أثر التغيرات المناخية في المياه الجوفية باستخدام نمذجة المحاكاة

Climate Change Impact on Groundwater Using Simulation Modeling

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overview

- ❑ Key issue(s) problem(s) addressed and objectives
- ❑ Integrated Methodology/Approach/Main steps/Uncertainties
- ❑ Assessment of CC Impacts on GW Resources
- ❑ Design of Geo-databases and models in steady and transient states
- ❑ Results, Analysis and interpretations
- ❑ Conclusions derived from the project and key recommendations for decision-makers in light to the technical findings.

Adressed Problems and Objectives of the Project/Arab region

- The Arab region currently faces major water challenges related to water scarcity, the sustainable management of water resources and the delivery of water services for domestic, agricultural and industrial uses. **Climate Change (CC) can increase the risks and the costs** of water resources management, impact the **quantity and quality** of water resources, and generate secondary effects that influence the climate resilience.

- A clear **understanding of these risks and impacts** is necessary to inform policy formulation and decision-making in support of efforts to achieve sustainable development in a changing climate context.

- The objective of this work, is to study the assessment of climate change impacts on groundwater resource **use and availability** in Morocco **(Using Modeling based on RICCAR Data)**, and particularly groundwater abstraction from the Tadla aquifer complex system that supplies water to several urban centres, as well as changes in groundwater availability for use in large irrigation schemes in the Beni Amir agricultural area, in addition to **2 important coastal aquifers**.

- The study will also identify the **primary and secondary implication** that these impacts pose for socio-economic vulnerability in Morocco, and propose **recommendations for enhancing climate resilience** in light of the technical findings. This will contribute to enhance regional **understanding of climate resilience, especially in similar areas of the Arab region**.

Integrated Methodology (1)

The proposed methodology is based upon simulating climate change scenarios using various integrated modeling and assessment tools:

1. Review the available Global Climate Models (GCMs) and selection of 1 or 2 GCMs to form the basis of the climate simulation in the region including the study area;

2. The climate change projections and outputs from one or more GCM will serve as the basis for generating an analysis of Regional Climate Models (RCMs) at the scale of basin/area, using downscaling techniques;

3. Based on the RCMs outputs, Regional Hydrological Models (RHMs) will draw upon global and regional databases with a view towards producing a series of regional hydrological impacts simulations for surface and groundwater systems (including coastal aquifers) for different climate projections;

4. A socio-economic vulnerability Assessment (VA) will be carried out based on the outputs of the impacts identified through the climate modelling and hydrological modelling components by incorporating socio-economic and environmental parameters;

5. Integrated mapping (IM) of the outputs generated from the impact assessment (steps 1-3) and vulnerability assessment (step 4) will facilitate understanding and analysis of the findings.

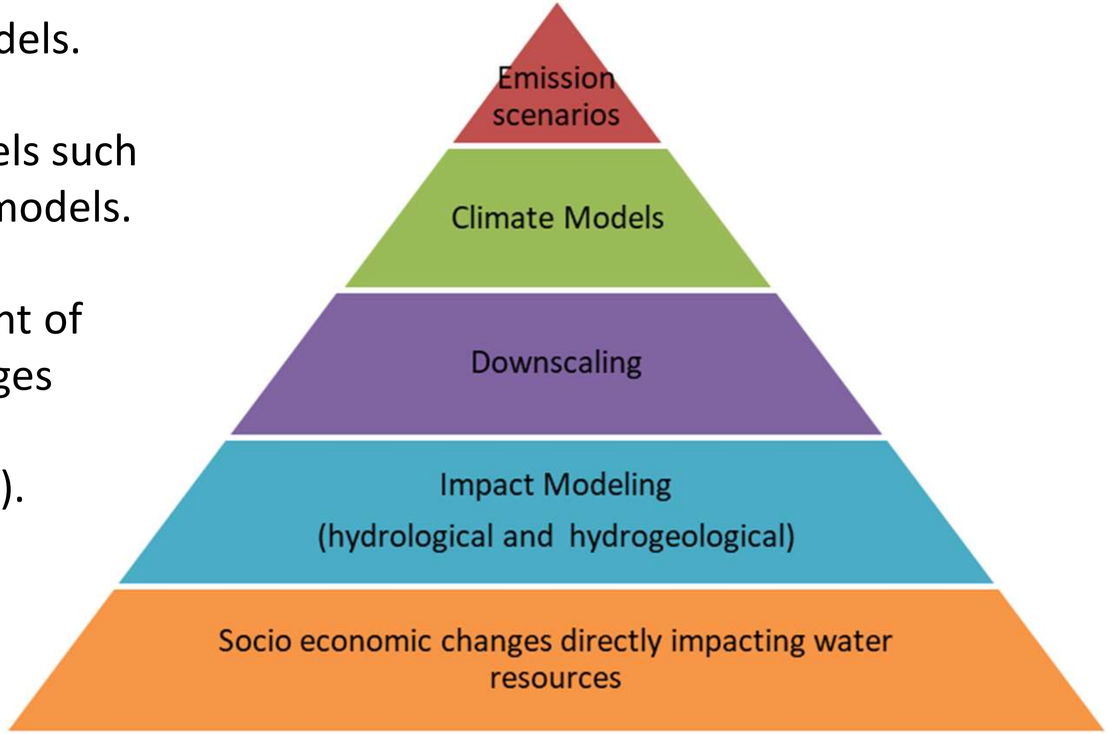
Integrated Methodology (2): Uncertainties

- This complementarity between disciplines is structured by incorporating impact assessment models and vulnerability assessment tools into an integrated assessment methodology. This will require use of various disciplines such as climatology, GIS, geophysics, geology, hydrology, groundwater hydrology, etc.

- Uncertainties relevant to climate models.

- Uncertainties related to impact models such as hydrological and hydrogeological models.

- Uncertainties linked to the assessment of vulnerabilities (socio-economic changes directly impacting water resources: population, agriculture, industry, etc.).



- Cascade of uncertainties in the assessment of the impact of climate change on water resources and their vulnerability.

Integrated Methodology (3): Main steps

It includes 3 main steps :

- • Climate modeling to generate GCMs and RCMs using *downscaling techniques* to draw climate variables at different scales and resolution. The outputs describe key climate parameters such as air temperature_and pressure, wind speed and direction, humidity, Mean sea level, precipitation, river discharge and runoff, ...Ex: **RICCAR**.

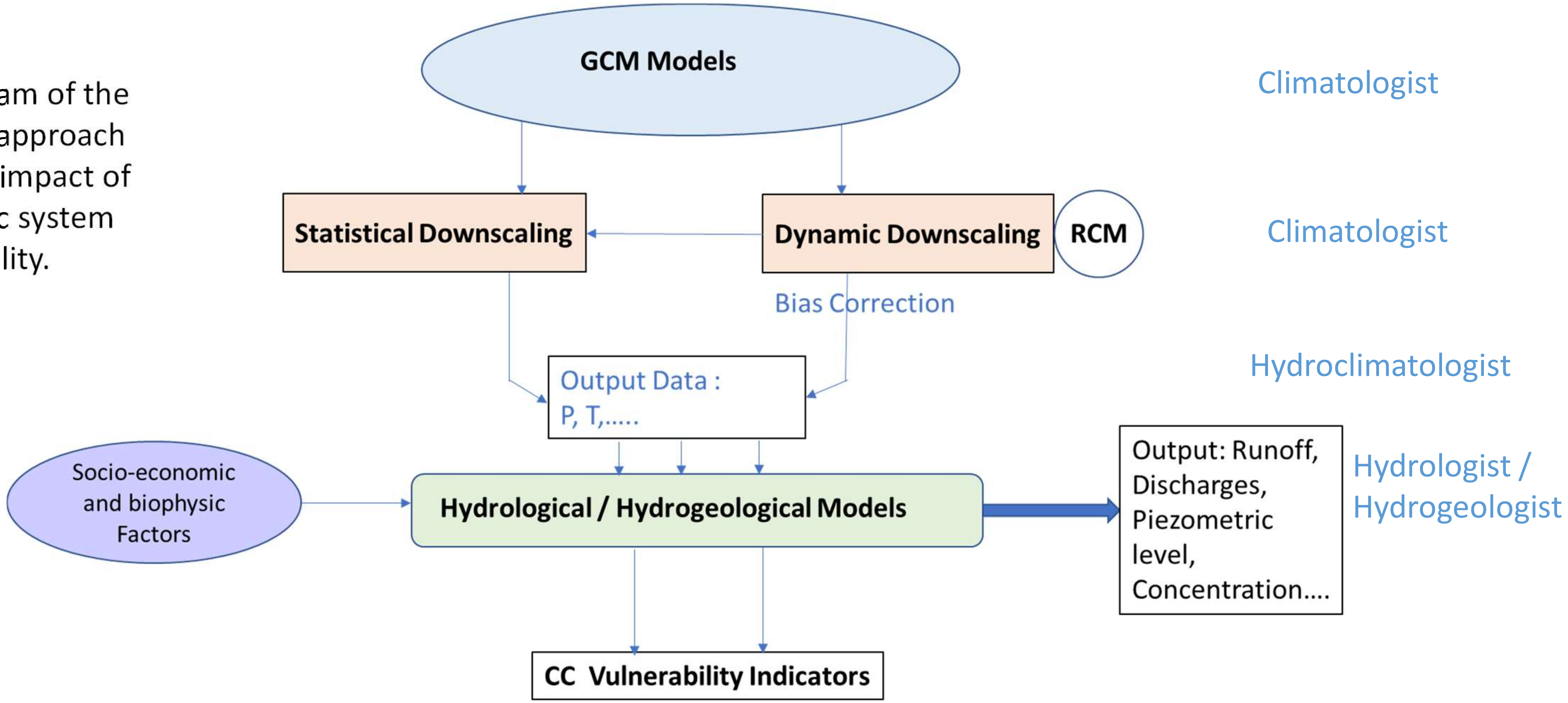
- • Regional hydrological modelling, including watersheds and groundwater modelling using *RCM outputs* as inputs to generate flow, hydrographs and/or groundwater levels and seawater intrusion toe/extension on the coastal aquifers, etc.

- • Vulnerability assessment will be carried out based on the outcomes of ***RCMs** and **RHMs** and impacts_assessment* will be made using socio-indicators. This can be mapped to support graphical analysis and identification of hotspots, which are in turn, presented in integrated maps for informing policy dialogue and decision-making on climate change adaptation.

- The final outcome of these consecutive main steps results in a socio-economic vulnerability assessment based on the impact of climate change on water resources in the particularly study areas located in Morocco through various <u>Mapping of the impacts of climate change</u>, using the *output of the RCMs combined to* RHMs.

Integrated Methodology (4): How to couple RCMs with RHMs

- Synthetic diagram of the methodological approach to assessing the impact of CC on a hydraulic system and its vulnerability.



- These output parameters are used to establish the **water balance** and its variation over time and space at the level of the watershed and / or at the level of the aquifer system.
- The manager will then have **key elements** such as the projected contributions (for future years) to dam reservoirs and the **volumes of water / renewable / mobilizable in the aquifer system**. This information is of great importance for **planning management and exploitation of WR at the hydraulic basin scale**, especially by supporting them in terms of **water demand and conflicts of use.**

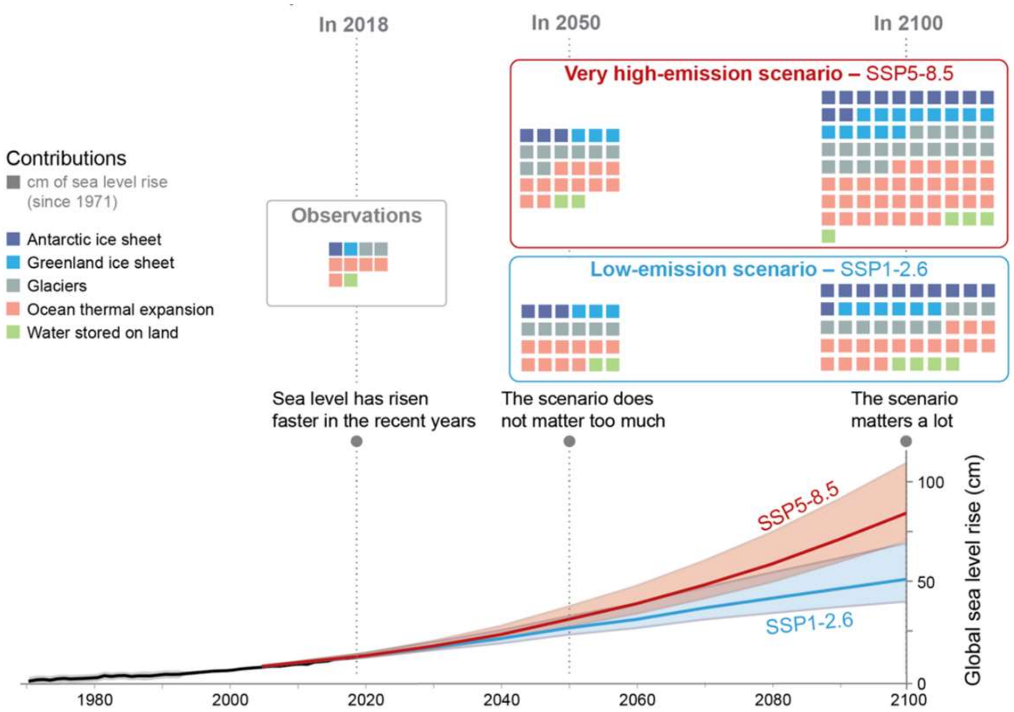
CC Impacts on Groundwater Resources

- A distinction is made between subsurface groundwater, easily accessible to exploitation, and also deep groundwater. These phreatic aquifers are the most **vulnerable to CC**:
  - Evapotranspiration highly influenced by **temperature**.
  - **Natural Recharge from net precipitation/snow.**
  - Recharge by **irrigation** water from dam reservoirs.

