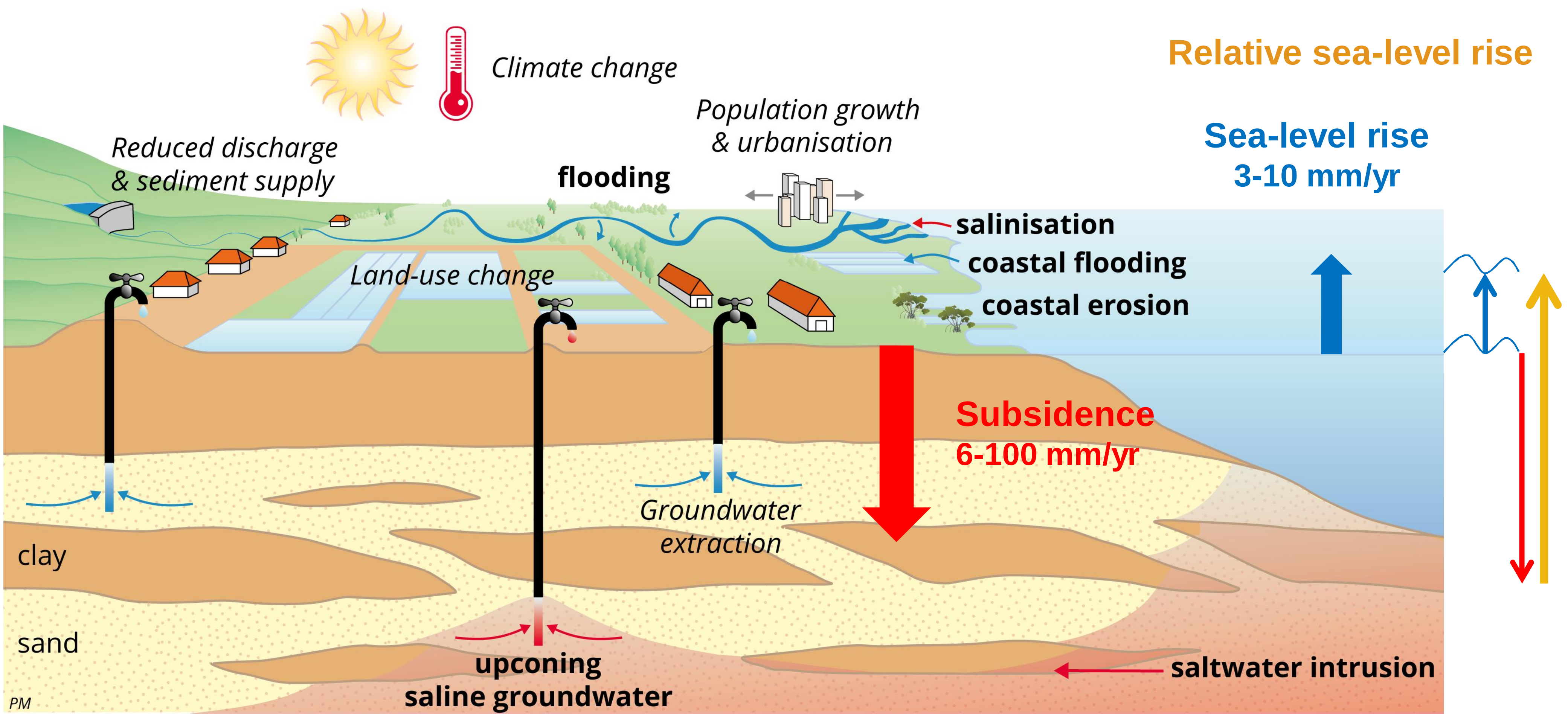
ENVIRONMENT

Saline intrusion threatens Mekong Delta

Vietnam's Mekong Delta region could suffer serious salt intrusion by the end of this month, according to th

VNA - Friday, January 25, 2019 11:20

Many changes in the Mekong delta
(and other deltas around the world)

