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Kingdom of Morocco
Ministry of Equipment and Water

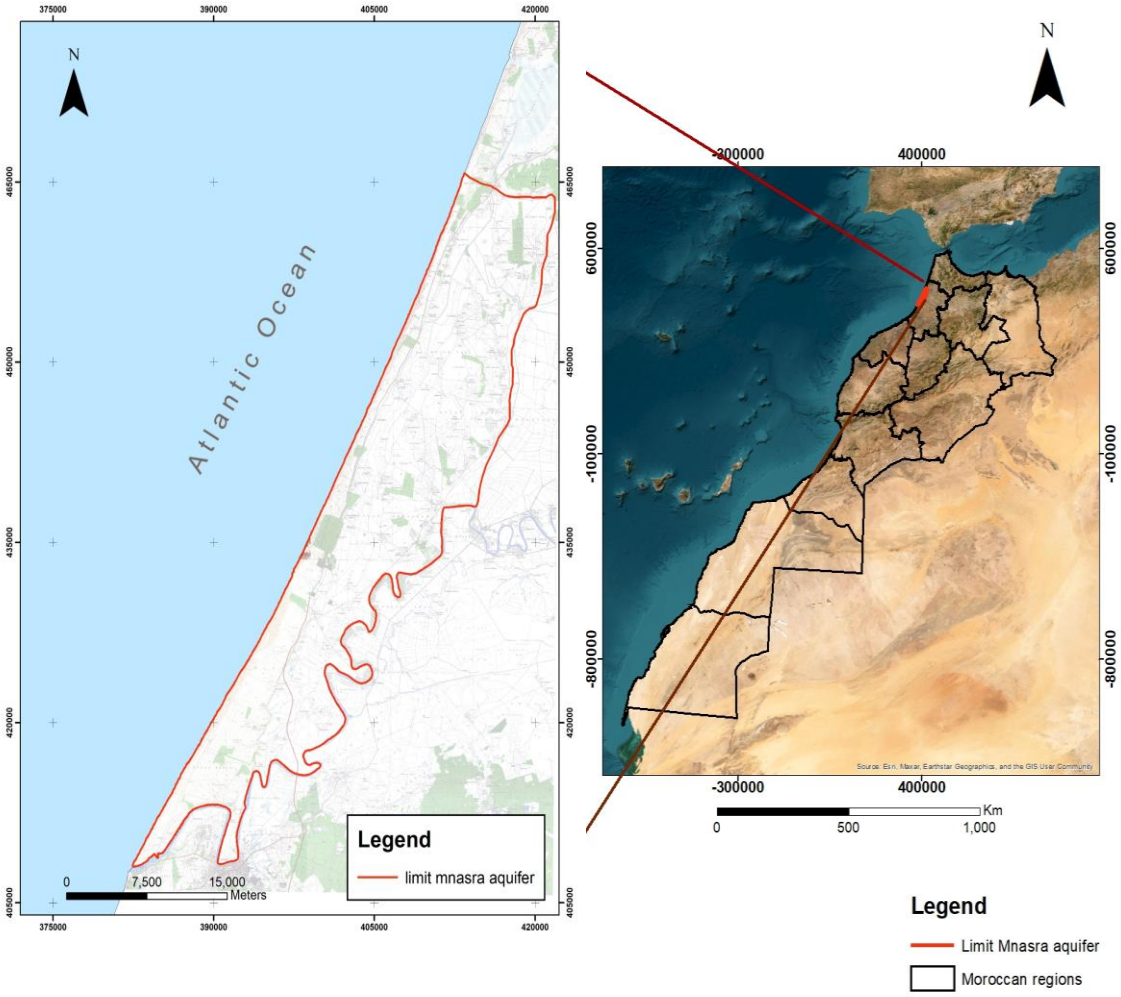
Enhanced 3D Hydrogeological Model for the Assessment of Groundwater and Seawater Intrusion in the Mnasra Coastal Aquifer by Advanced Modeling

Amale SOUDANI, Mohamed Jalal EL HAMIDI, Abdelkader LARABI,
Mohamed FAOUZI, Taha EL GHAZLANI
LAMERN, Department of Mineral Engineering, Mohammadia Engineering School, MOHAMMED V University in Rabat, Morocco
Direction of the Research and the Planning of water (DRPE)

Study area

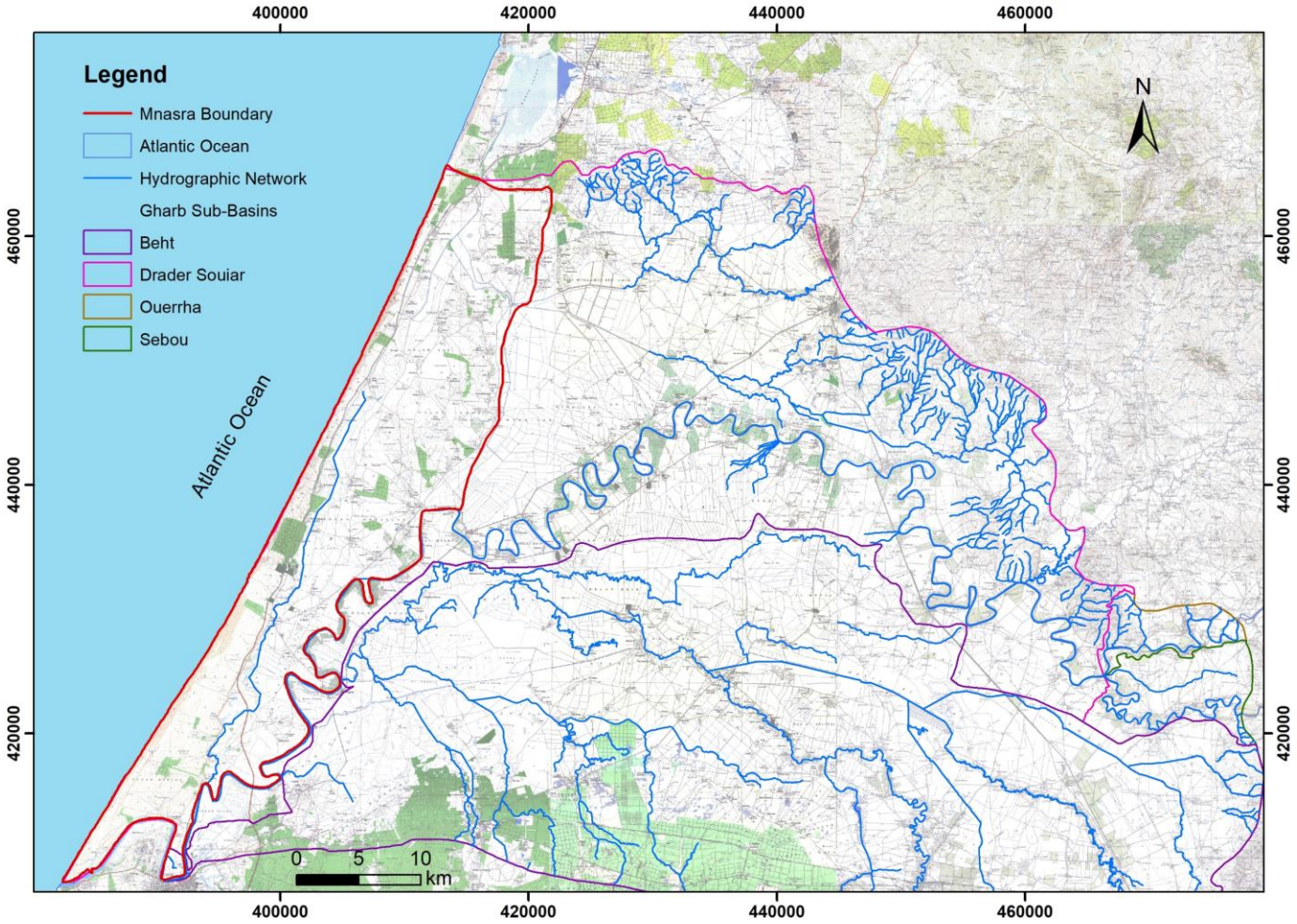
- The Mnasra area is about 600 km2 located in the coastal area of the Gharb Plain, bounded by the Atlantic Ocean to the west, the Sebou River to the south, and the Lalla Zohra hills to the north.