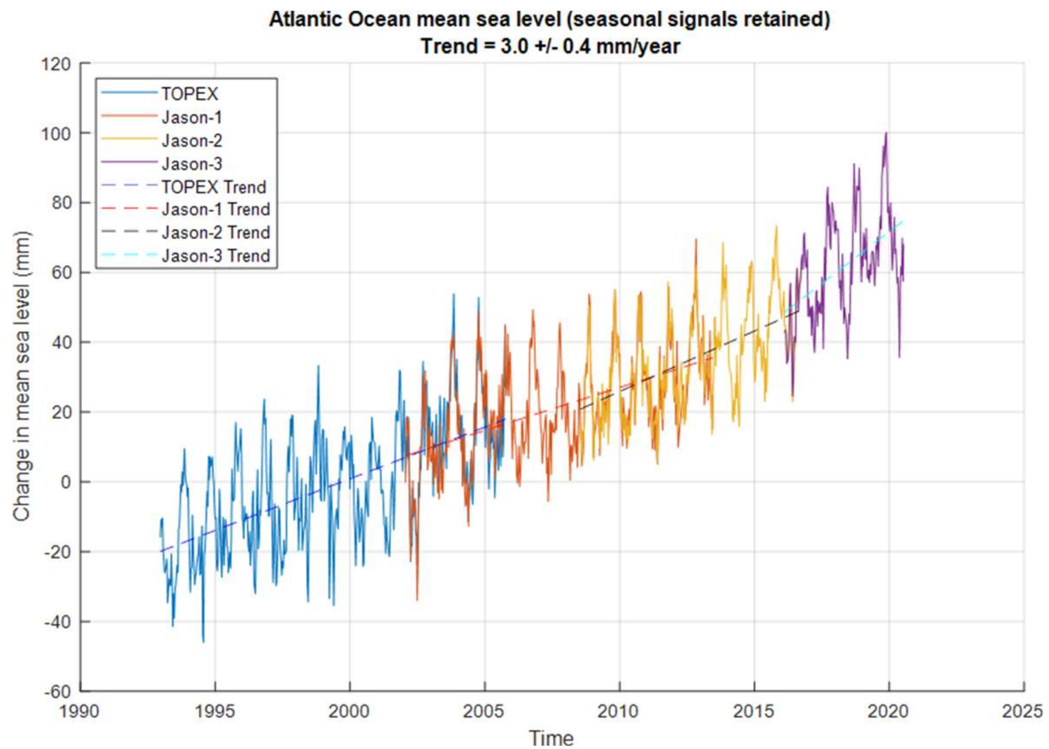
- Moreover, coastal aquifers/islands/islets are at high risk of seawater intrusion under the effect of the rise in mean sea level:
  - Evapotranspiration highly influenced by **temperature.**
  - **Natural Recharge from net precipitation/snow.**
  - Recharge by **irrigation** water from dam reservoirs.
  - **Change in mean sea level MSL (Rise).**

- The impact of CC on water resources does not only affect **the quantitative aspect, but also the qualitative aspect (often neglected!).**

MSL Changes



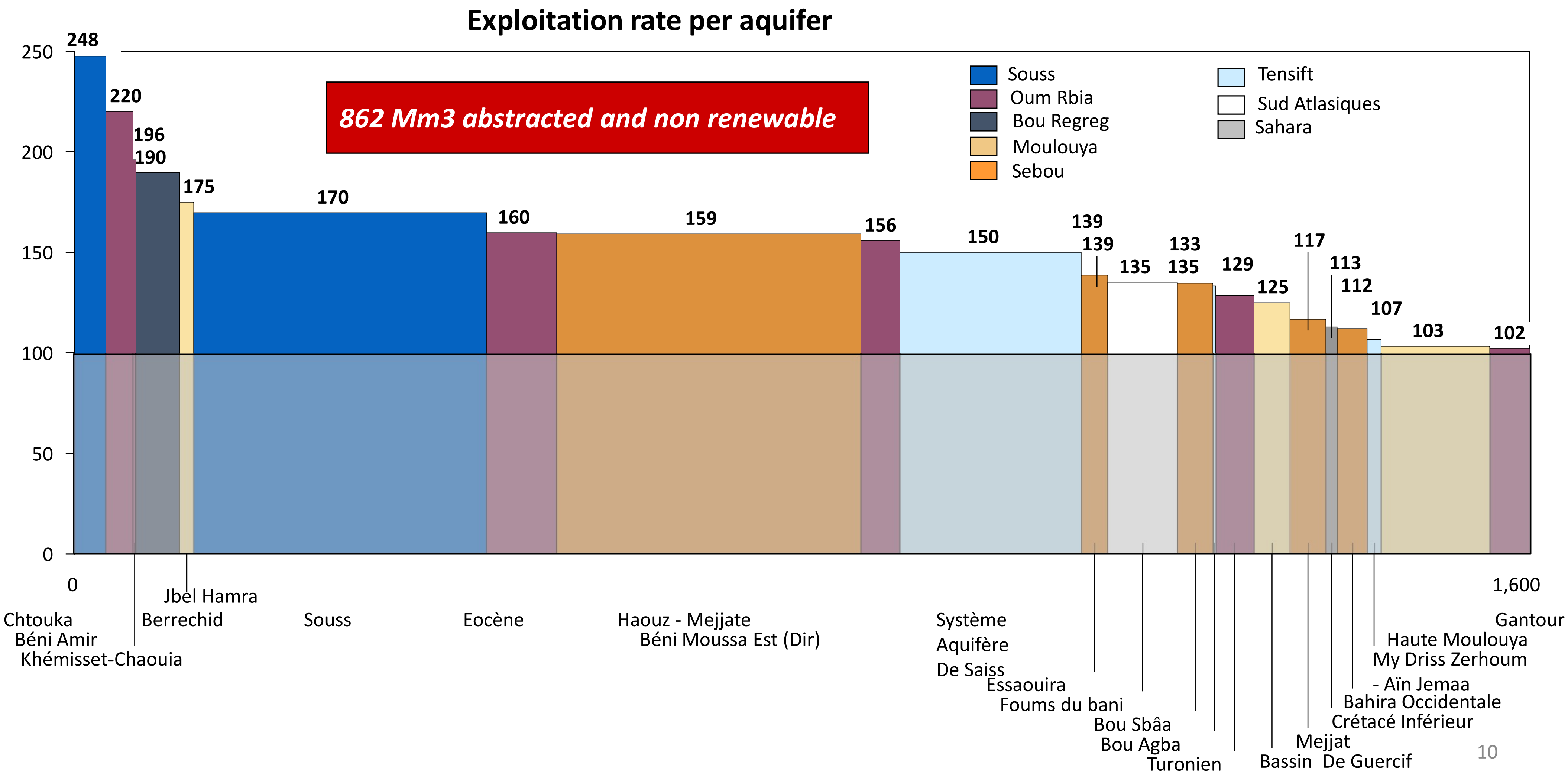
The rise in sea level is inevitable. But its short-term development depends little on our current emissions. However, by 2100, these emissions can change their magnitude considerably. In the longer term (3 centuries), a scenario of 4 ° C in 2100 can lead to an increase of several meters (6th IPCC Report, 2021).



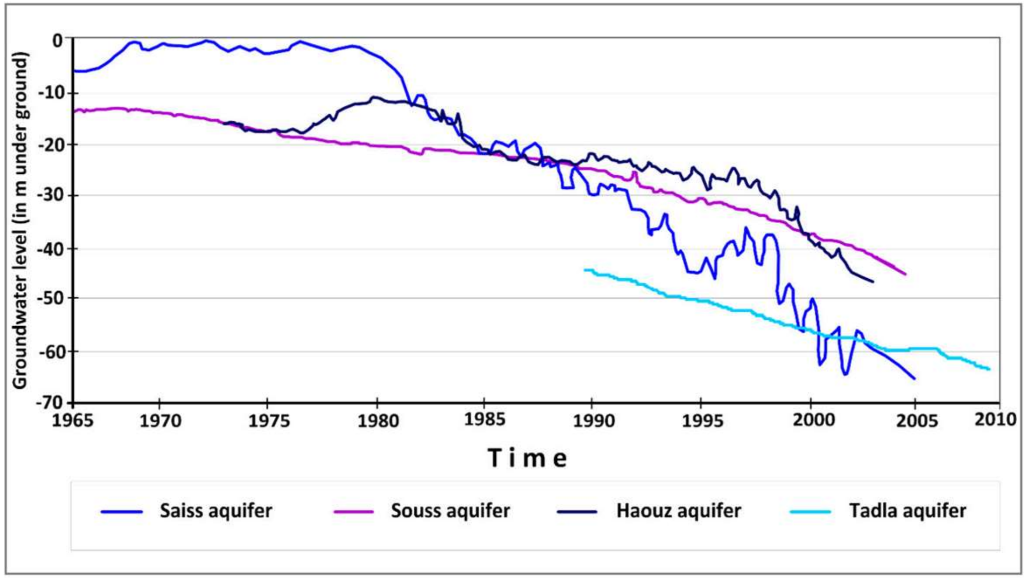
Atlantic mean sea level from TOPEX, Jason-1, Jason-2, and Jason-3 (NOAA data) for the Rmel Aquifer in Morocco.

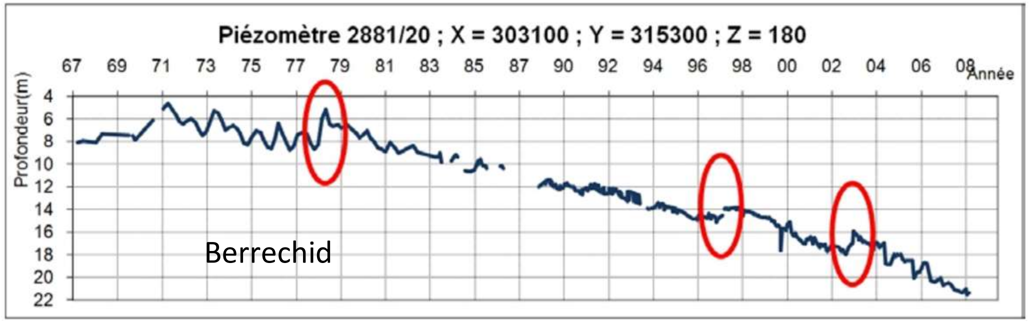
(Larabi et al., 2021)

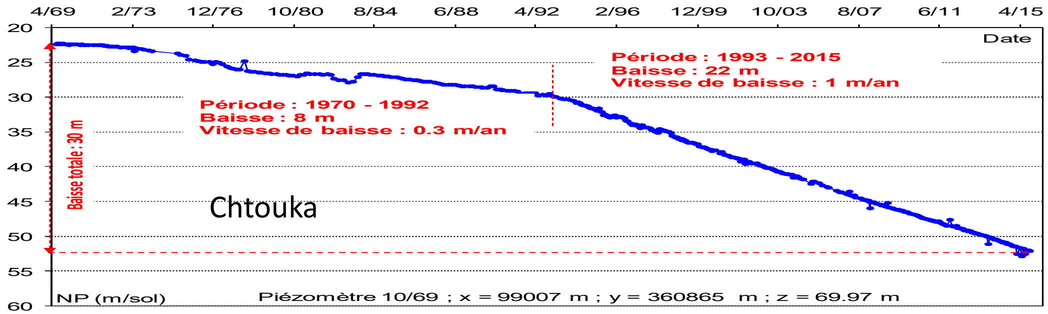
Overexploitation of Groundwater in Morocco (due to demand & CC)