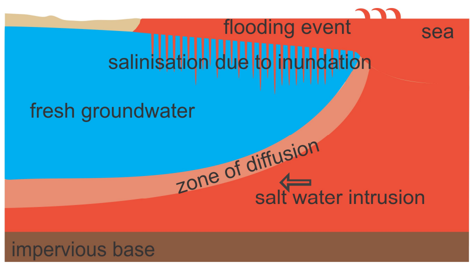


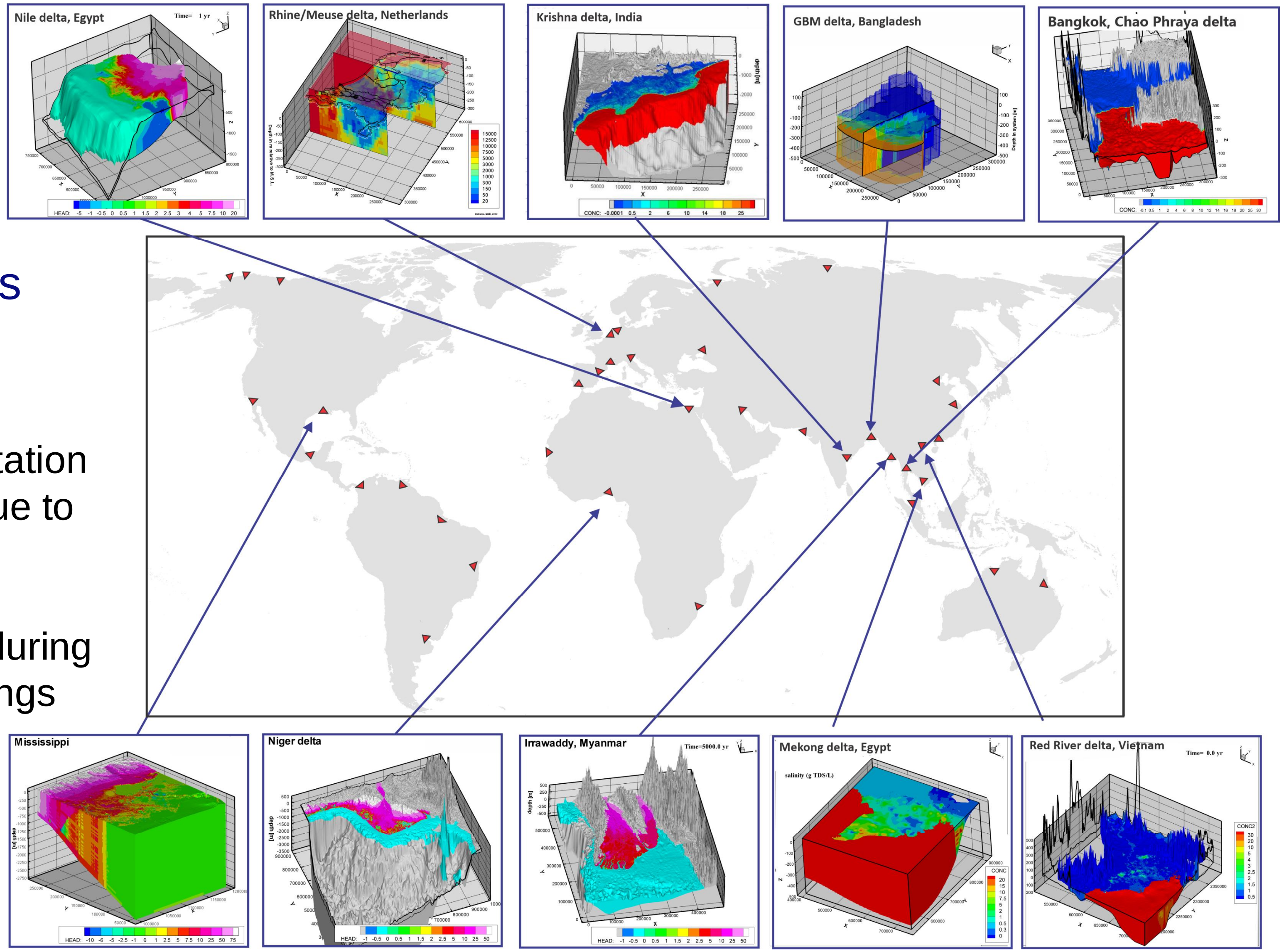
Minderhoud, 2019

Groundwater salinization

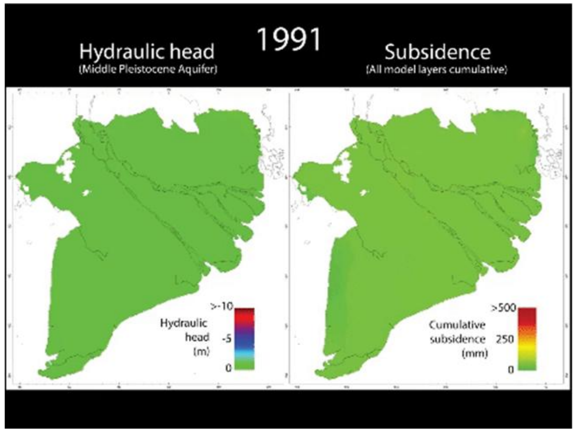
Fresh groundwater volumes in many deltas of the world are under stress:

- groundwater overexploitation
- limited replenishment due to sealing of clay layers
- sea-level rise
- overwash saline water during storm surges and floodings



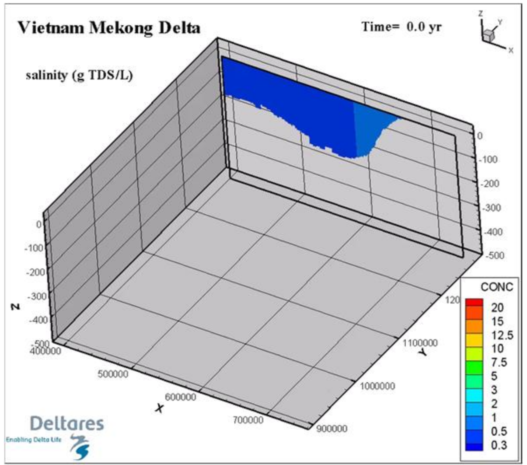


Modeling toolboxes to understand processes and to create projections Case Mekong Delta