- It is a primary source of freshwater for the region, used for both drinking water and extensive irrigation for agriculture.



Limit of The Region Mnasra

Hydrological Characteristics



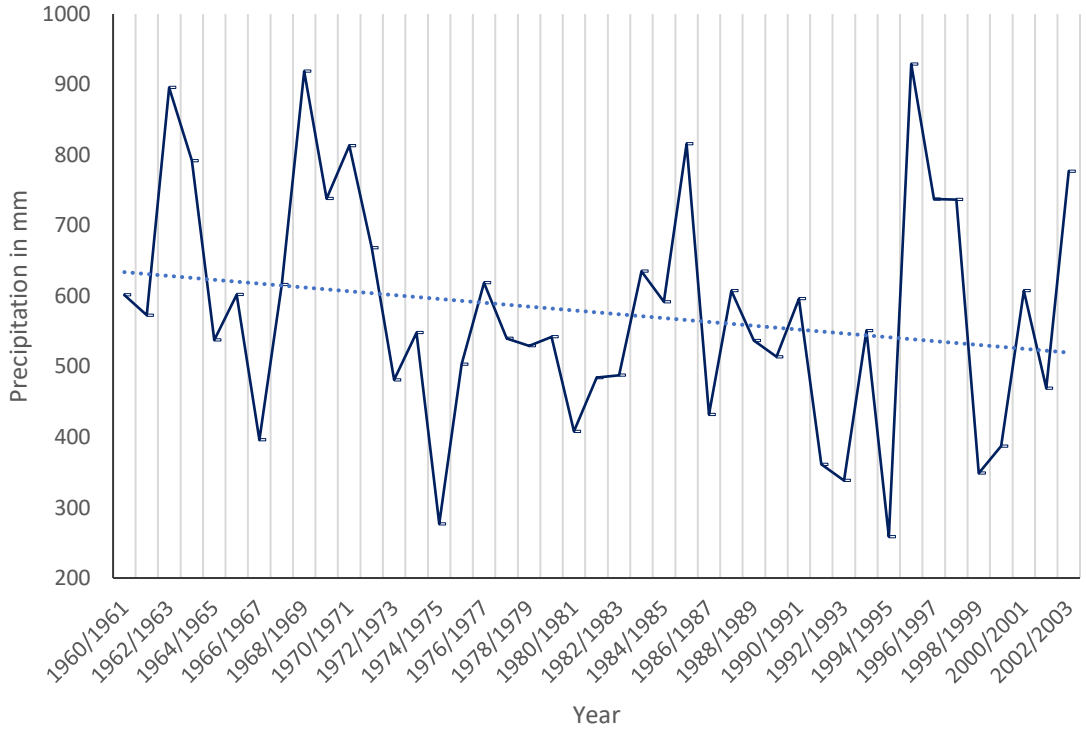
Hydrological map of Mnasra region

- Mnasra is a poorly drained area with weak runoff and flat relief.
- Sandy soils allow infiltration, while clayey layers cause water stagnation.
- This leads to temporary merjas drained by the Fakroun Canal to the Sebou River.

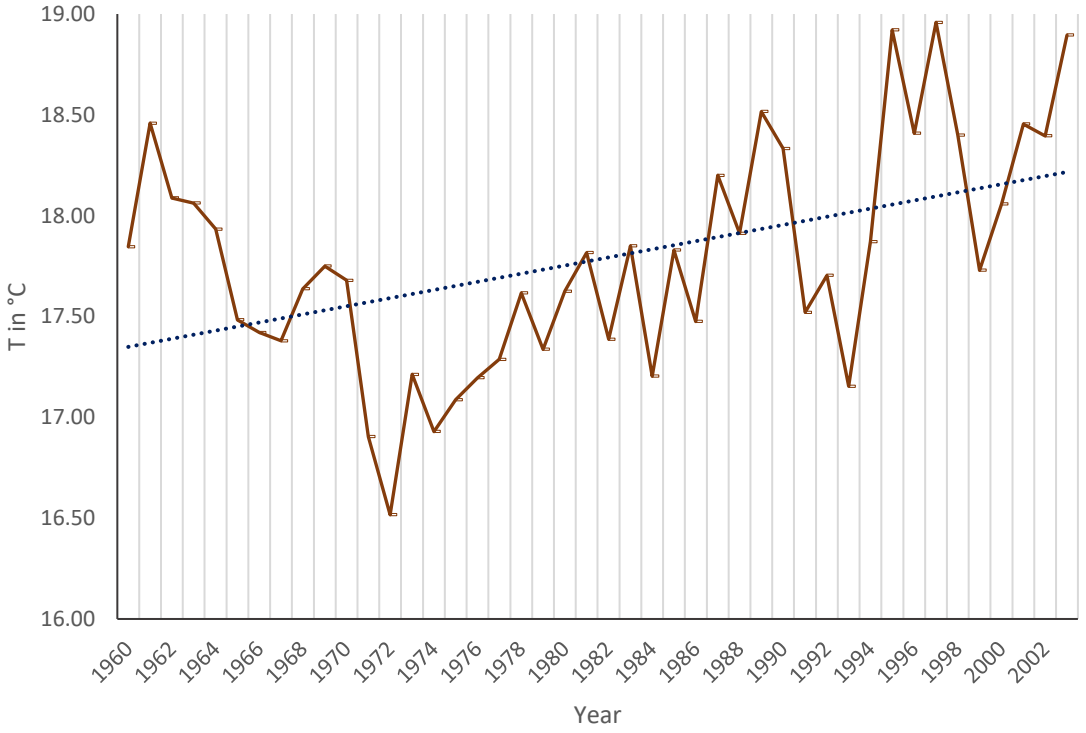
Past Climate Trends

- The average rainfall in the study area is about 555mm, and the average monthly temperatures are between 11.5°C and 23.2°C

- Subhumid oceanic climate with wet winters, dry summers, and moderate temperatures influenced by the Atlantic Ocean