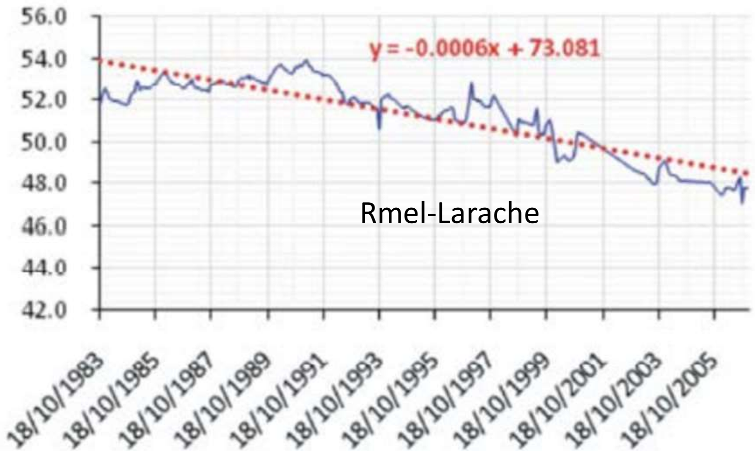


Impacts on Piezometric Levels/drawdowns



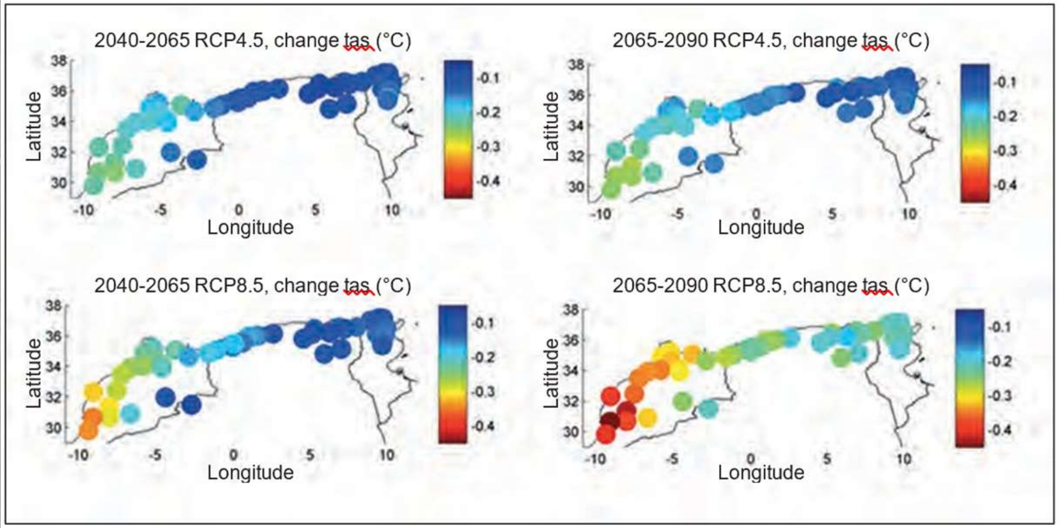




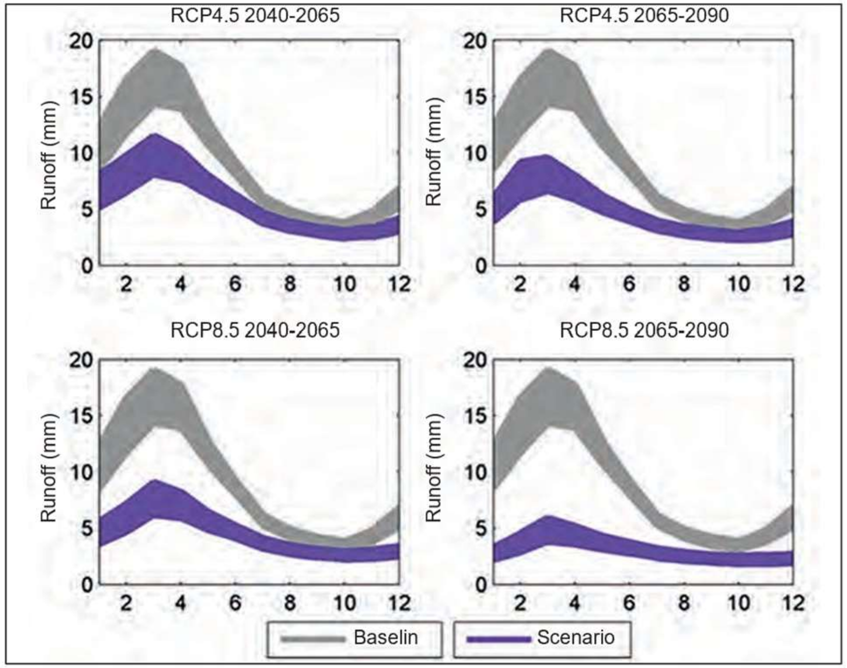


- Observation wells in continuous decline/aquifer depletion

Integrated Methodology (5): Examples of the Maghreb region



Future changes in precipitation in the 47 main dam catchments in North Africa, simulated by the SMHI-RCA4 regional climate model driven by 5 global climate models (CNRM, IPSL, HADGEM, ECEARTH, MPI) under the emission scenarios RCP 4.5 and 8.5.

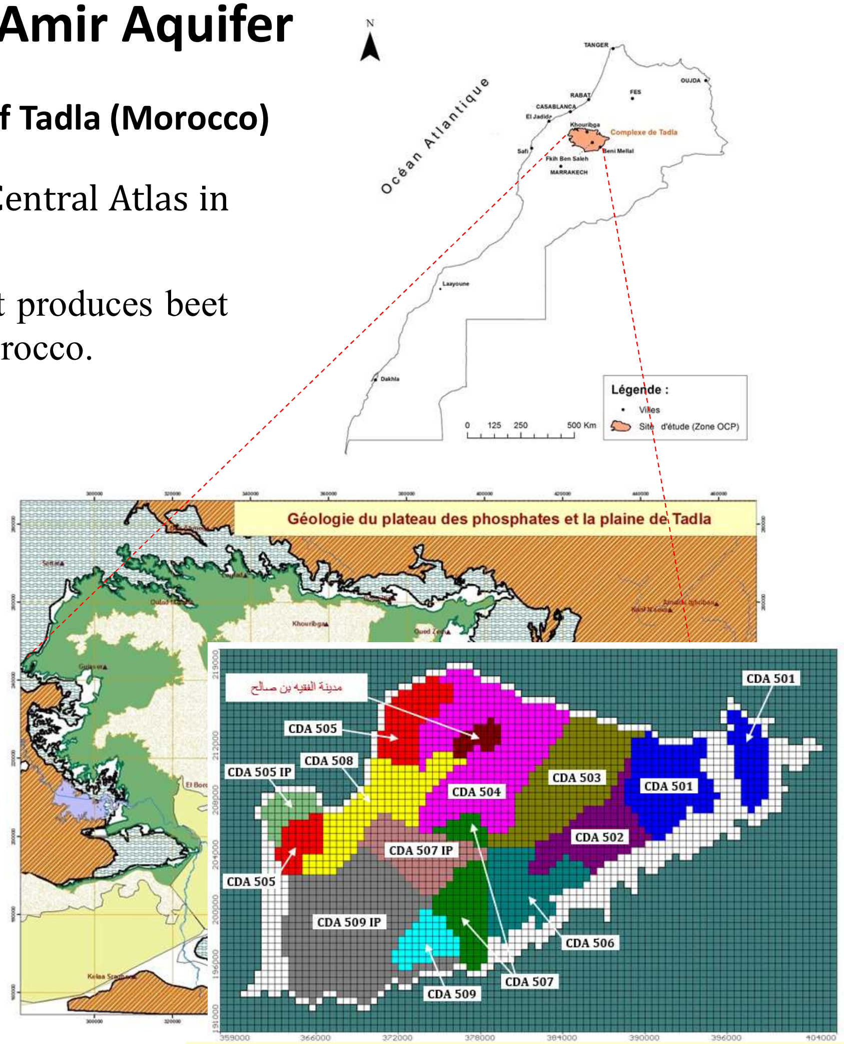


Future changes in mean monthly runoff for the Bin Ouidane dam (south Morocco). The band width indicates the uncertainty on model projections (simulated by the SMHI-RCA4 regional climate model driven by 5 global climate models: CNRM, IPSL, HADGEM, ECEARTH, MPI).

Assessment of Climate Change Impacts on Groundwater Resources using RICCAR Data in the Beni-Amir Aquifer

Situation of the study area : Complex aquifer system of Tadla (Morocco)

- Located in the Oum Er Ribia basin, between the High Central Atlas in the South and the phosphate highlands in the North.
- Covers an important agricultural area of 10,000 km2 that produces beet cultures to supply 3 important sugar industrial units in Morocco.
- Described as a multilayer system made up of 3 main hydrogeological units closely dependent (with age ranging from Turonian to Plio-Quaternary).
- The main supplier of water resources for drinking water of several urban centres of the area and the industrial water supply of the OCP installations and the processes of phosphate washing, besides the water requirements of the agriculture of large irrigated perimeters of Tadla.



Distribution of the Agricultural Development Centres (CDAs) in the area.

a) Purpose:

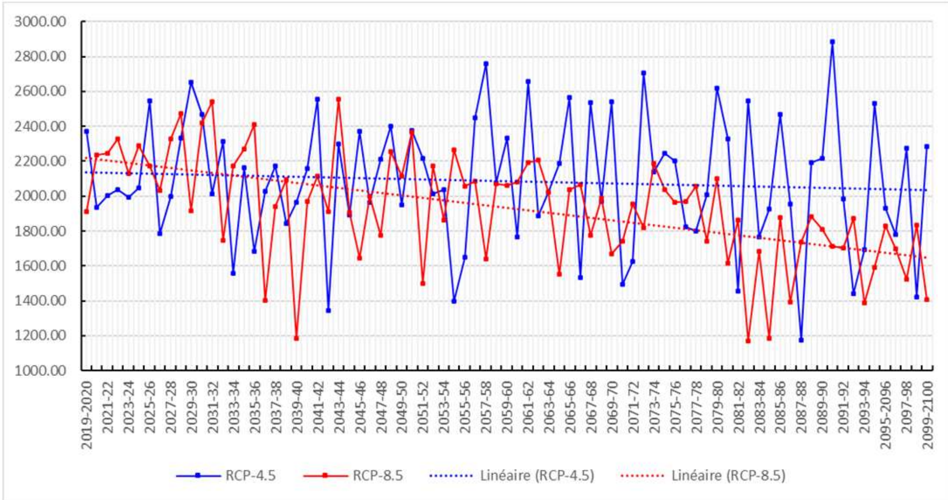
- **Assessment of climate change impacts on groundwater resource availability and use in Morocco, specifically on groundwater abstraction from the Tadla aquifer complex system that supplies domestic water as well as large irrigation schemes in the Beni Amir agricultural area.**

b) Key issue(s) and problem(s) addressed in the study area

- The Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (**RICCAR**) has shown that the Arab region will experience **rising temperature** and largely **decreasing precipitation**. More specifically, ***precipitation trends*** will be largely decreasing across the Arab region through mid-century.

- Hence, groundwater resources will be affected by climate change due to a ***reduction in natural recharge*** from reduced precipitation and the increase in evapotranspiration caused in part by higher temperatures.