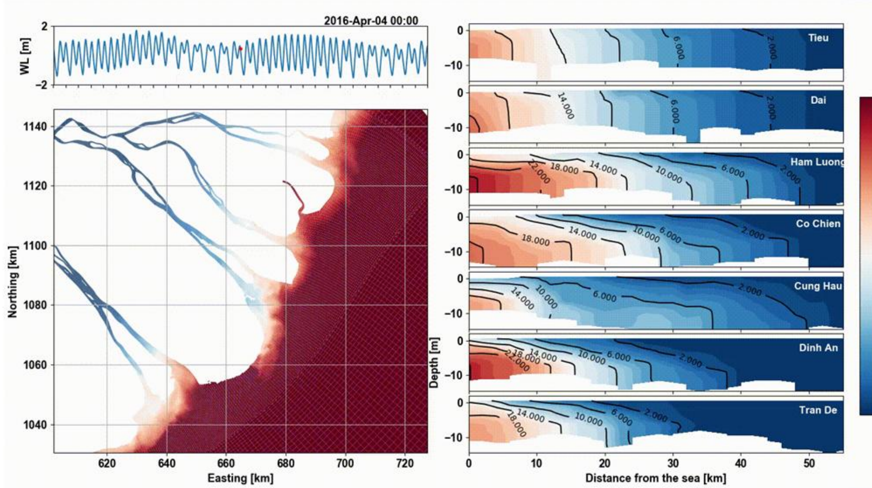
Land subsidence

iMOD SUB-CR:
Modeling subsidence



Groundwater salinity

iMOD WQ-SEAWAT:
Modeling salt transport
Modelling groundwater flow



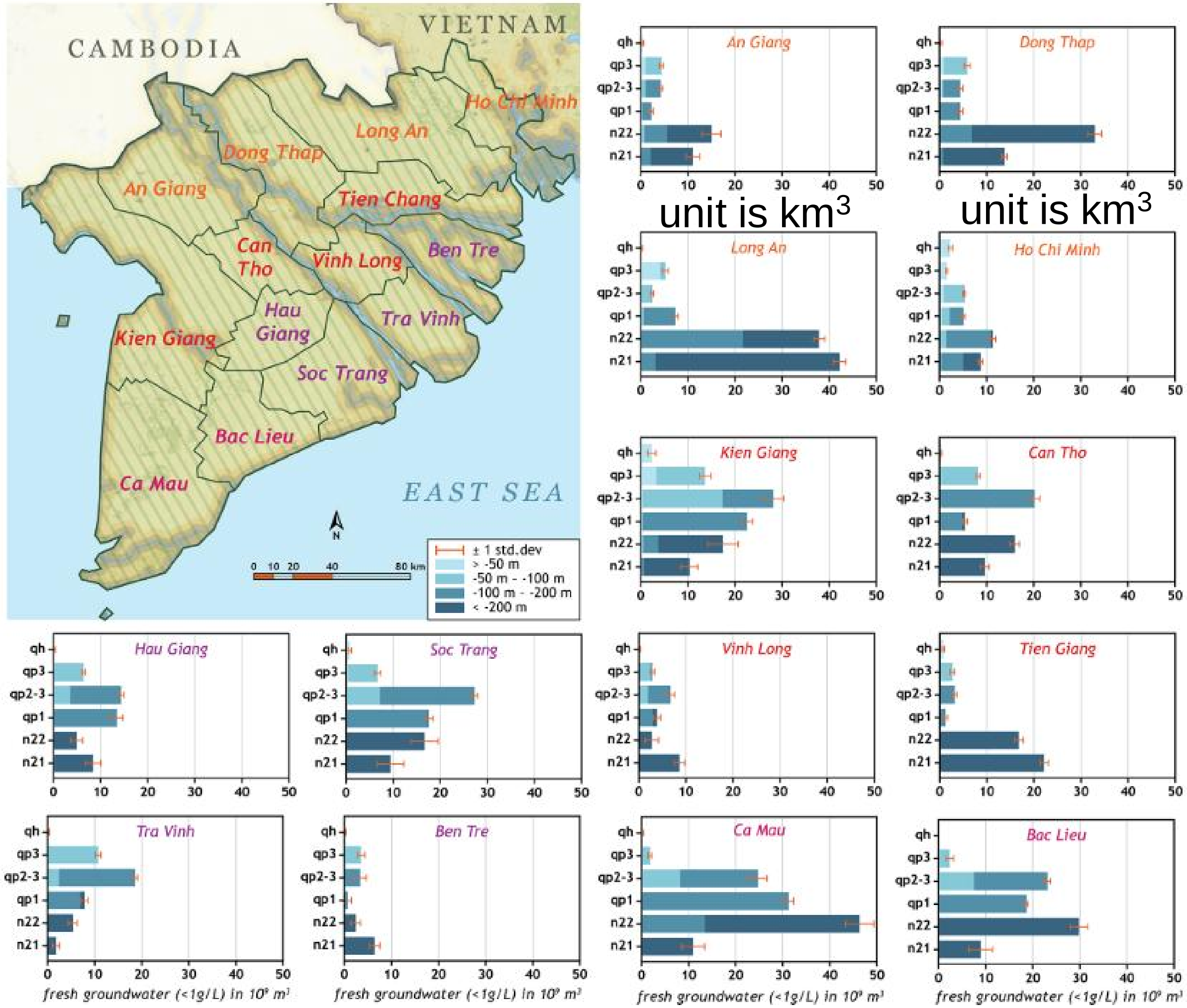
Surface water salinity

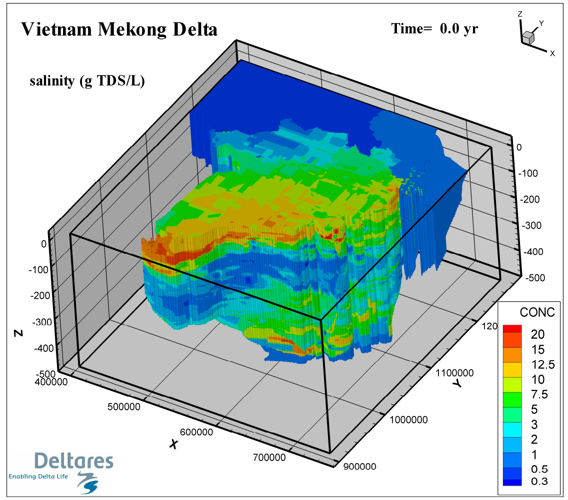
Delft3D-FM:
Modeling fresh and saline surface water

Open Source software (https://oss.deltares.nl/**)**

Universiteit Utrecht DWRPIS SIWRR Deltares TNO innovation for life Vitens Evides international NWO Netherlands Organisation for Scientific Research WOTRO Science for Global Development

Estimated volume of fresh groundwater (km³) per province per aquifer (total: 830 to 900 km3)

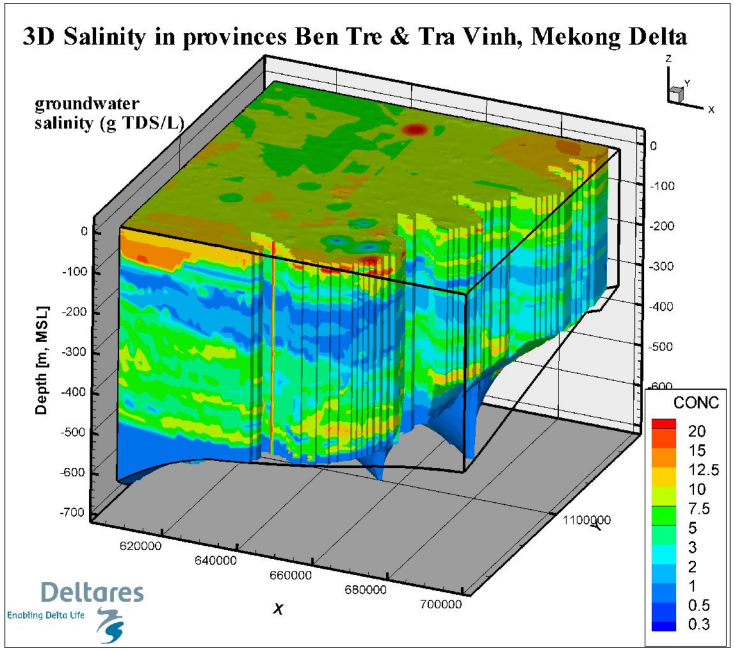


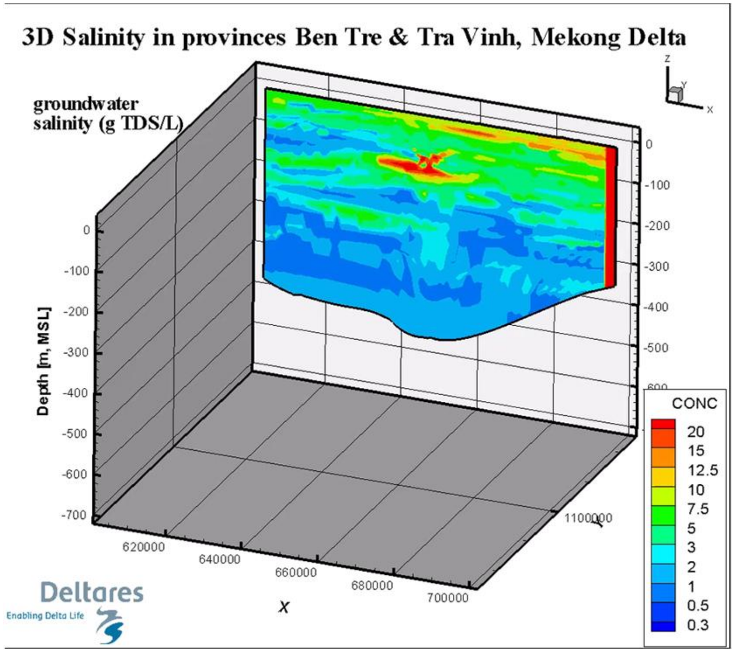


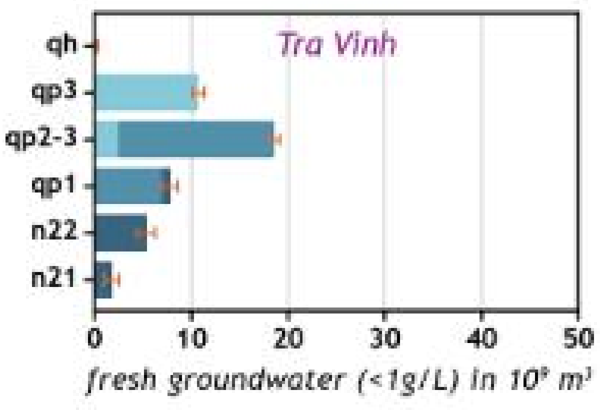
ref:

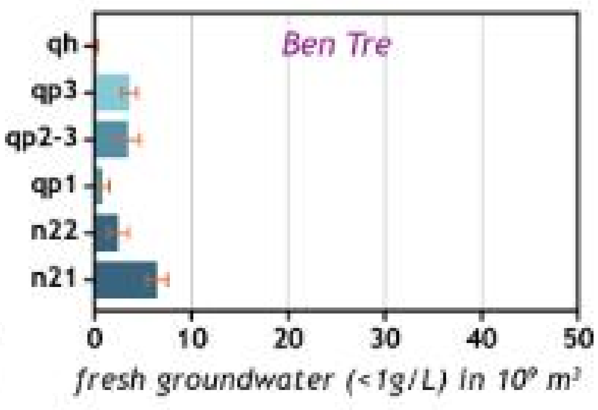
Gunnink, J.L., Pham, V.H., Oude Essink, G.H.P., Bierkens, M.F.P. The 3D groundwater salinity distribution and fresh groundwater volumes in the Mekong Delta, Vietnam, inferred from geostatistical analyses. Earth Syst. Sci. Data 13, 3297–3319. https://doi.org/10.5194/essd-13-3297-2021

Distribution of fresh-saline groundwater, Ben Tre and Tra Vinh









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Gunnink, J.L., Pham, V.H., Oude Essink, G.H.P., Bierkens, M.F.P. The 3D groundwater salinity distribution and fresh groundwater volumes in the Mekong Delta, Vietnam, inferred from geostatistical analyses. Earth Syst. Sci. Data 13, 3297–3319. https://doi.org/10.5194/essd-13-3297-2021

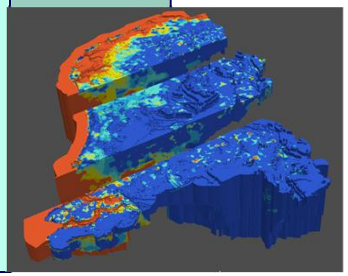
Intermezzo: volumes of fresh groundwater and stresses