Annual Precipitation Evolution



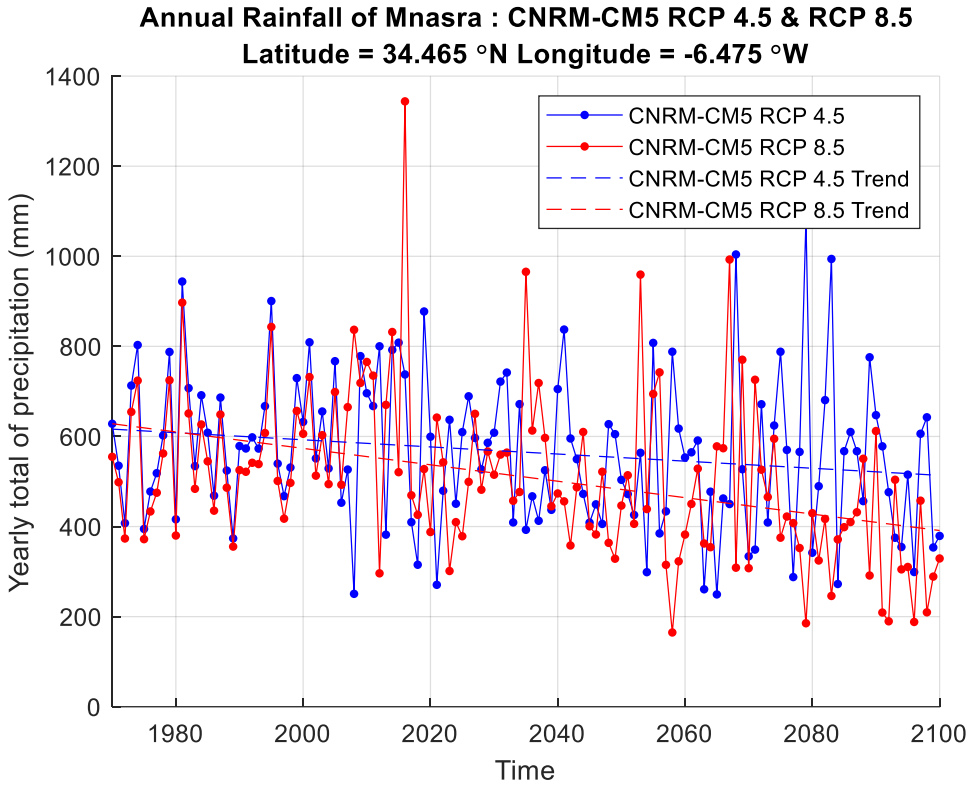
Annual Temperature Evolution

Projected Climate Trends Under RCPs

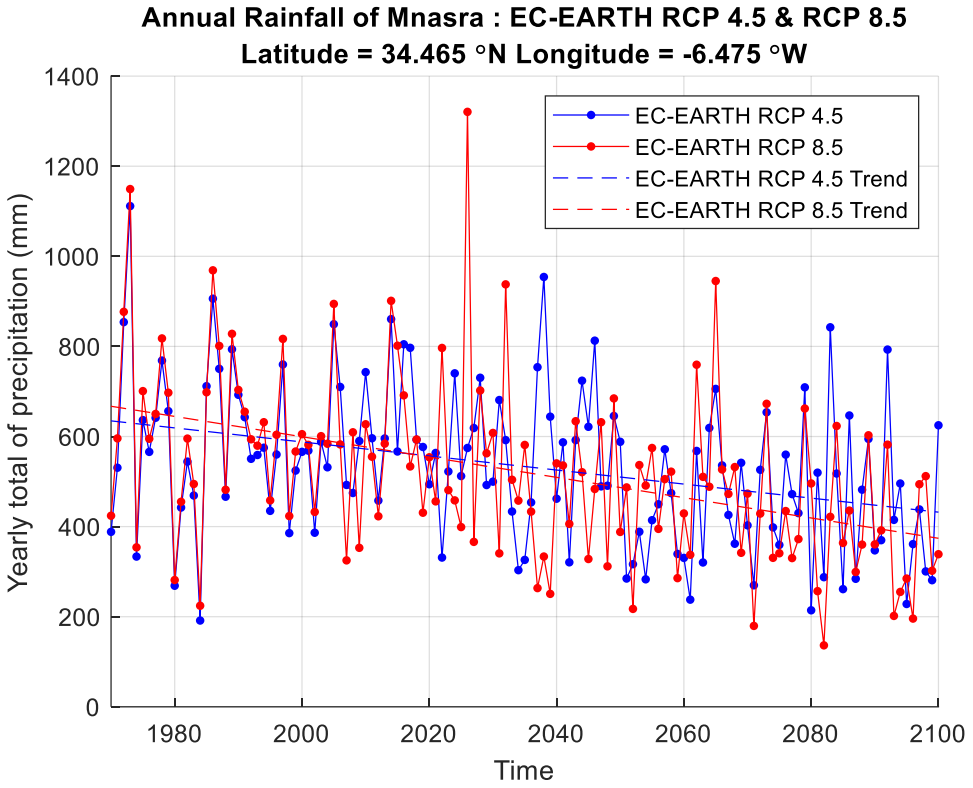
RCPs (Representative Concentration Pathways)
represent different future climate scenarios based on varying levels of greenhouse gas emissions

RCP4.5
A moderate pathway where emissions decline over the latter half of the century.

RCP8.5
the "worst-case" scenario, assuming high greenhouse gas emissions continue to increase throughout the century.

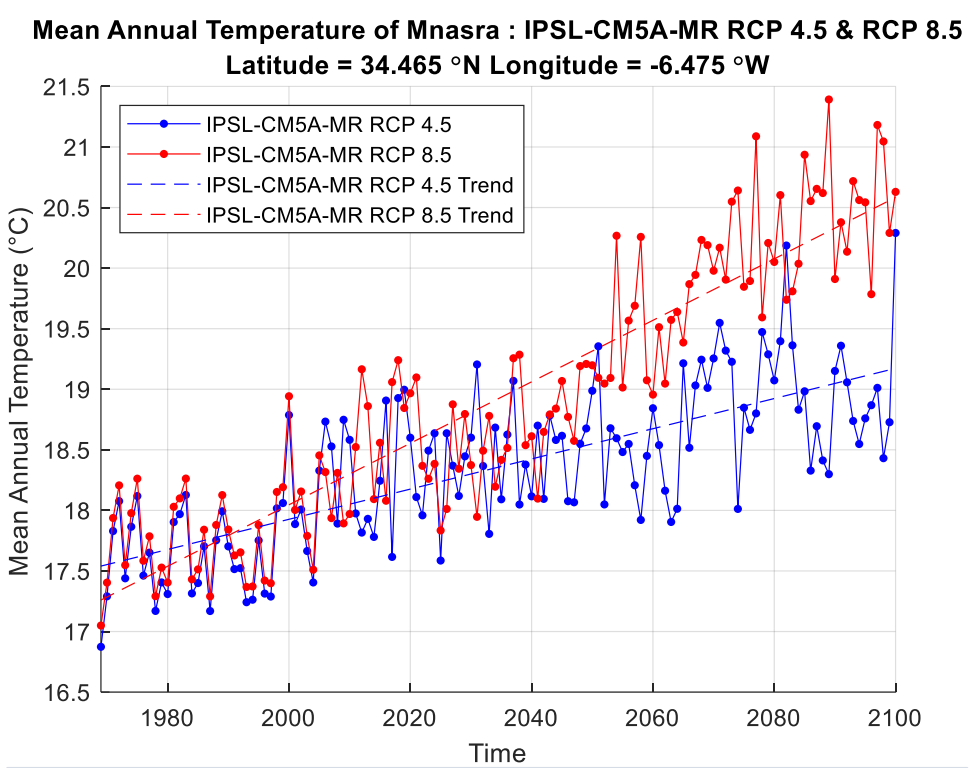


Precipitation (mm/year) over time (1980-2100) in the study area (CNRM-CM5 for RCP 4.5 and RCP 8.5)