- **Pilot case study in Morocco: How groundwater availability will vary under CC? Can we extend irrigated area, especially sectors based on groundwater supply? What are the best management schemes of groundwater?**



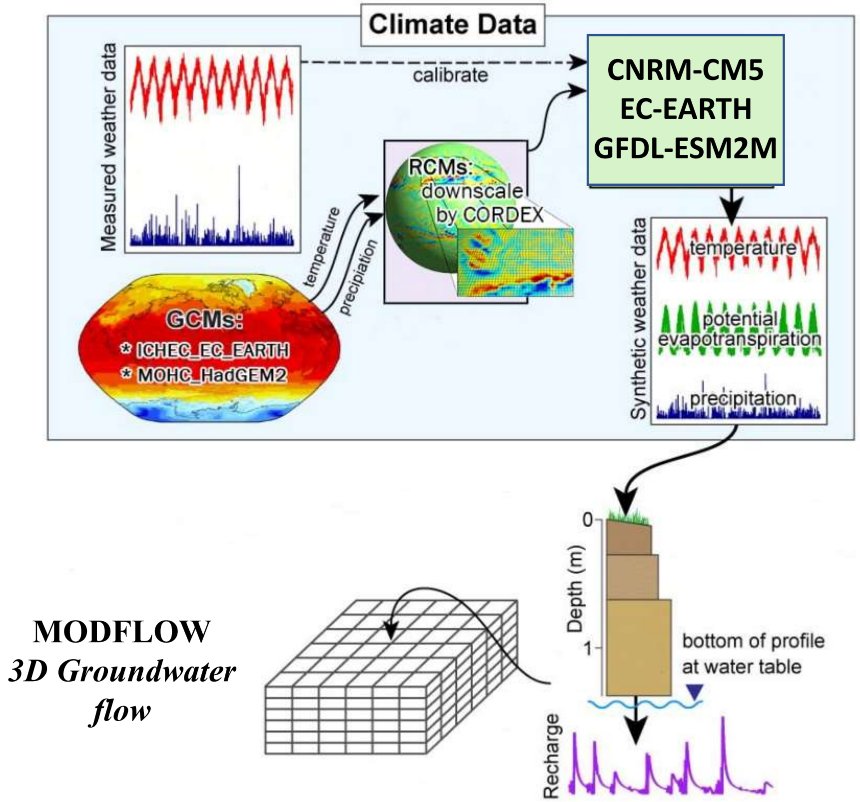
c) Coupling Climate and Hydrological Modeling

Analysis of climate change on water resources in the Tadla Aquifer System based on the two RICCAR climate change scenario (**RCP 4.5** and **RCP 8.5**) and the scenarios use, which entails:

a. Drawing upon RICCAR regional climate modeling projections and regional hydrological modelling outputs as the basis for generating an analysis of climate change impacts on the Oum Er-Rbia basin;

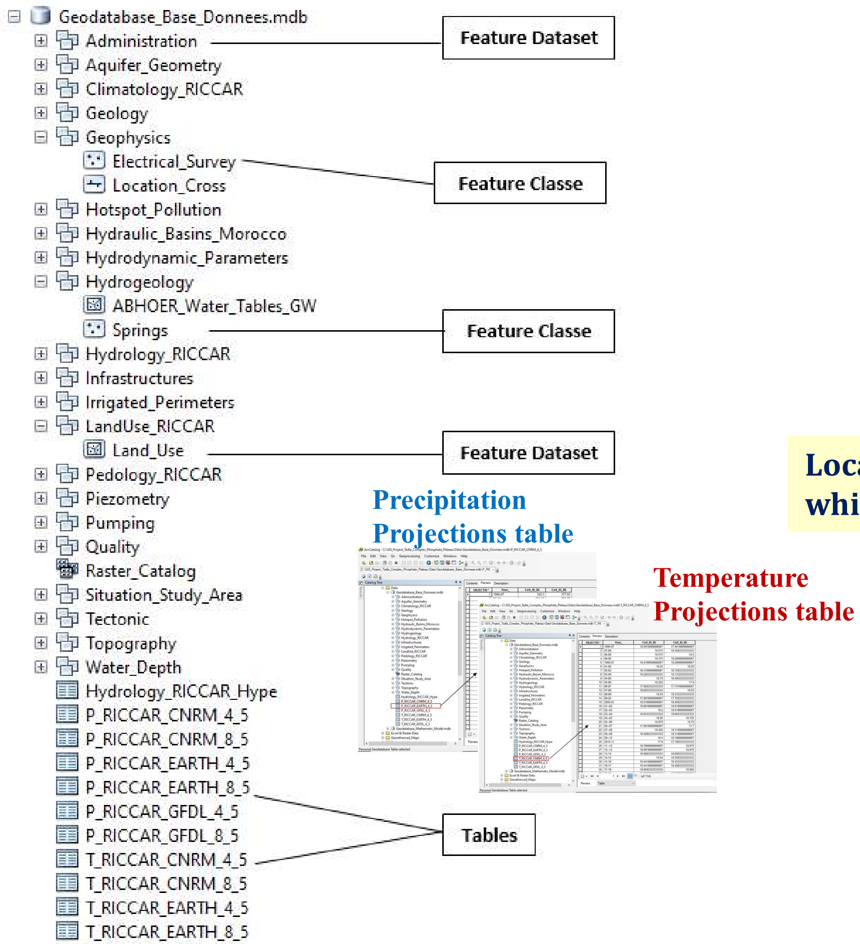
b. A three-dimensional conceptual groundwater model was designed and simulated a comprehensive set of physical processes and was compared, calibrated and verified with observations.

c. 3D model in steady state, which is followed by a developed transient and management model that includes the effects of climate change on the Tadla Aquifer System using **RICCAR outputs** and hydrological modeling and coupling for **RCP 4.5** and **RCP 8.5**, across the same time periods (2020-2100).

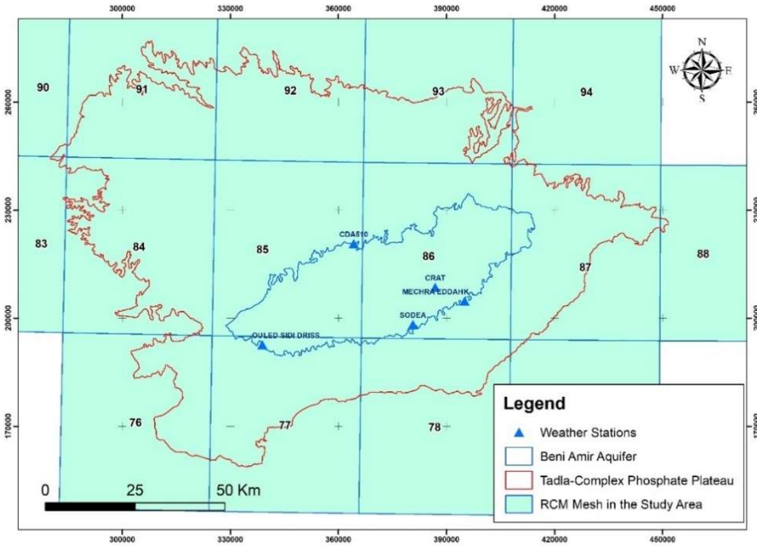


d) Results derived from the project: Geodatabase

Hydrogeological Database including RICCAR



Hydrogeological database structure of the Tadla – Beni-Amir aquifers



Location of Cells 85 and 86 (RICCAR Data) covering the study area which is included in the Tadla Complex Phosphate Plateau zone

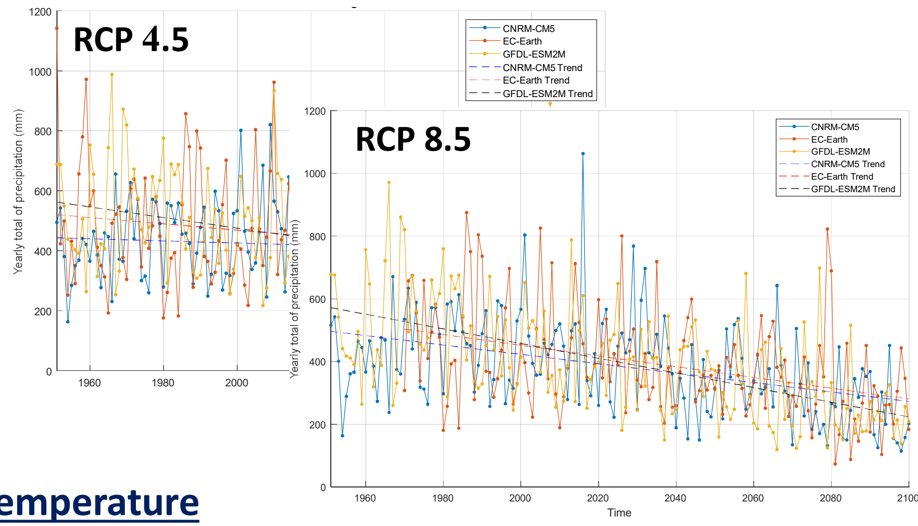
The data under which articulates this database, were collected from various local and regional organizations (ABHOER, DRPE, ORMVAT, ONEE-Khouribga and DPA-Khouribga and DPA-Settat, EMI and RICCAR)

d) Results derived from the project: (Evolution and general Trends -----→2100)

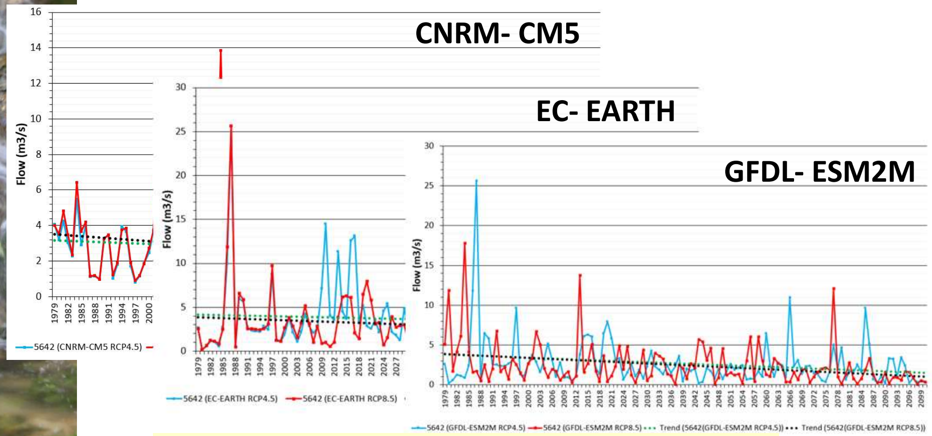
Local RICCAR Data Processing

Temperatures are mainly increasing, while precipitation are mainly decreasing for both scenarios. This surely will have negative impact on water resources availability in the study area. The main trend for RCP 8.5 is relatively much stronger, as temperatures increase more and precipitations decrease more.

Precipitation

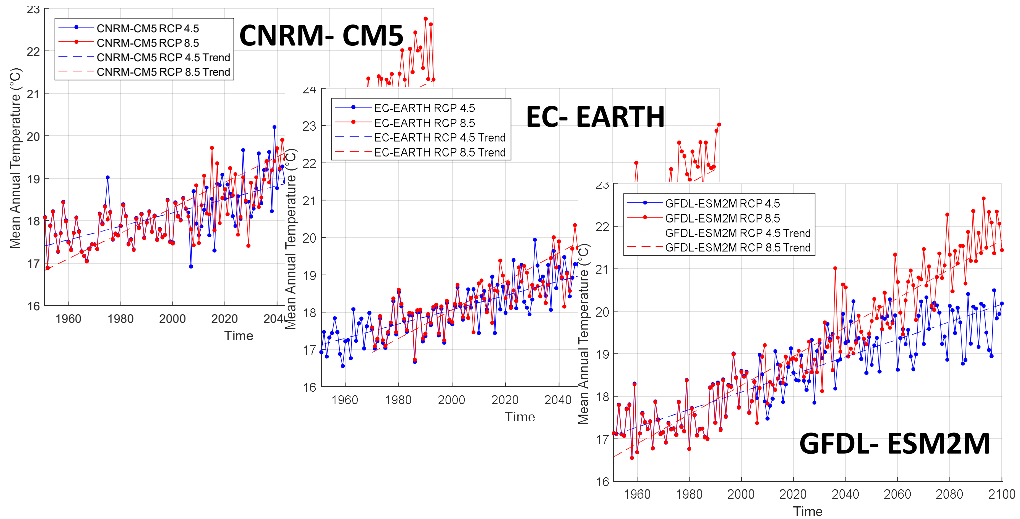


Hydrology

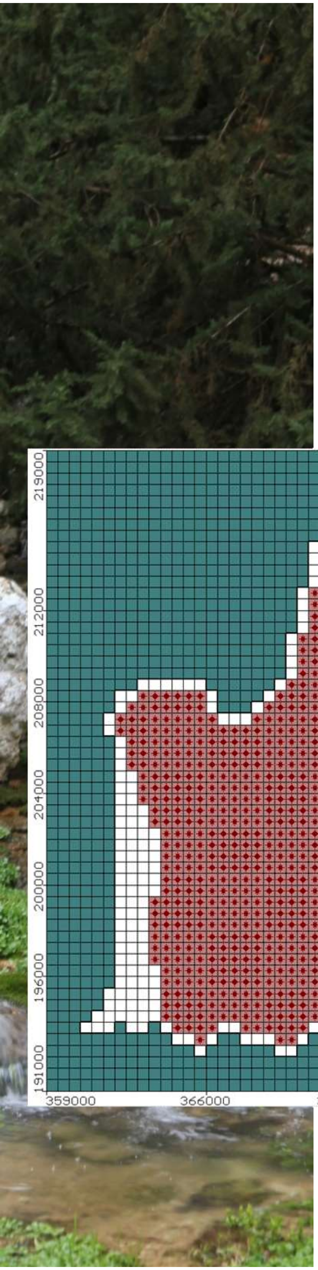


Simulated flow over time (1979-2100)