Netherlands

~30BCM/yr precipitation

~1.5BCM/yr extraction

1100 BCM (km^3)
fresh groundwater



yet 20% drinkingwater wells have been abandoned

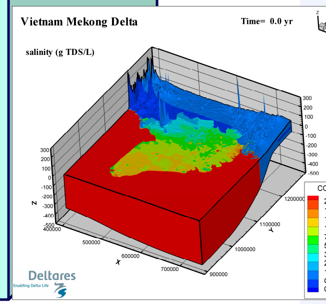
1BCM=1km^3

Mekong Delta

~45BCM/yr precipitation

~1.0BCM/yr extraction

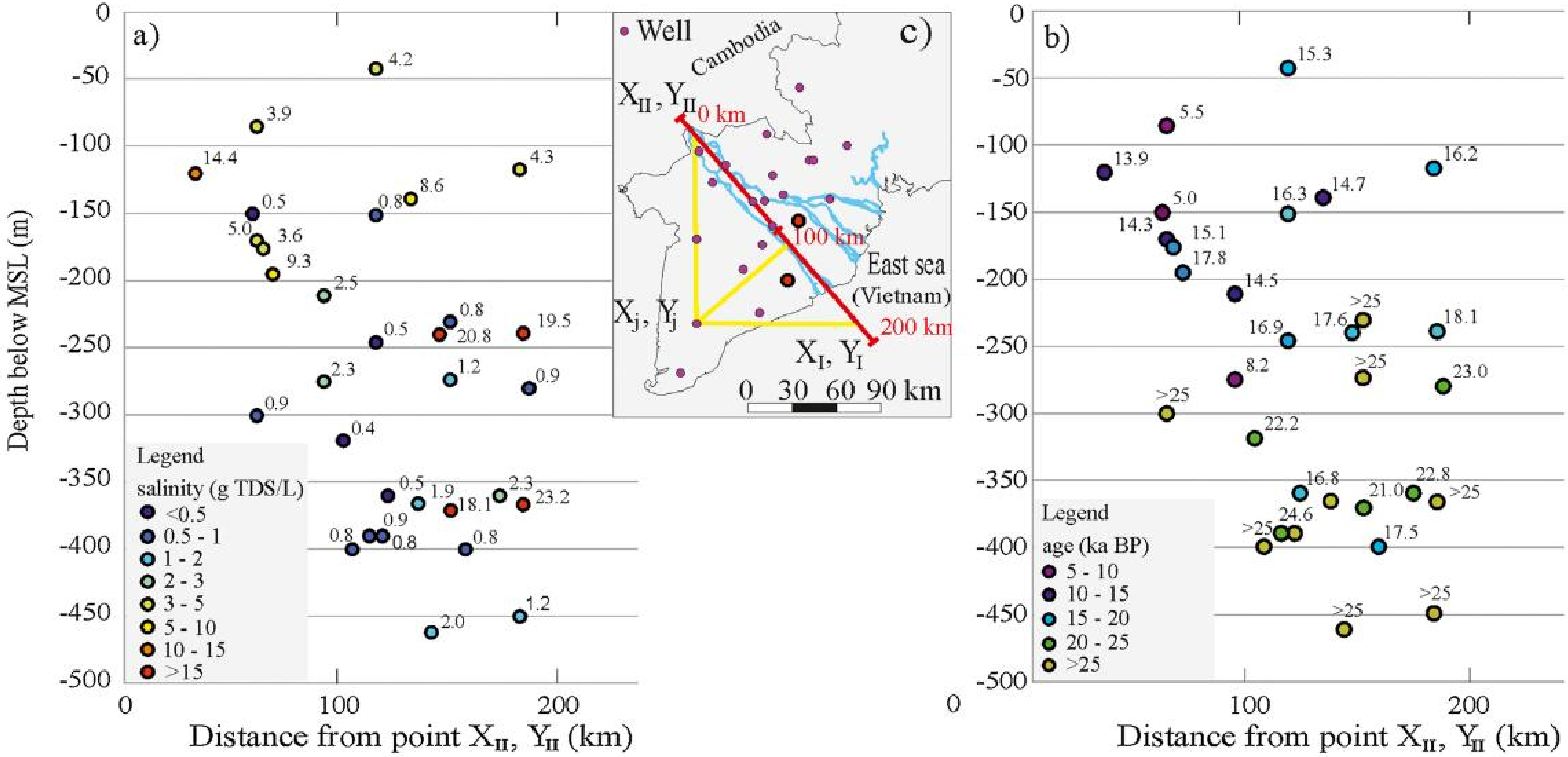
860 BCM (km^3)
fresh groundwater



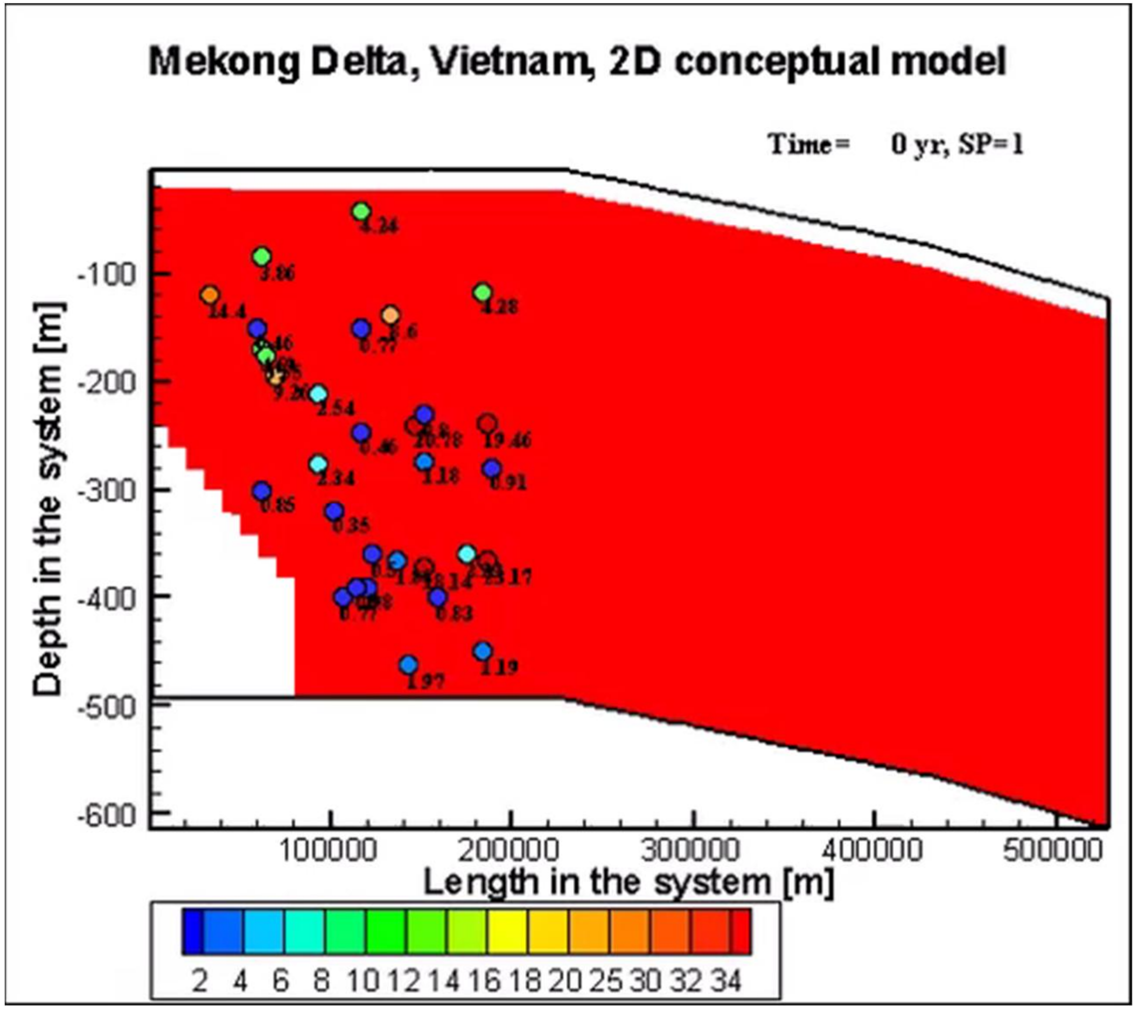
yet >0.2m subsidence over 25yr

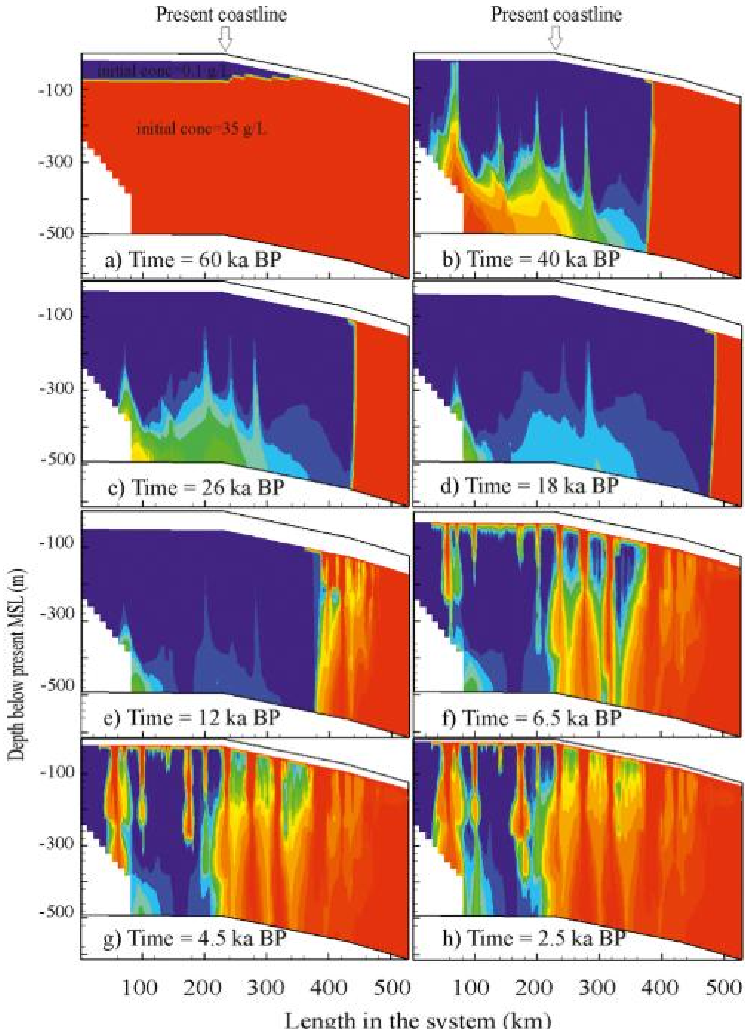
(DEM Mekong delta on average: +0.8m)