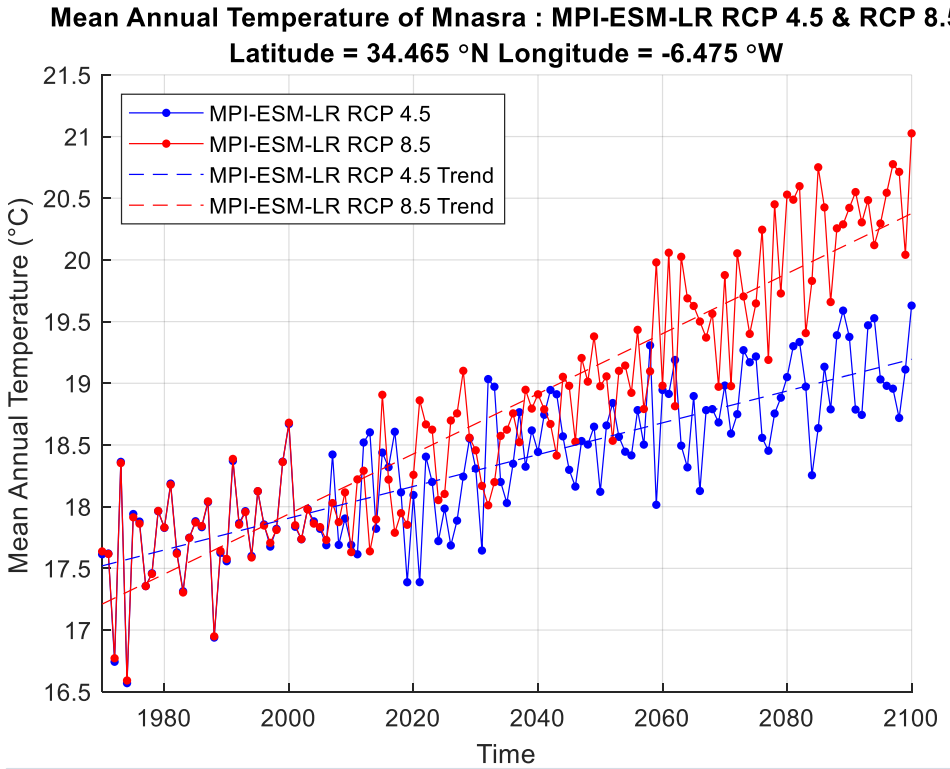


Precipitation (mm/year) over time (1980-2100) in the study area (EC-EARTH for RCP 4.5 and RCP 8.5)

➡ indicate declining annual rainfall, with larger reductions under high-emission scenarios (RCP 8.5)



Temperature (°C) over time (1980-2100) in the study area (IPSL_CM5A_MR for RCP 4.5 and RCP 8.5)



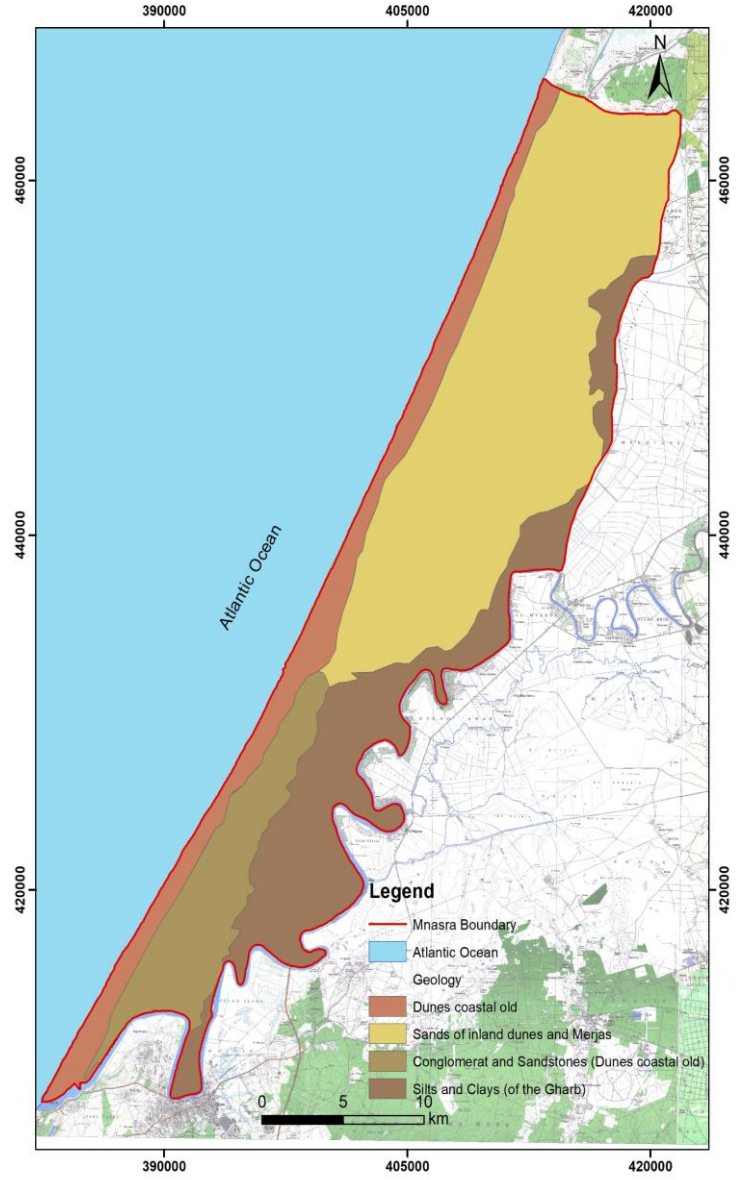
Temperature (°C) over time (1980-2100) in the study area (MPI_ESM_LR for RCP 4.5 and RCP 8.5)

➡ Projected temperatures rise significantly under both scenarios, reaching ~20°C under RCP 4.5 and up to ~22°C under RCP 8.5

Geological Context

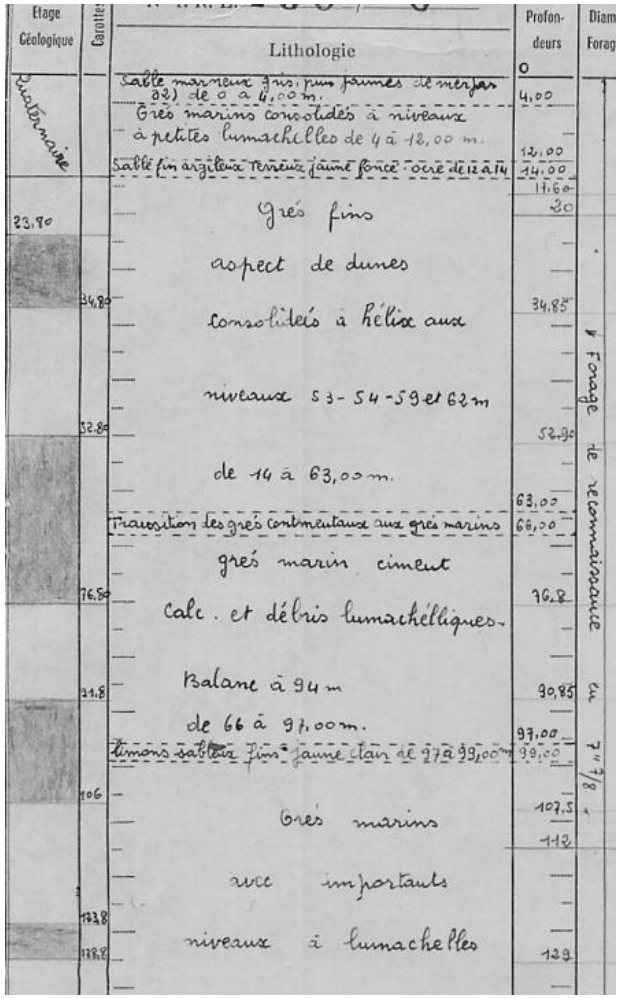
- The Mnasra area is situated within the Gharb basin, a large, subsident plain bordered by the active Rif chain to the north and the stable Hercynian Meseta to the south.

- The geology of the Mnasra region is primarily characterized by Plio-Quaternary sedimentary formations.