Temperature



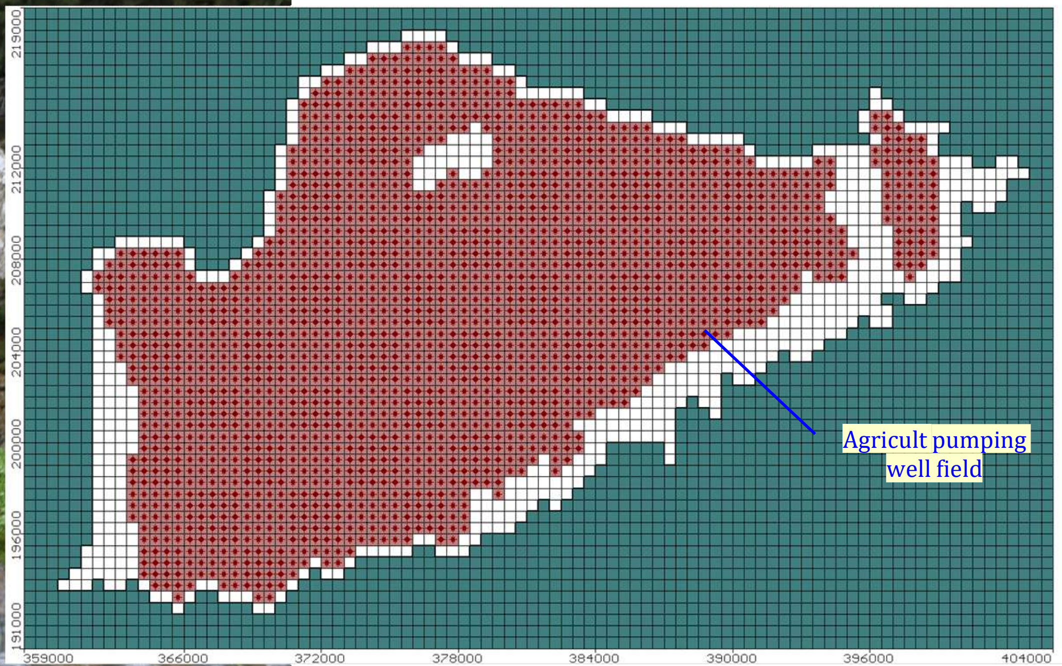
d) Results derived from the project: Steady State/Conceptual model



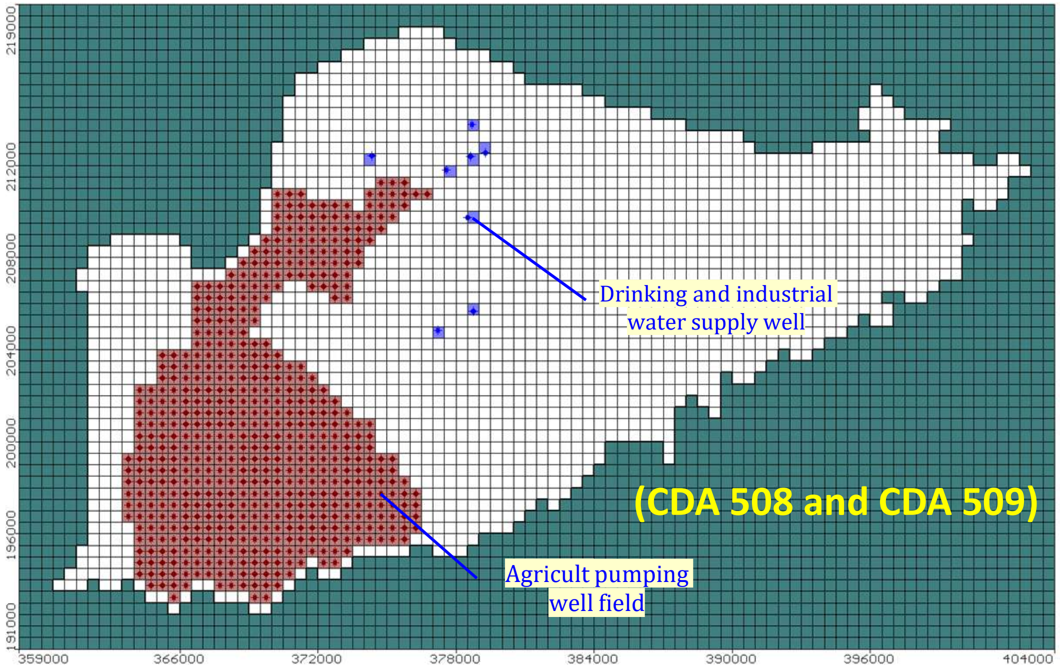
<u>Groundwater pumping</u>

Groundwater pumping from the aquifer system correspond to agricultural pumping for irrigation, DW ONEP and OCP pumping around Fquih Ben Salah city (DWSI) for drinking and industrial demand, in addition to artificial drainage of the water table rise in order to protect the root unsaturated zone saved for agriculture and culture development.

1980-1994



1978

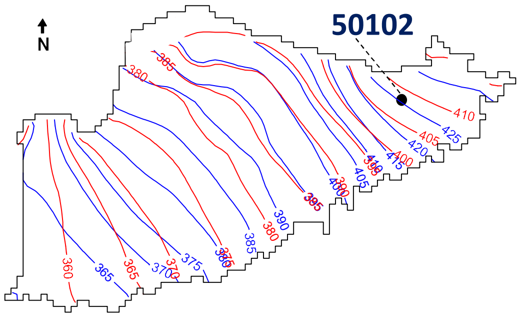


Distribution and density of pumping wells for irrigation and drinking/industrial water supply.

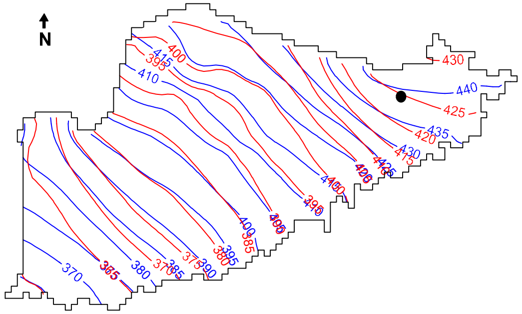
d) Results derived from the project (Piezometric maps & records and WB)

Simulations of the impacts of CC using RICCAR data

Climate Model
CNRM- CM5



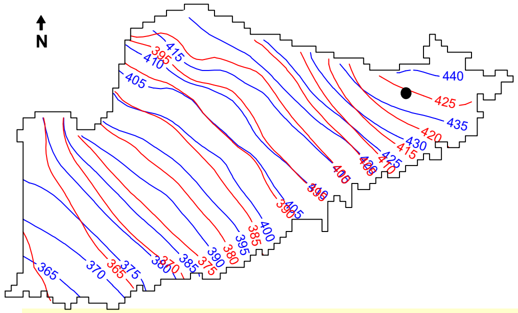
Climate Model
EC-EARTH



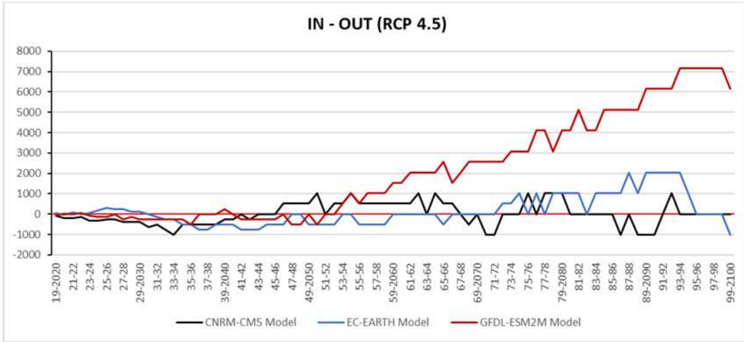
Isoline for RCP 4.5

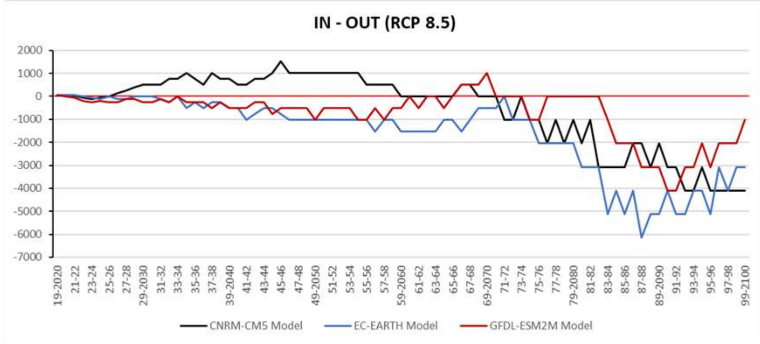
Isoline for RCP 8.5

Climate Model
GFDL- ESM2M



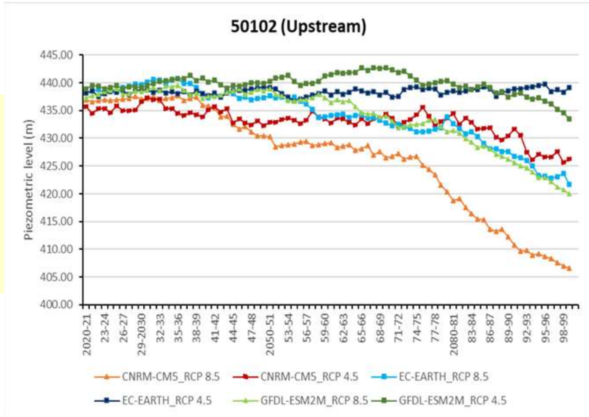
Piezometric maps in 2093/2094 (t = 27375 days)





Storage and destocking of the aquifer reservoir (2020-2100)

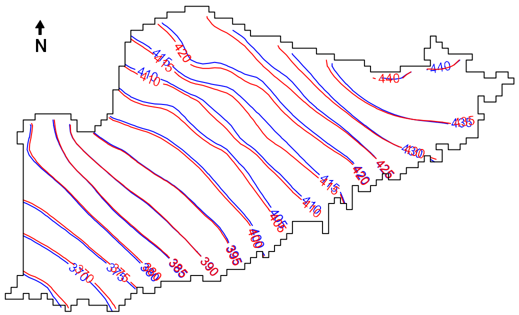
Drawdowns variation in 50102 observation well (2020-2100)



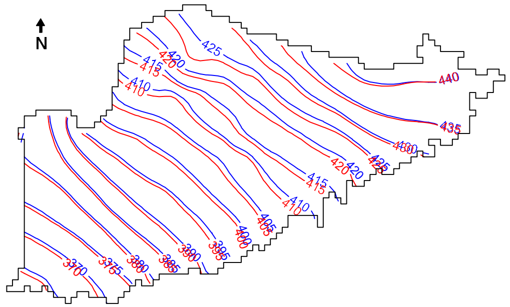
d) Results derived from the project (Piezometric maps within time)

Simulations of the impacts of CC using RICCAR data

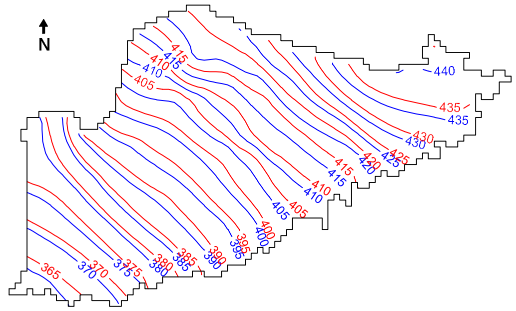
Average of the 3 RCM Models



Piezometric maps in 2021/2022 (t = 1095 days)



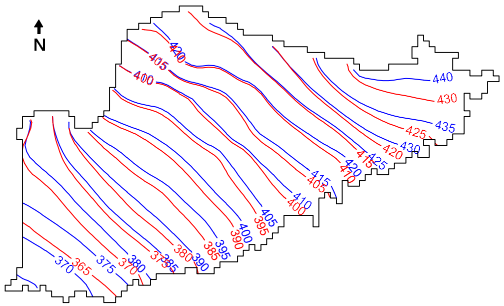
Piezometric maps in 2030/2031 (t = 4380 days)



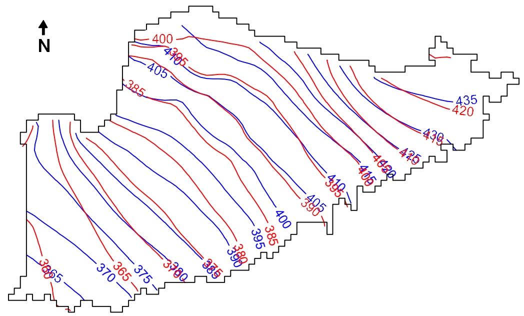
Piezometric maps in 2047/2048 (t = 10585 days)

Isoline for RCP 4.5

Isoline for RCP 8.5



Piezometric maps in 2075/2076 (t = 20805 days)