Paleo reconstruction groundwater salinity Mekong delta

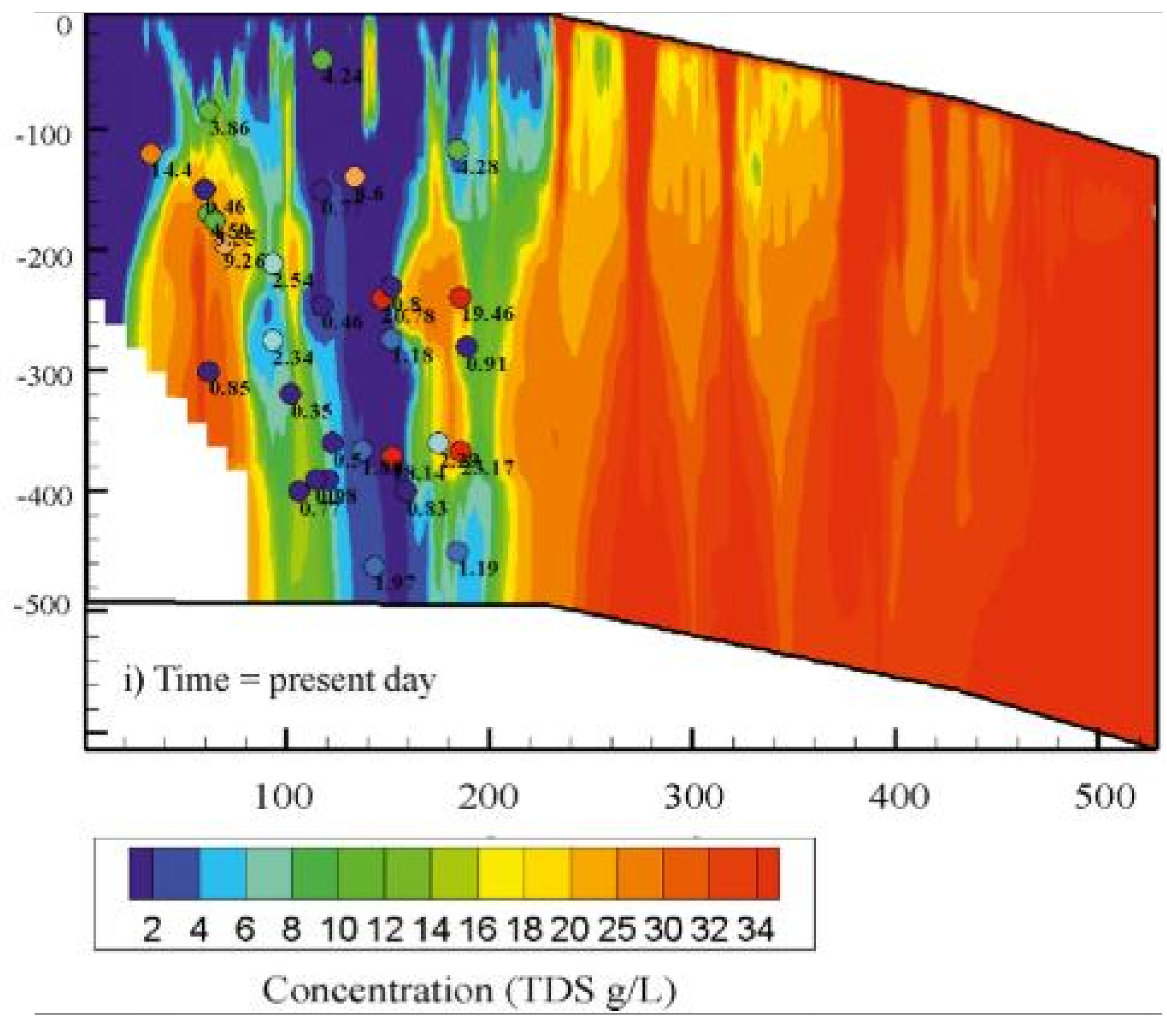


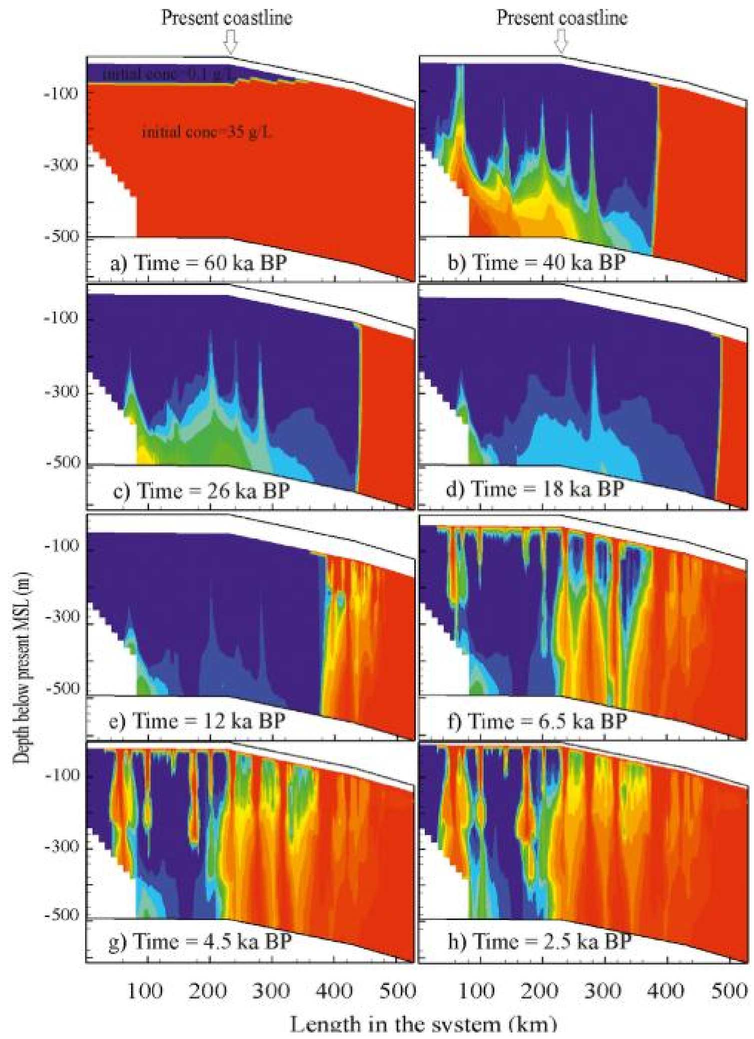
Modelling groundwater salinity Mekong delta over 40kyr





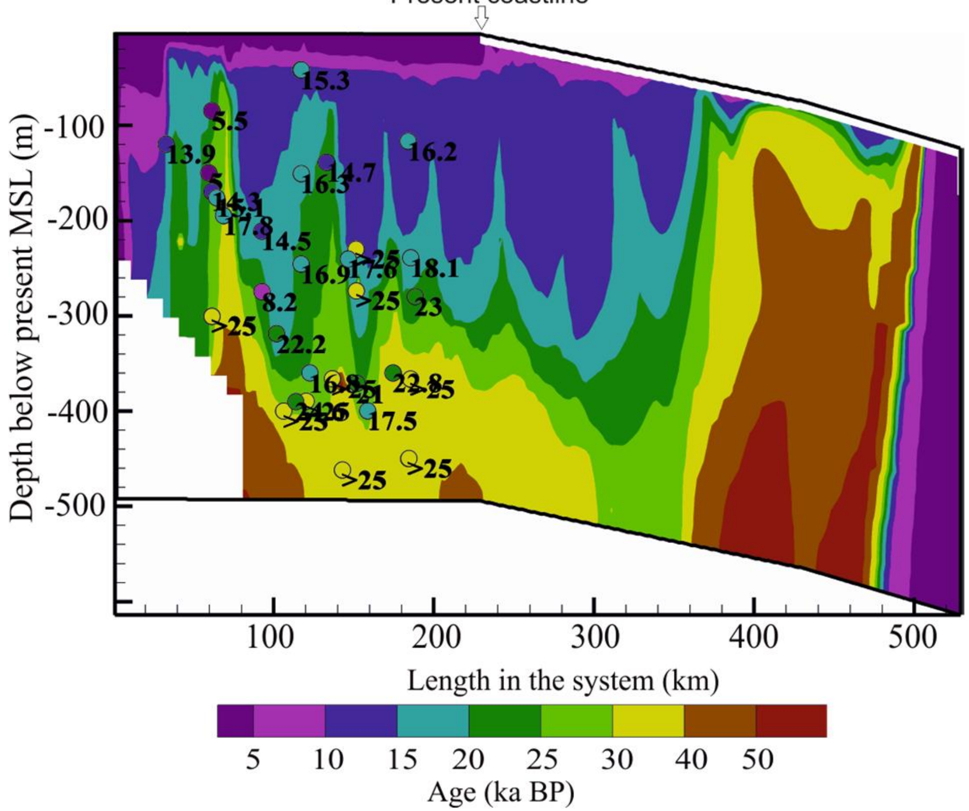
Modelling groundwater salinity Mekong delta over 40kyr