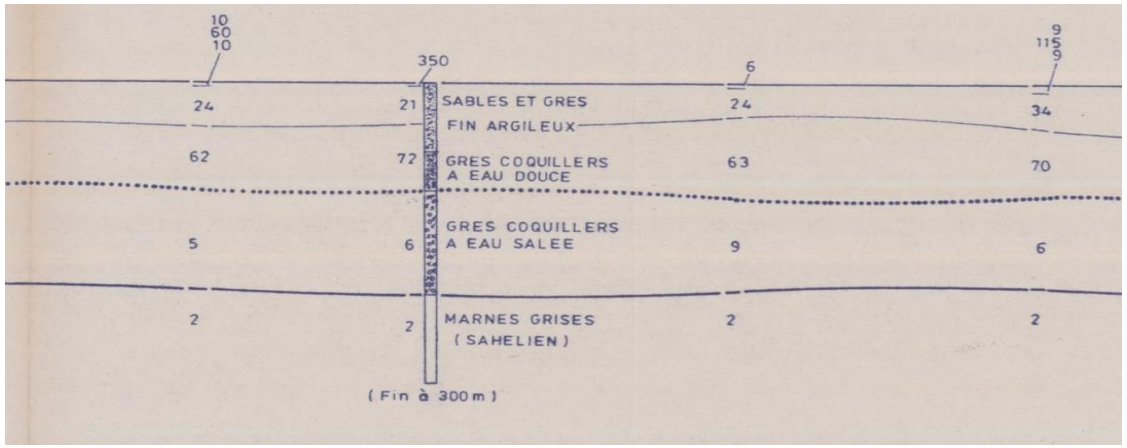


Geological map of Mnasra Region

Data Types For 3D Hydrogeological Model



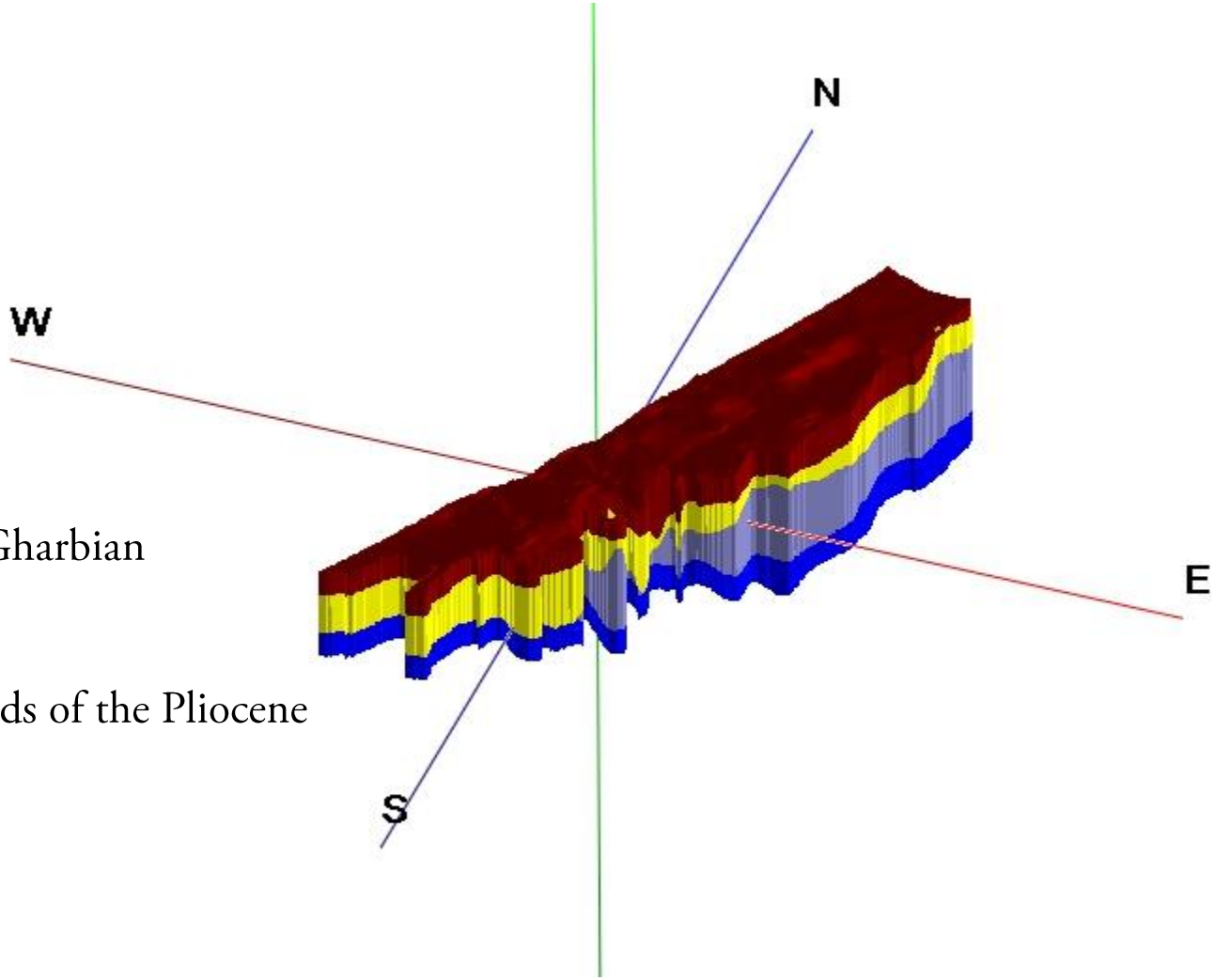
Example of lithology data in borehole



Example of geophysical measurements:
Vertical Electrical Sounding Cross-Section

3D Geological Model

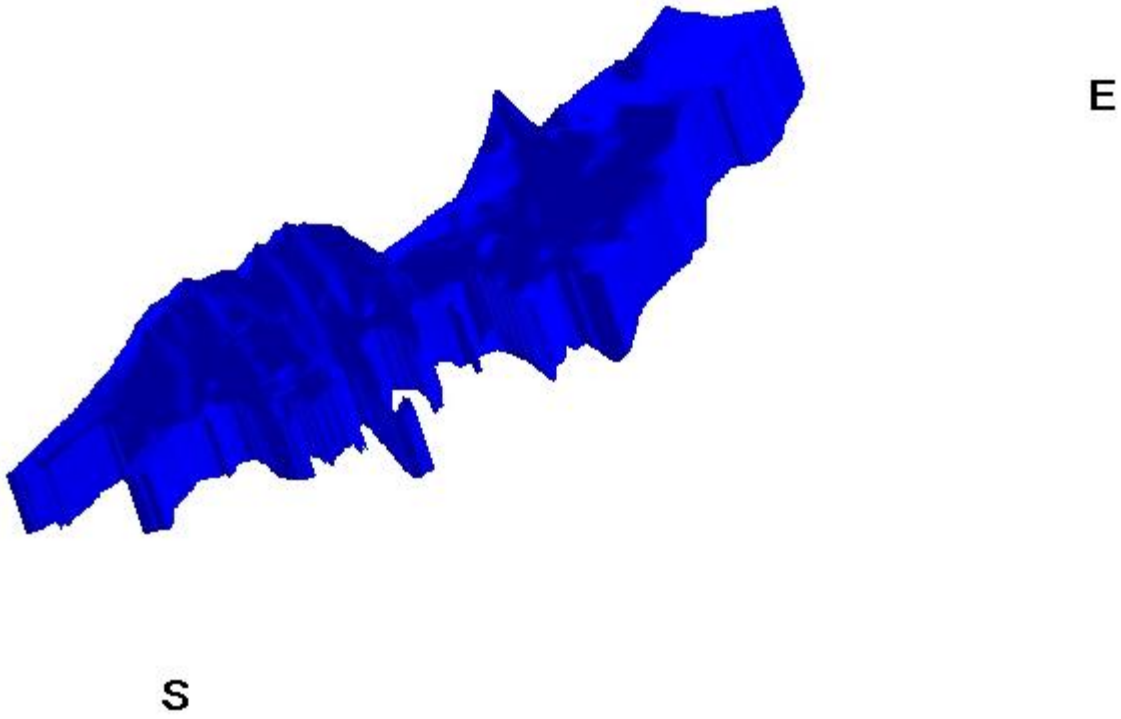
- Sands and sandy-clay deposits of the Soltanian / Gharbian
- Sandy sandstones of Villafranchien
- Lumachelle beds and sandstones with clay interbeds of the Pliocene
- Blue marls of the Mio-Pliocene