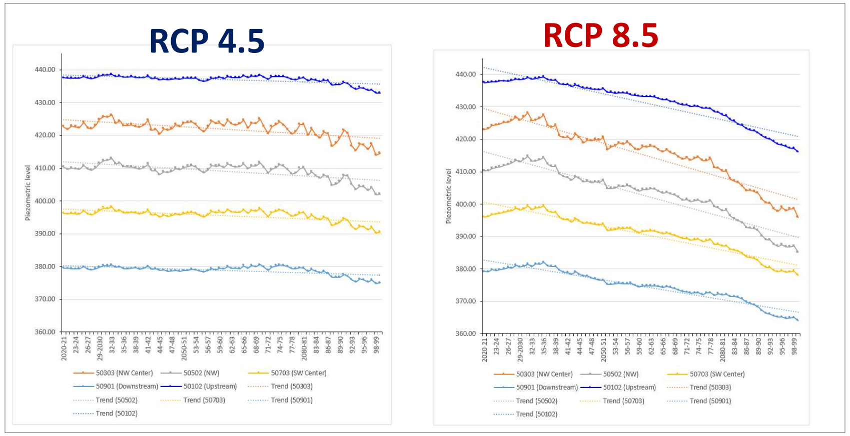
Piezometric maps in 2093/2094 (t = 27375 days)

Piezometric maps selected for some years in the study area (Average of CNRM-CM5, EC-EARTH, GFDL-ESM2M Models for RCP 4.5 and RCP 8.5 Scenarios).

d) Results derived from the project (Projected piezometric records)

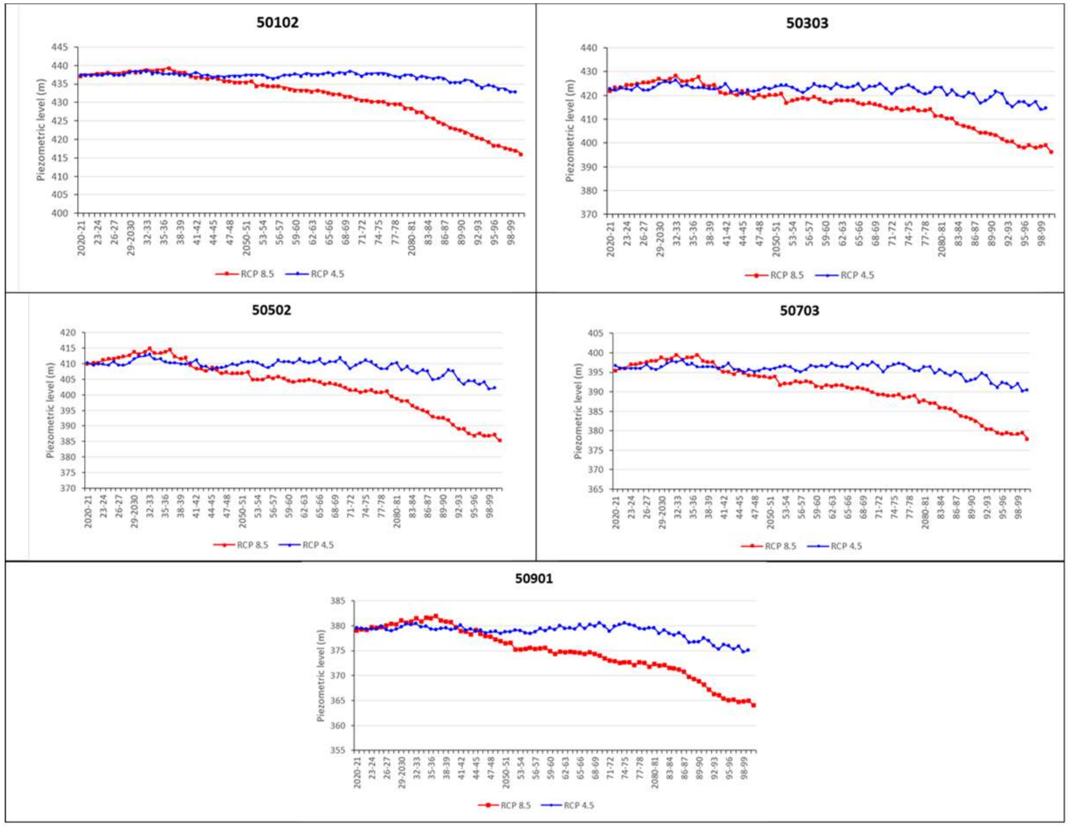
Average of the results with the 3 RCM Models

Time	Head	50102	50303	50502	50703	50901
21-2022	RCP 4.5	437.53	421.90	409.62	395.96	379.45
	RCP 8.5	437.60	423.28	410.31	396.18	379.12
	DH	0.07	1.38	0.69	0.22	-0.33
2030-31	RCP 4.5	438.50	425.77	412.35	397.88	380.34
	RCP 8.5	438.65	427.15	413.85	398.68	380.84
	DH	0.16	1.38	1.49	0.79	0.51
2047-48	RCP 4.5	437.13	422.08	421.90	395.60	378.72
	RCP 8.5	435.47	419.57	423.28	393.94	377.26
	DH	-1.66	-2.51	1.38	-1.66	-1.46
2075-76	RCP 4.5	437.99	423.14	410.56	396.91	380.22
	RCP 8.5	429.66	413.41	400.65	388.46	372.06
	DH	-8.32	-9.72	-9.91	-8.45	-8.16
2093-94	RCP 4.5	428.22	411.19	398.99	385.66	372.31
	RCP 8.5	419.32	398.55	387.55	379.51	365.42
	DH	-8.89	-12.64	-11.44	-6.15	-6.90



Drawdowns variation in 5 observation wells 2020-2100

Comparison of drawdowns in the 5 observation wells for some selected dates (RCP 4.5 and RCP 8.5)



Comparison of simulated piezometric records in the study area (RCP 4.5 and RCP 8.5)

d) Results derived from the project (Water balance variation)

Average of the results with the 3 RCM Models (RCP4.5)

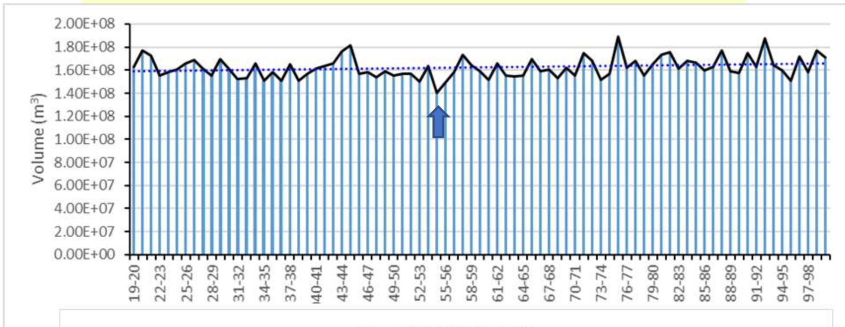
Analysis of these water balances shows that the minimum water balance over the entire period would be **140 Mm3** and would be reached in 2055, while the simulated aquifer balances vary between **200 Mm3** and **140 Mm3**.

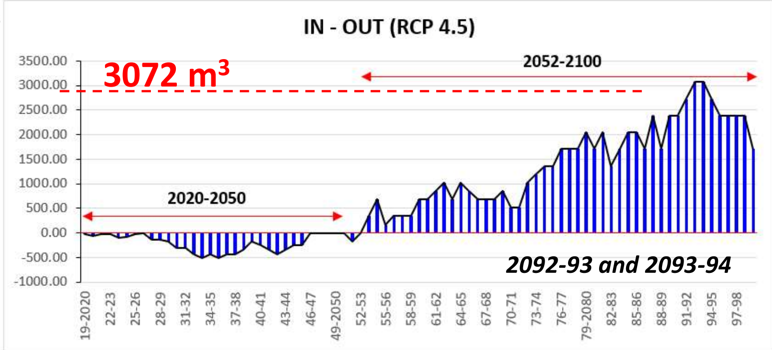
RCP 4.5

DWA = 140 210 347 m^3 ≅ 140 Mm^3 (2054-2055)

Time (Year)	2021/22	2030/31	2047/48	2075/76	2093/94	2095/96	2099/2100
STORAGE IN (m^3)	31 822 542	1 182 872	6 307 541	41 799 467	39 752 919	16 095 337	23 793 023
RECHARGE IN (m^3)	81 930 203	101 135 208	90 524 583	90 032 127	69 130 923	78 731 437	93 460 137
FLOW IN (m^3)	58 914 224	58 786 965	57 225 513	57 020 073	55 837 183	55 836 500	54 082 730
TOTAL IN (m^3)	**172 666 987**	**161 105 027**	**154 057 730**	**188 851 197**	**164 720 967**	**150 663 500**	**171 335 667**
STORAGE OUT (m^3)	18 581 147	26 854 379	15 421 280	26 847 295	4 532 927	7 315 437	34 634 966
WELLS OUT (m^3)	154 085 819	134250797	138 636 377	162 004 137	160 188 067	143348033	136 700 967
TOTAL OUT (m^3)	**172 666 955**	**161105153**	**154 057 730**	**188 851 197**	**164 720 967**	**150 663 867**	**171 336 400**

Water balance evolution in the study area





Storage and destocking of the aquifer reservoir (2020-2100)

d) Results derived from the project (Water balance variation)

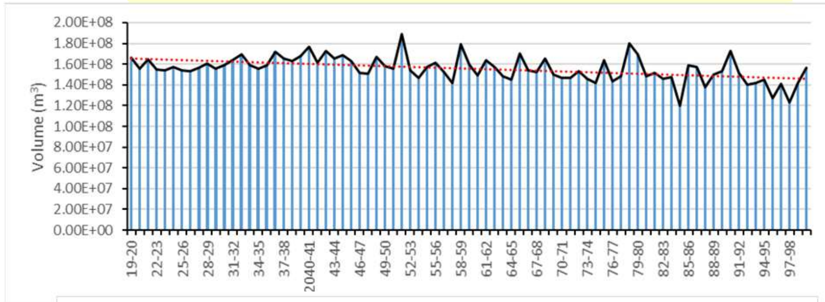
Average of the results with the 3 RCM Models (RCP8.5)

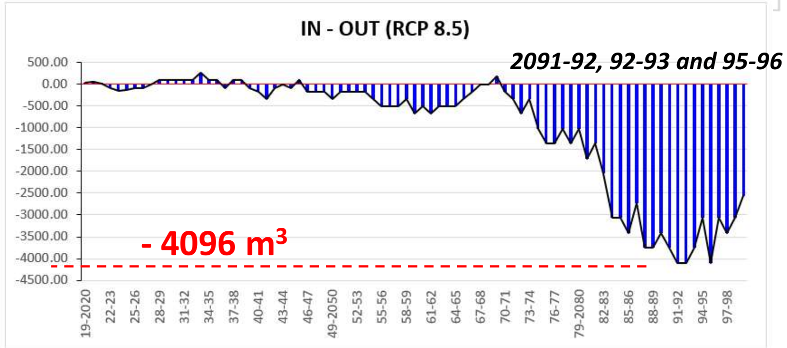
Analysis of these water balances shows that the minimum balance that would be recorded over the entire period is **120 Mm3** (i.e., less than **15%** of the balance obtained by the RCP 4.5 scenario) and would be reached in 2085. The same analysis indicates also that the balance sheet of the simulated aquifer over the whole period 2020-2100 varies between **200 Mm3** and **120 Mm3**.