Modelling groundwater age Mekong delta over 40kyr

Modeled GW age distribution reference case at present day



Pham, V.H., Van Geer, F.C., Bui, V.T., Dubelaar, W., Oude Essink, G.H.P., 2019. Paleo-hydrogeological reconstruction of the fresh-saline groundwater distribution in the Vietnamese Mekong Delta since the late Pleistocene. J. Hydrol. Reg. Stud. https://doi.org/10.1016/j.ejrh.2019.100594

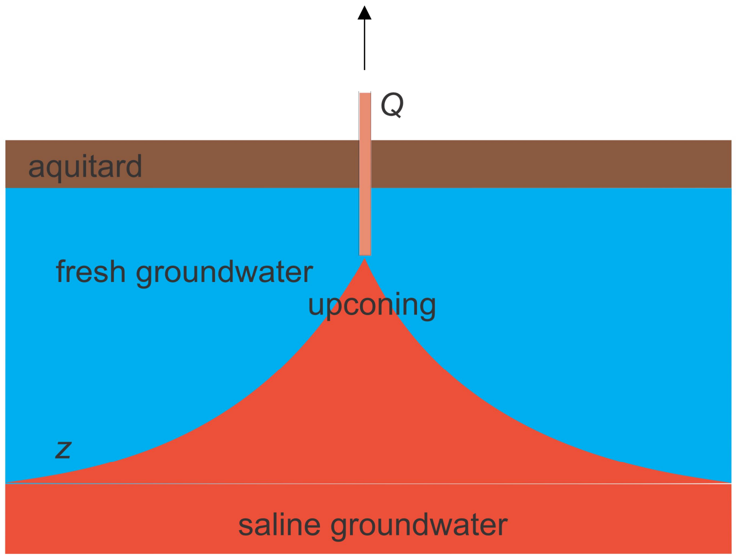
- Most fresh groundwater in the Vietnamese Mekong Delta was recharged 60-12 kyr ago
- Presently, groundwater is hardly being recharged due to high resistance top layer

Salt water intrusion in deltaic (ground)water systems

When fresh groundwater is extracted, the fresh groundwater volume decreases much faster due to:

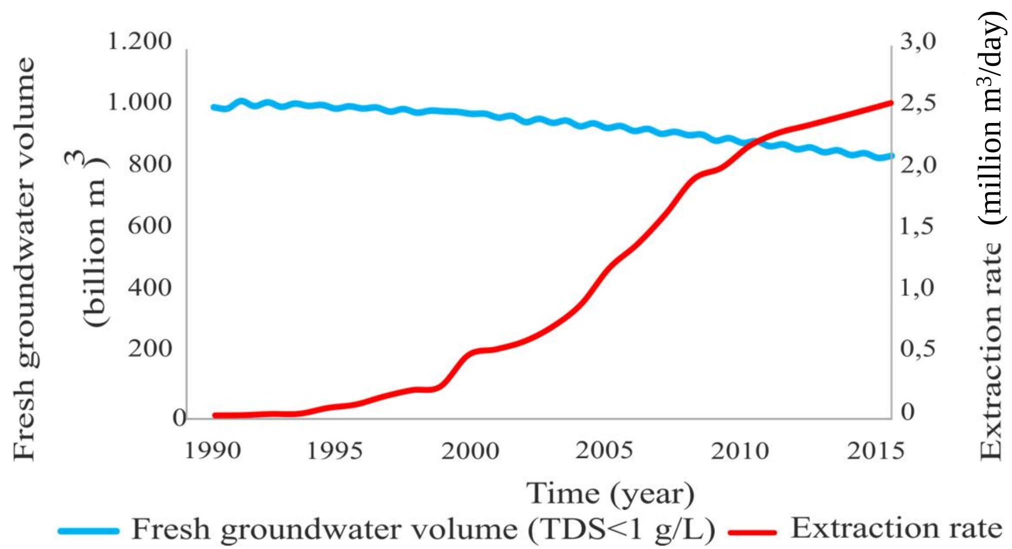
- **natural salt water intrusion**
- **mixing with brackish groundwater**

Rule of thumb: for every **1 m³** fresh groundwater you extract, you **loose ~10 m³** of fresh groundwater stock



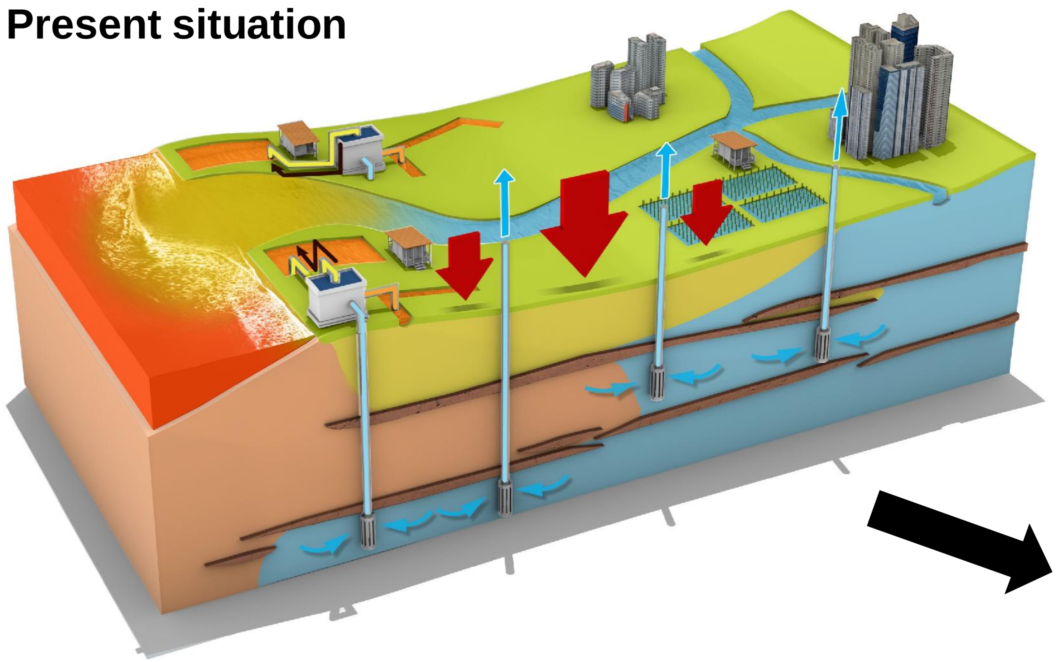
Upconing saline groundwater

Example The Mekong Delta
Effect of 25 years of simulated groundwater extractions on fresh groundwater volume