Stratigraphy Model of Mnasra Aquifer

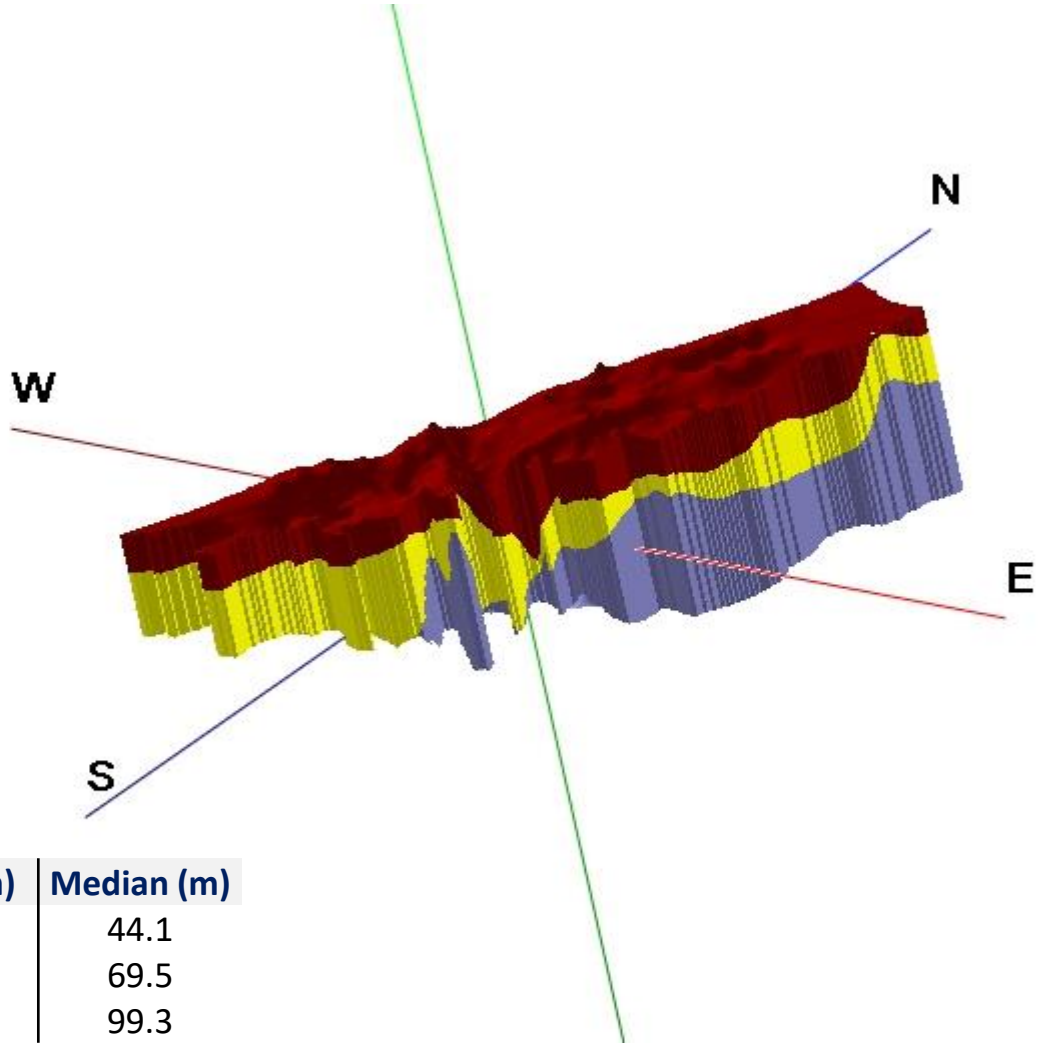
Aquifer Substratum

- It is characterized by a thick series of gray marls, pyrite, called “blue marl,” whose thickness can reach 2000 m. It constitutes the general substratum of the overlying formations.



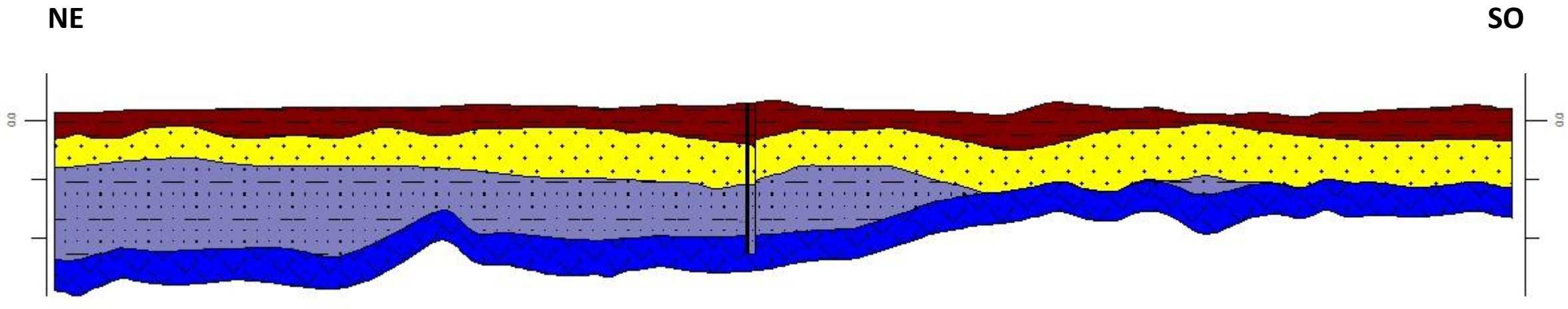
Plio-Quaternary Aquifer

- The Plio-Quaternary aquifer is heterogeneous, with rapid vertical and lateral facies changes.
- It contains permeable sands and sandstones, interrupted by clay and sandy-clay lenses.



Layer	Min Thickness (m)	Max Thickness (m)	Mean (m)	Median (m)
Soltanian / Gharbian Sands	0.0	158.9	39.7	44.1
Villafranchian Sandstones	0.0	192.6	75.2	69.5
Pliocene Lumachelles & Sandstones	0.0	208.4	77.6	99.3