RCP 8.5 — **DWA = 119 911 067 m^3 ≅ 120 Mm^3 (2084-2085)**

Time (Year)	2021/22	2030/31	2047/48	2075/76	2093/94	2097/98	2099/2100
STORAGE IN (m^3)	13 882 443	85	21 439 701	30 485 205	37 121 320	124 43 437	51 375 443
RECHARGE IN (m^3)	91 821 317	99 657 727	72 594 433	80 233 473	56 422 400	70 176 257	57 085 610
LAT FLOW IN (m^3)	59 127 336	59 127 339	56 822 483	53 351 850	48 507 053	48 347 733	47 786 153
TOTAL IN (m^3)	**164 831 093**	**158 785 157**	**150 856 360**	**164 070 397**	**142 051 000**	**130 966 533**	**156 247 067**
STORAGE OUT (m^3)	13 437 434	19 634 981	5 703 669	5 866 283	269 717	13 169 941	216 107
WELLS OUT (m^3)	151 393 691	139 150 163	145 152 937	158 204 417	141 781 000	117 797 200	156 030 967
TOTAL OUT (m^3)	**16 4831 125**	**158 785 153**	**150 856 363**	**164 070 743**	**142 050 667**	**130 967 167**	**156 246 700**

Water balance evolution in the study area



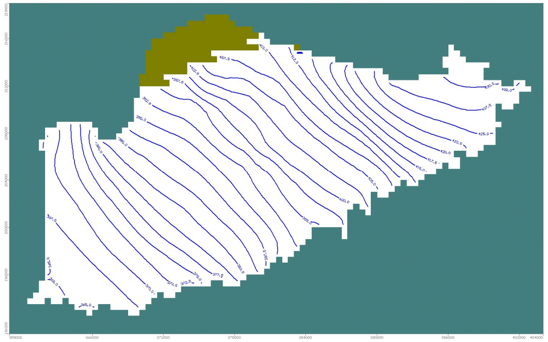


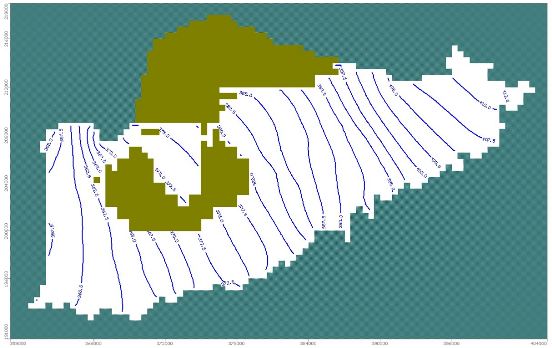
Storage and destocking of the aquifer reservoir (2020-2100)

d) Results derived from the project (extension of impacted areas by dry wells)

❖ **2nd layer**

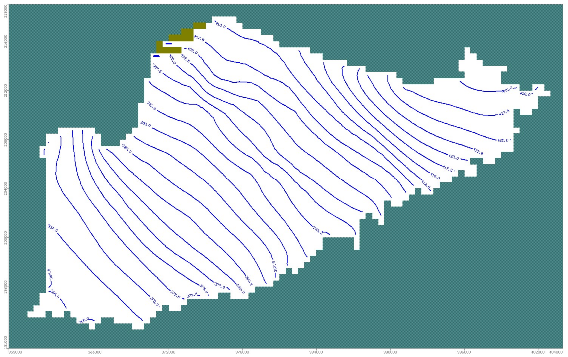
(Dry cells over 16.5 Km^2)	(Dry cells over 68.5 Km^2)
RCP 4.5	**RCP 8.5**

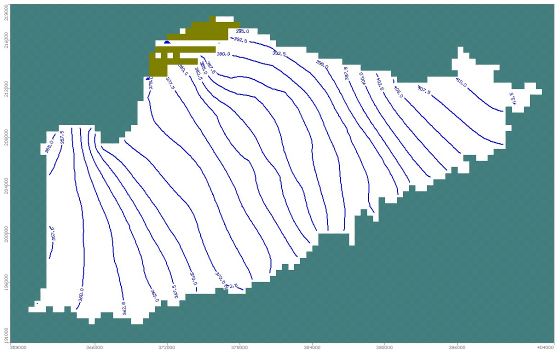




❖ **3rd layer**

(Dry cells over 1 Km^2) | (Dry cells over 4.5 Km^2)





Groundwater level in 2099-2100 for the second and third layers

Analysis of the aquifer piezometry at the end of the century shows that several sectors of the aquifer ***will be partially or completely*** dried up :

❖ for **RCP 8.5 scenario :**

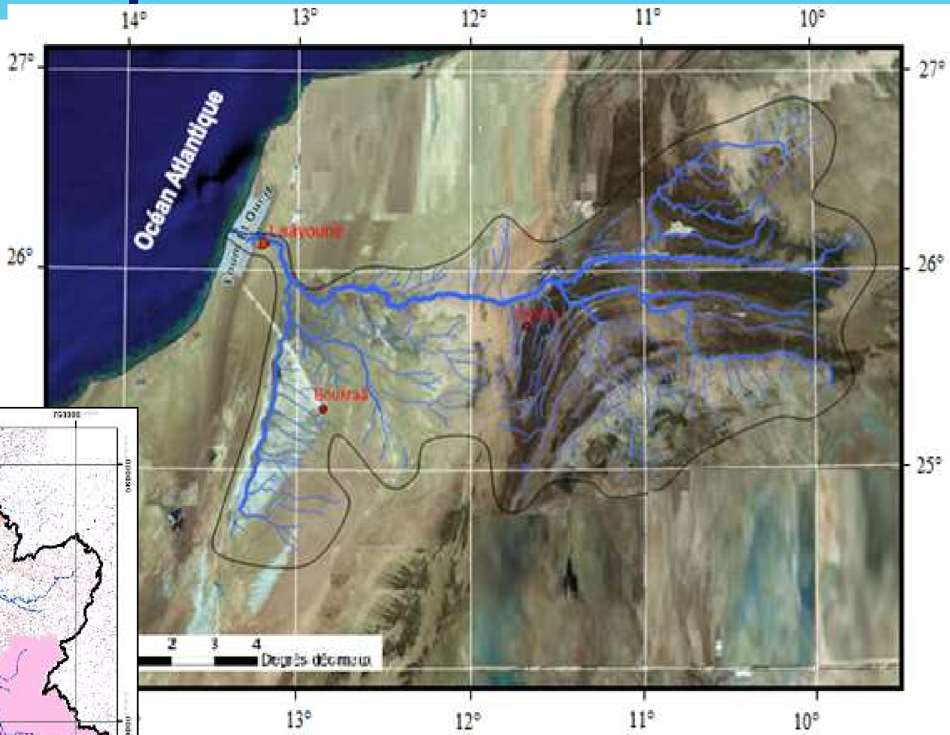
- all the pumping wells crossing the first layer ***will be dried***,
- as well as over an area of **68.5 km^2** of the 2nd and
- **4.5 km^2** of the last layer.

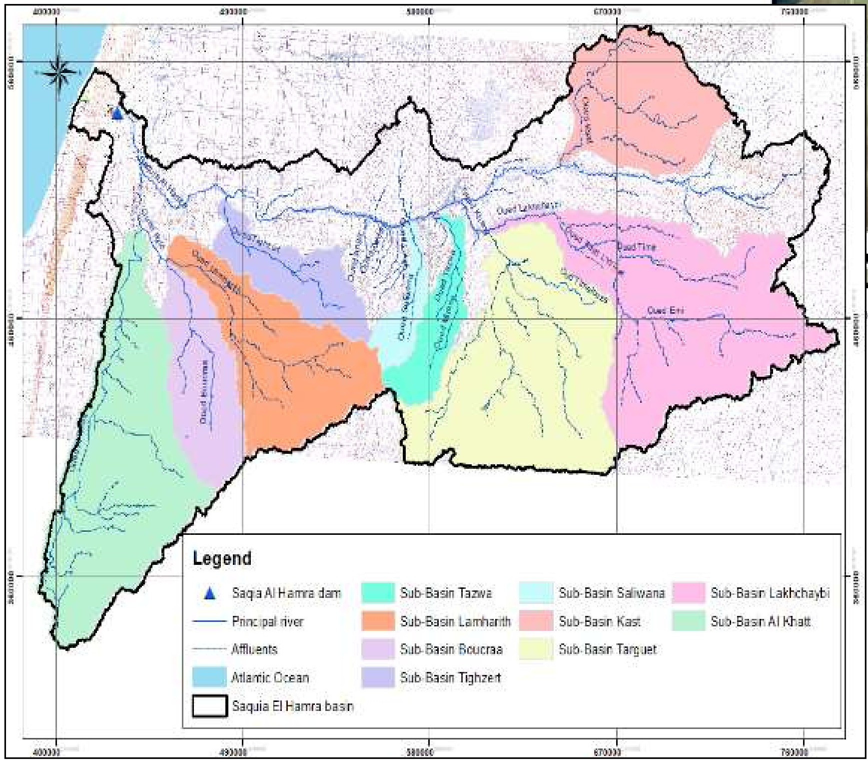
❖ Whereas for the **RCP 4.5 scenario :**

- ***the dried areas*** are relatively reduced to **16.5 km^2** on the 2nd layer and
- **1 km^2** on the 3rd layer located at the north of the study area.

CC Impacts on the Foum El Oued Aquifer: Watershed characteristics

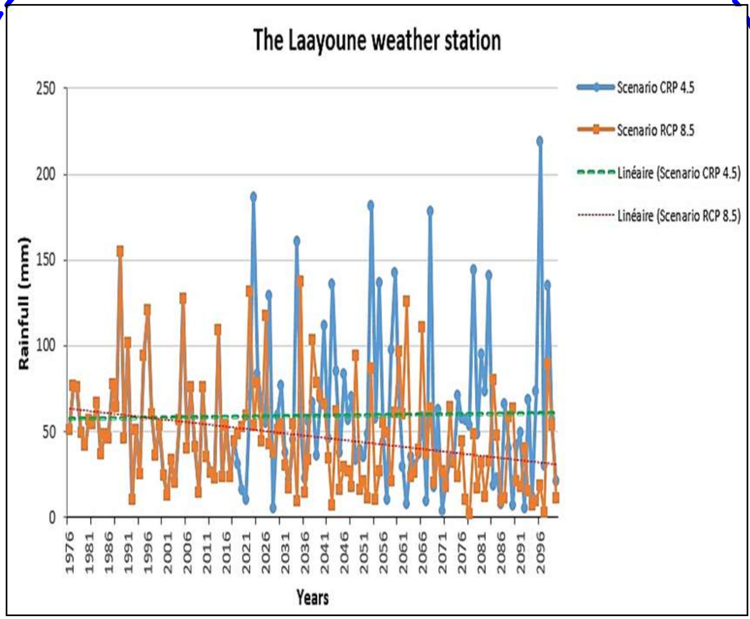
- ❑ The Saquia El Hamra is marked by a strong seasonal and inter-annual irregularity.
- ❑ The maximum input occurs during major floods from upstream sub-watersheds.
- ❑ The flood frequency is about two to five years





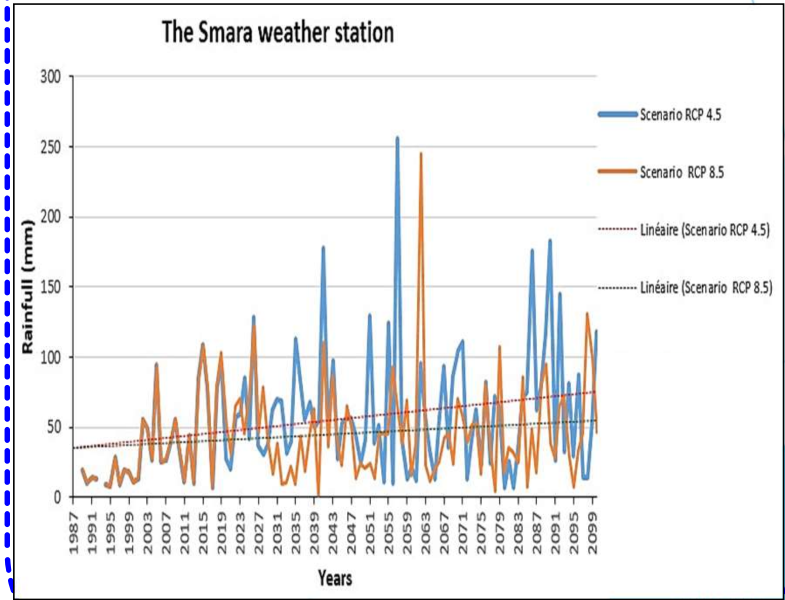
- ❑ The river length is 400 km and the watershed is extended on a total area of 82 000 km^2.
- ❑ The river is characterized by a wide bed which can reach 2 to 3 km in some sections
- ❑ The hydrographic network of the watershed includes many rivers, the most important ones are those of the left bank of the stream; El Khatt, Boucraa, Tizert, Target, etc