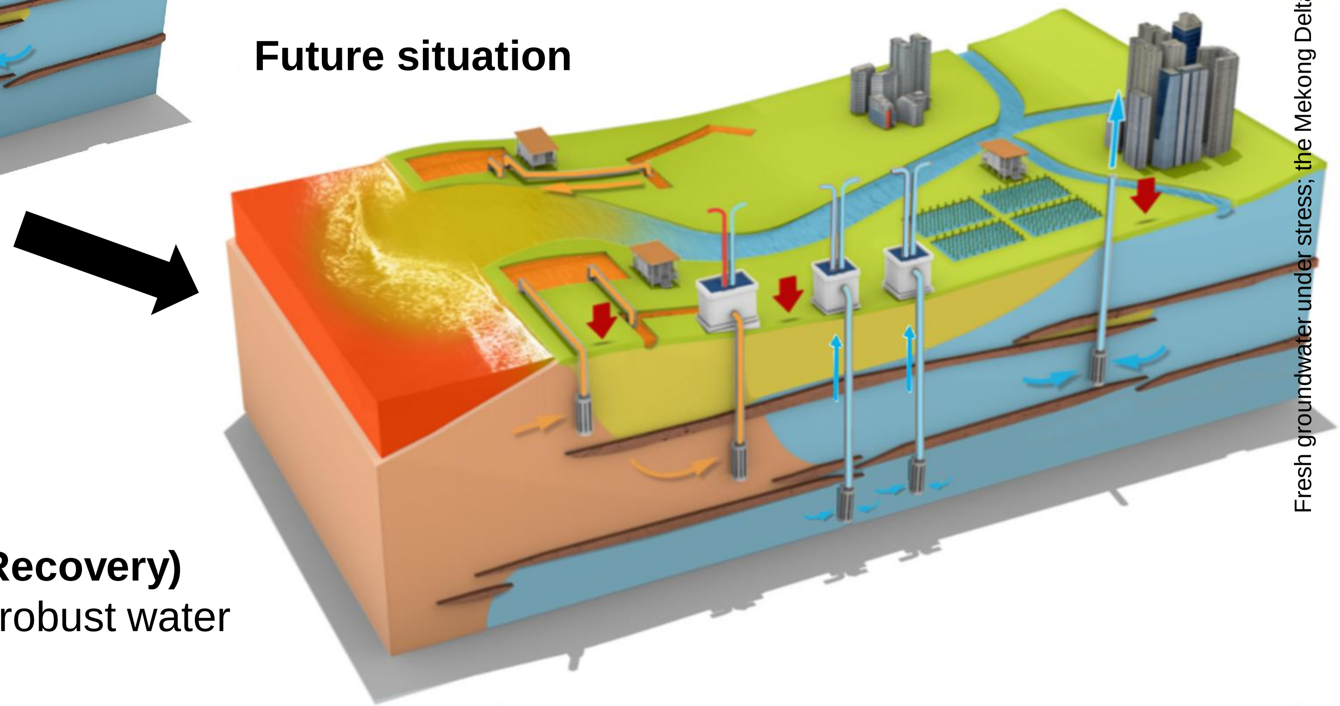
Deep-well Aquifer Storage and Recovery: Case Mekong Vietnam

Present situation



- Mitigating groundwater extraction and land subsidence.
- Mitigating salt water intrusion groundwater system.
- Quality freshwater supply during shortage.
- Scalability.

Future situation



COASTAR (COastal Aquifer STorage And Recovery)
Large scale use of subsurface solutions for a robust water supply and water management by:

Combine smart freshwater practices

"There is no solution that fits all"

1. Regulate and minimize groundwater extractions (as soon as possible); save precious fresh groundwater as a strategic reserve for the uncertain future.
2. Promote water savings in agriculture, drinkingwater sector and industry.
3. Create land use shifts to relieve freshwater demand (salt-resistant agriculture, reallocate crops).
4. Store water in the subsurface through Aquifer Storage and Recovery techniques.
5. Increase the capacity of rainwater infiltration in the coastal zone.
6. Use waste water in a circular economy.
7. Use brackish groundwater and desalinize it.

Key messages for a future sustainable delta

- On the long run, delta life is not obvious anymore if no measures are taken in time: create awareness of subsurface threats (subsidence and salinization freshwater resources).
- Man-induced subsidence and salinization exceed sea-level rise effects.
- Fresh groundwater is not a free resource; you ‘pay for it’ with elevation and salinization.
- Before implementing measures, understand your water system first.
- Use modeling tools to asses responses of increased stresses and evaluate effective measures.
- There is no solution that fits all; integrated tailor-made strategies are needed in an adaptive pathway setting.
- Create a sense of urgency under water managers, policy makers and investors.

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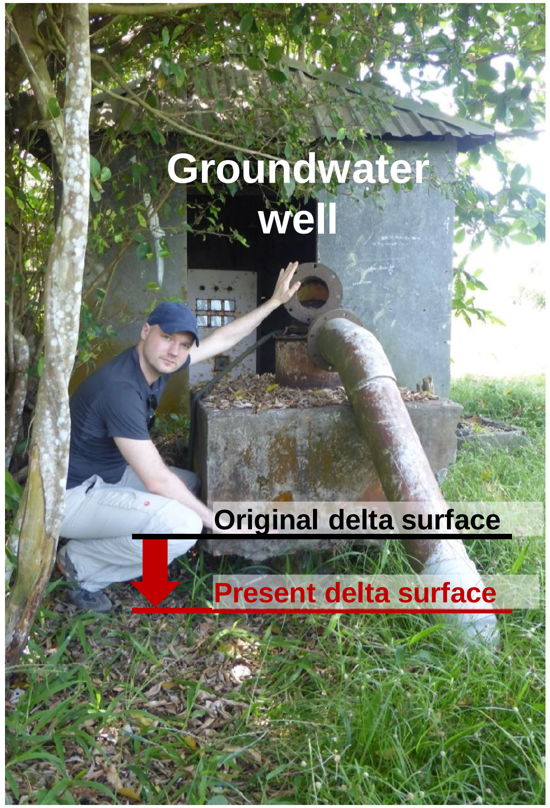

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