Aquifer Stratigraphy profils



NE-SO Stratigraphy profil of the aquifer Mnasra

Formation

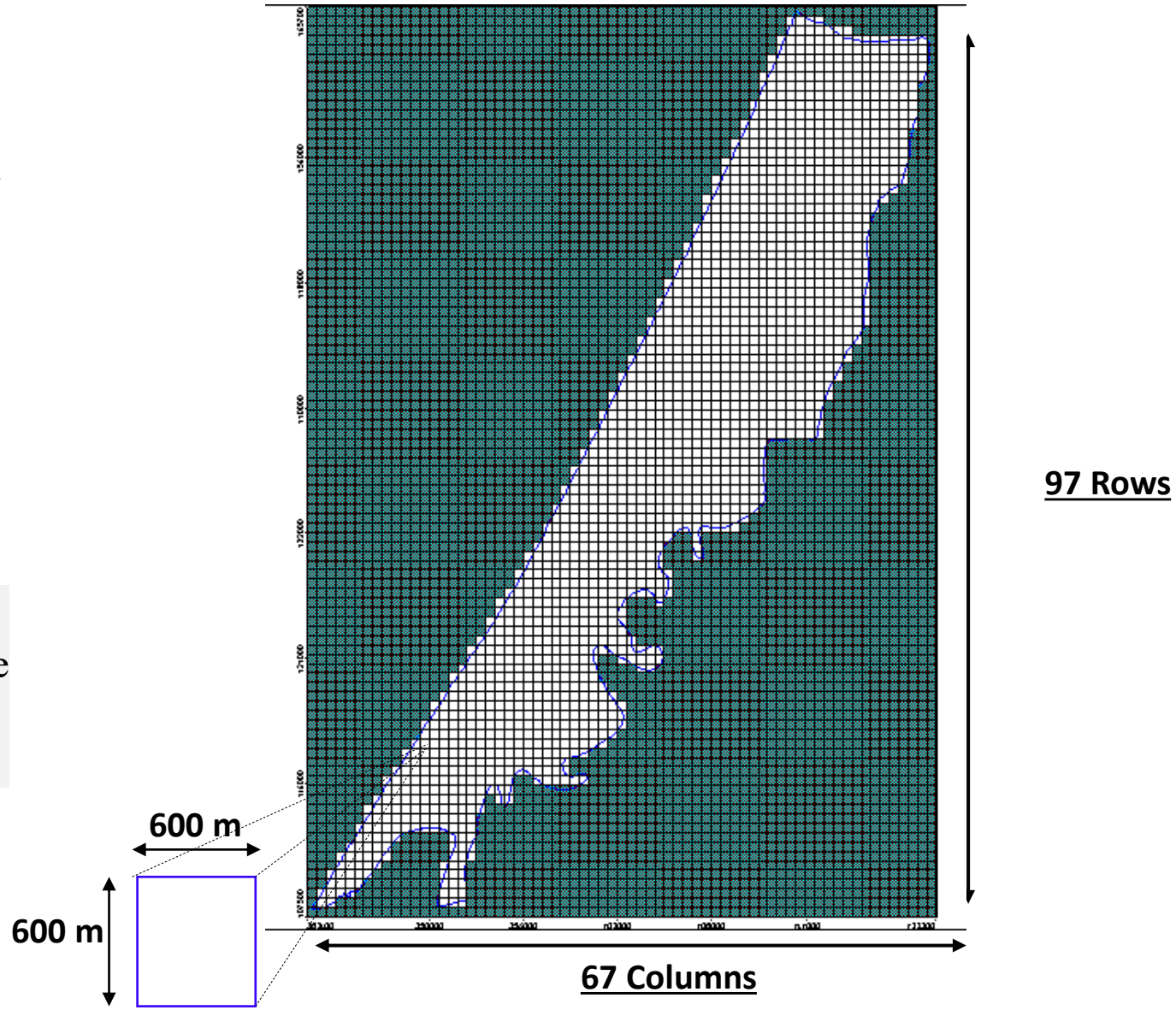
- Sands and sandy-clay
- Sandy sandstones
- Lumachelle beds and sandstones with clay interbeds
- Blue marls

Steady-state hydrodynamic modelling

- Steady-state hydrodynamic modeling is a simplified approach to studying fluid flow where properties are assumed to be constant over time

Spatial discretization:

- The area covers 600 Km2.
- The discretization scheme used is the finite difference method (MODFLOW).
- Design of grid of square cells of 600 m.



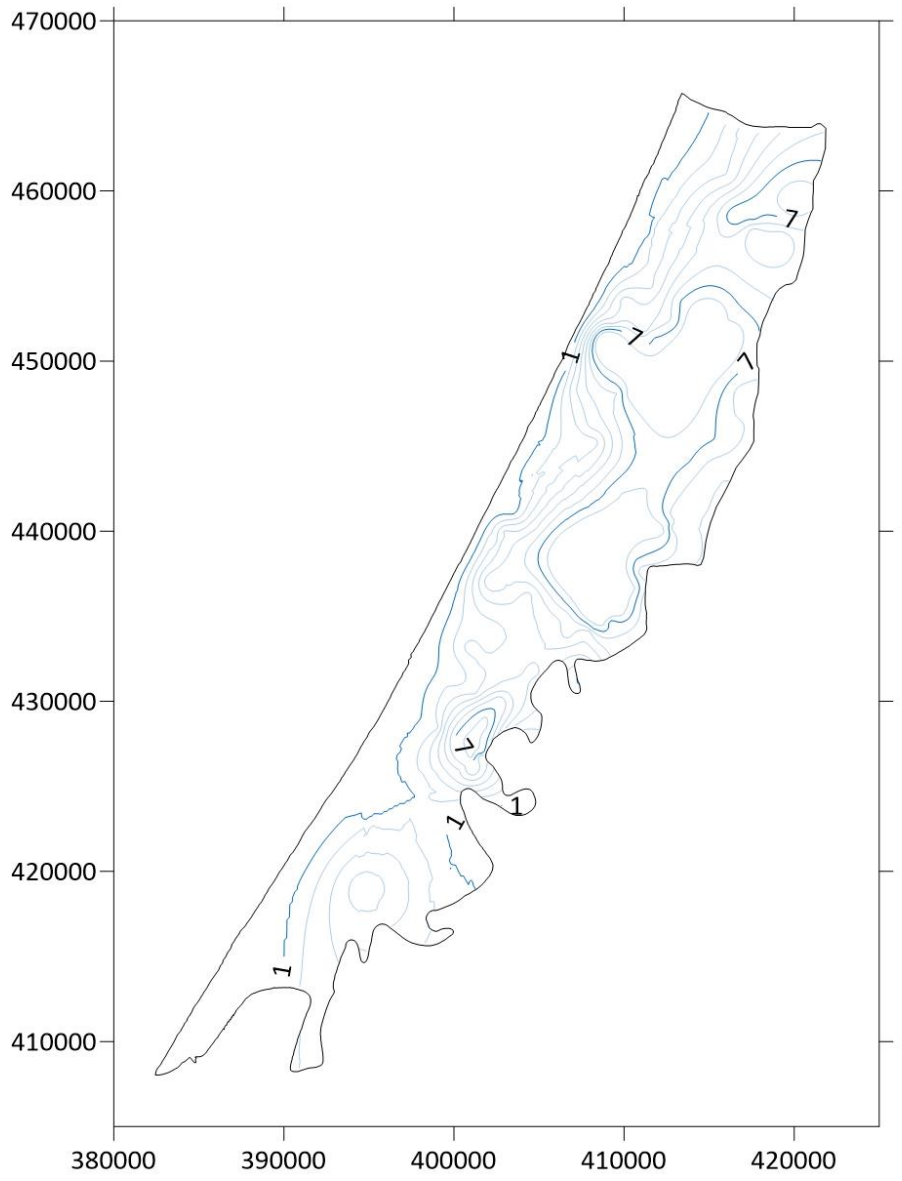
Reference piezometry

- The aquifer's historical and natural conditions before significant human impact. This period predates large-scale pumping and modern development, when groundwater levels were relatively stable

Darcy's Law $$Q = T \times L \times I$$

Q : discharge (Mm^3/year)
T : aquifer transmissivity (m^2/s)
I : hydraulic gradient (%)
L : width of the considered section (km)

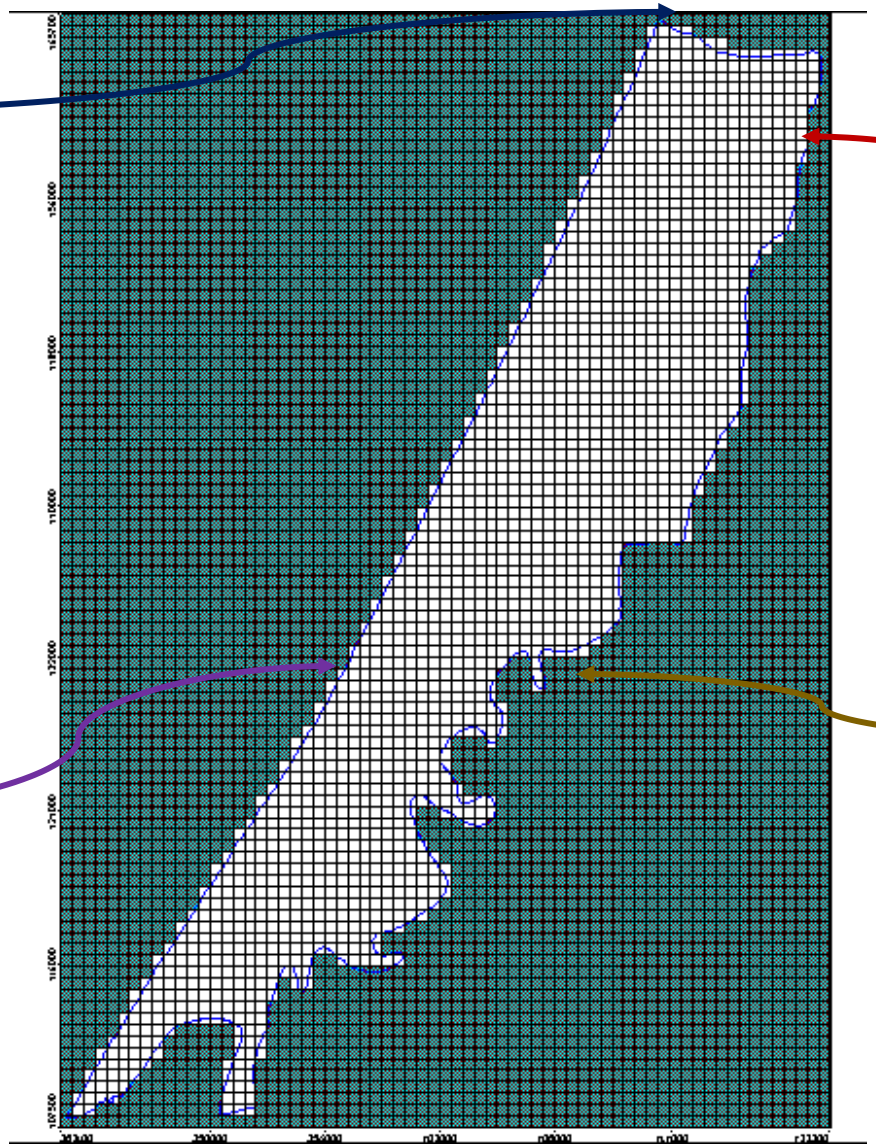
Flow towards	Q (m^3/day)
Atlantic Ocean	95068.49
Sebou River	20736
Gharb Aquifer	19440



Piezometry in 1963

Boundary conditions

- North: The boundary is perpendicular to the equipotential lines; therefore, this boundary is considered as a zero-flow leak-tight limit.



- East: This boundary constitutes the direct contact between the Gharb and the Mnasra tables

- West: The direct contact of the aquifer with the ocean is considered as a limit with zero potential.

- South: The boundary is a limit with imposed potential given the presence of Sebou River along this limit.

Hydrodynamic parameters of the aquifer system

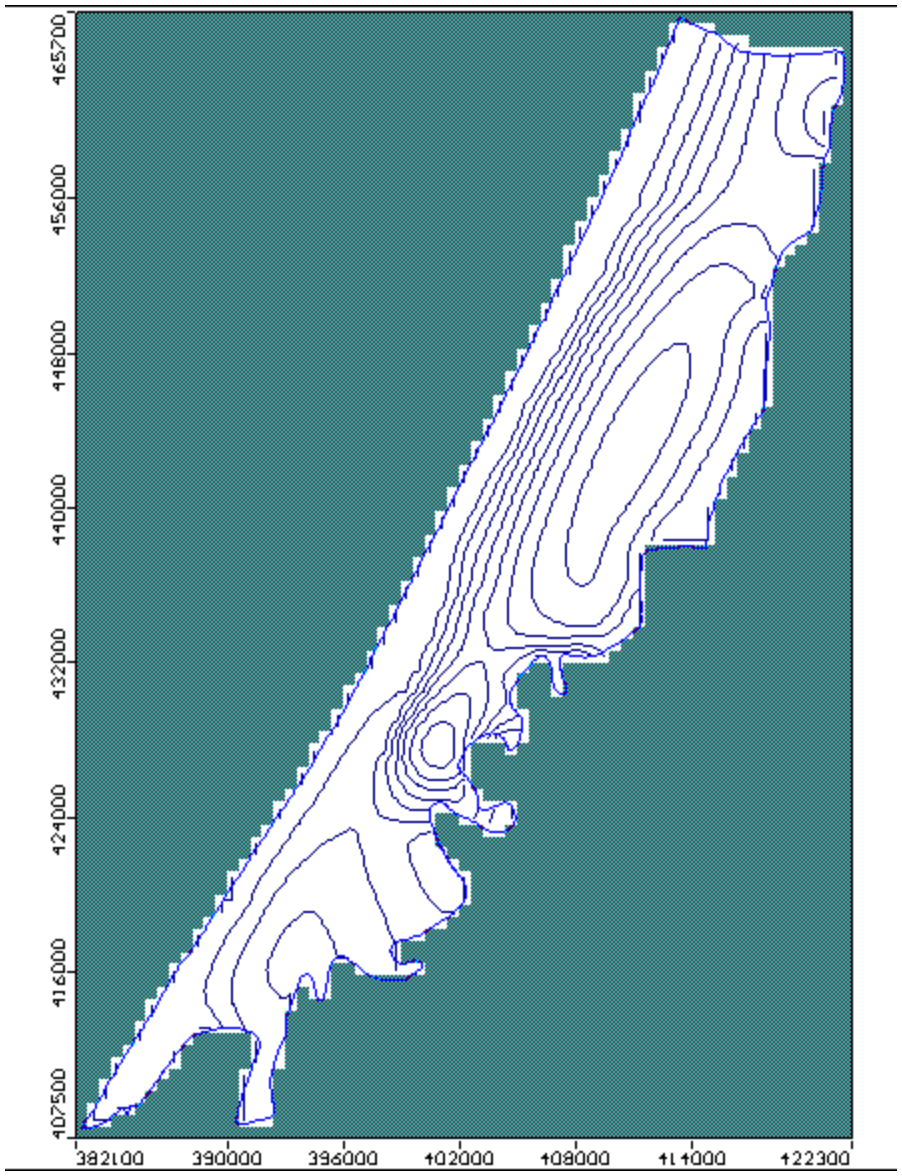
- Recharge:

Soil Type	Recharge Coefficient (%)	Recharge Equivalent (mm/year)
Sandy soils	20%	120 mm/year
Waterlogged soils	15%	90 mm/year
Vertisols	3%	18 mm/year
Total Rainfall Input		**600 mm/year**

- Permeability:
- The permeability is distributed in three zones of equal permeability values and of unequal importance. The values in these three zones are between 10^-5 m/s and 10^-4 m/s.

Piezometry After Calibration

- The steady-state simulation conducted in this study reproduces the hydraulic balance of the aquifer under conditions where seawater contributions are not influential.



simulated piezometry after calibration in steady state (1963)

Water table for the year 1963

	Water Balance Terms	Volume (m^3/day)
Inflows	Precipitation recharge	126855
	Gharb Basin recharge	6262.3
	Sebou recharge	2031.8
	Total Inflows	**135184**
Outflows	Atlantic Ocean discharge	92613
	Lateral transfer to Gharb Basin	19750
	Sebou River Discharge	21292
	Total Outflows	**133655**

Overall balance of the Mnasra aquifer calculated after calibration of the model in steady state.