The hydrogeological geodatabase results: Climate change projections

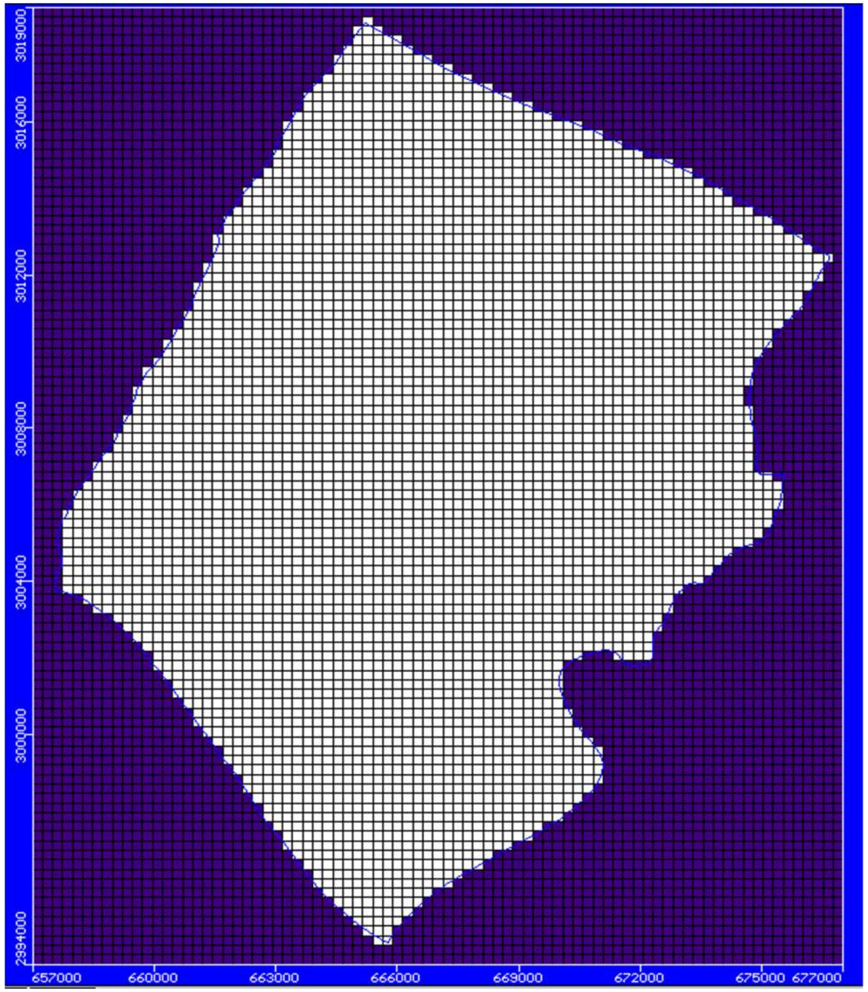


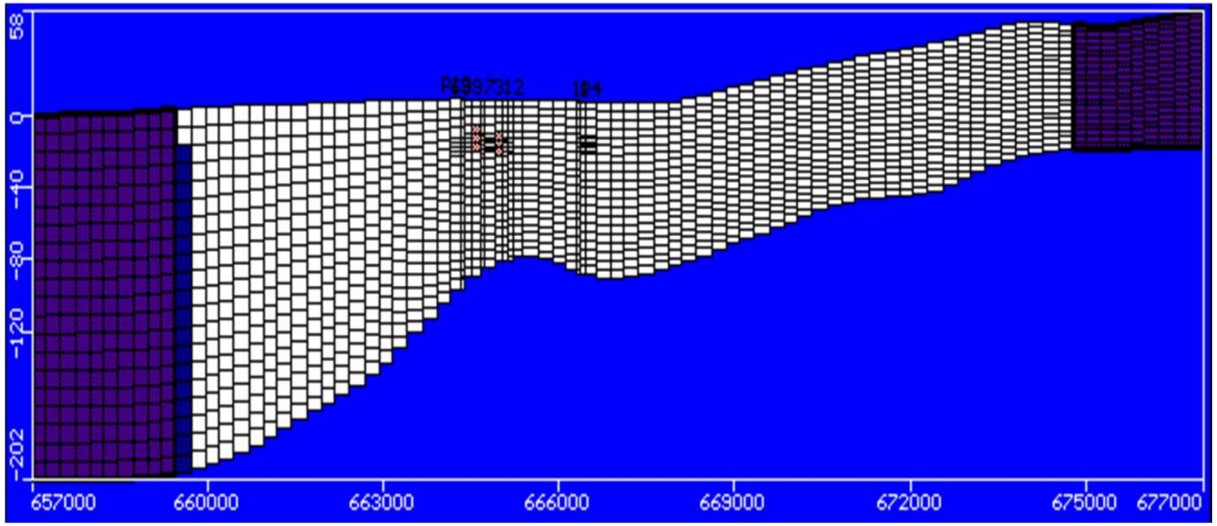
The projections of rainfall in Laâyoune station indicate that for the RCP4.5 scenario there will be increasing trend, which is unlike the prediction for the north-eastern regions of Morocco where there will be an overall decrease in the rainfall. While, the RCP8.5 scenario will expect a precipitation decrease in the global trend.

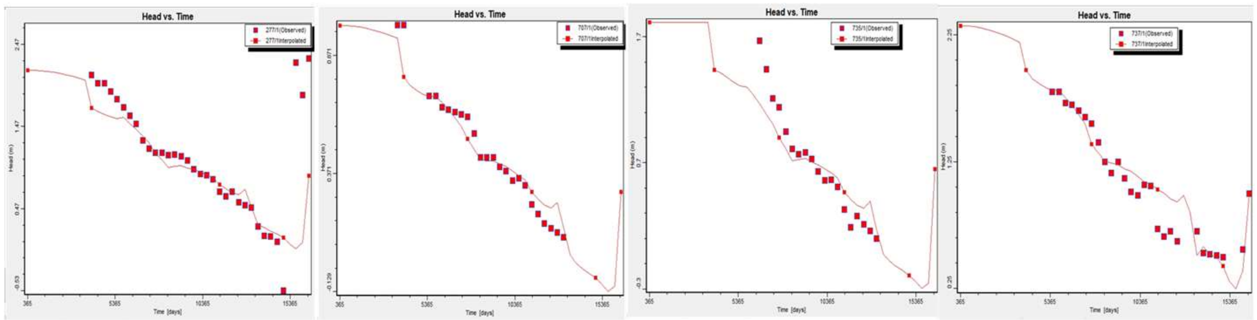
However, for Smara weather station, the projections predict an increasing of rainfall for both scenarios. This will result in a positive impact on the Foum El Oued aquifer recharge, as the main recharge comes from the Saquia Al hamra river floods of upstream sub-basins covering the Smara area



CC Impacts on the Foum El Oued Aquifer (Mathematical Model)

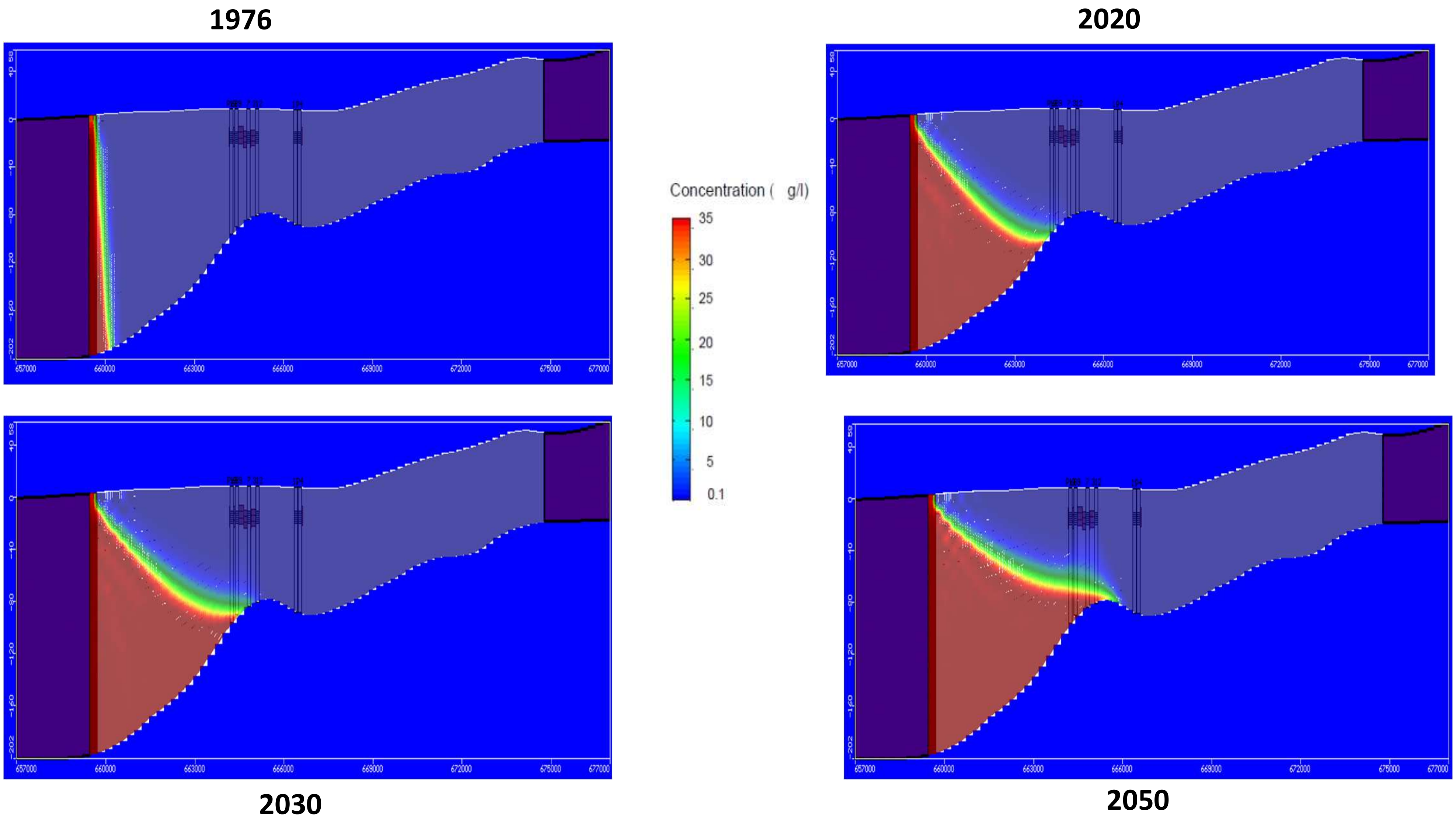






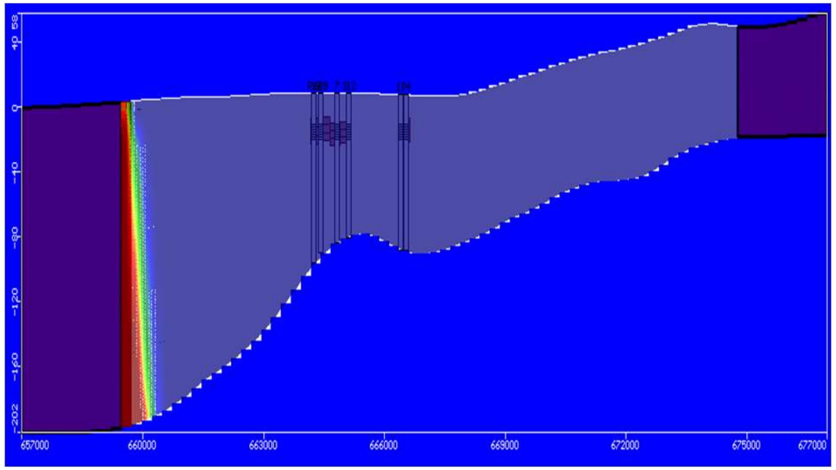
8181 mailles, pas de discrétisation spatial de 250 m.

CC Impacts on SWI in the Foum El Oued Aquifer (RCP4.5)

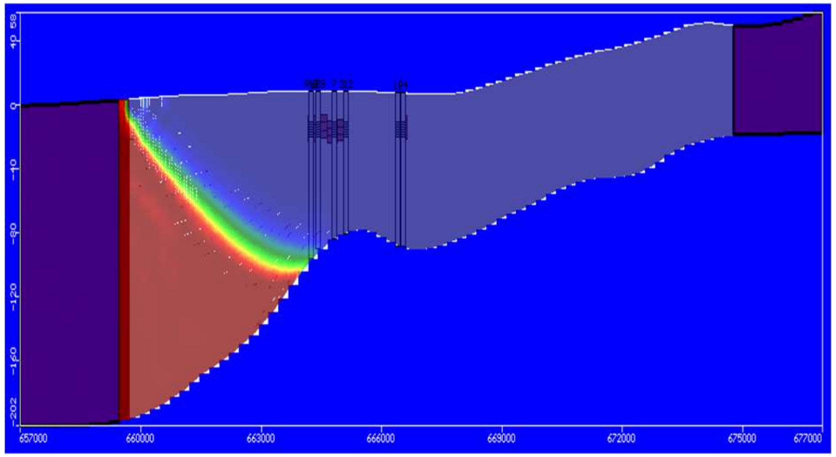


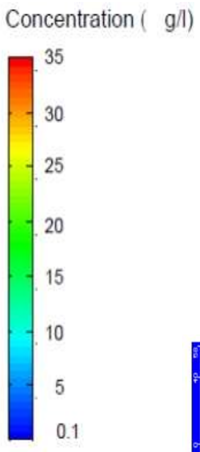
CC Impacts on SWI in the Foum El Oued Aquifer (RCP8.5)

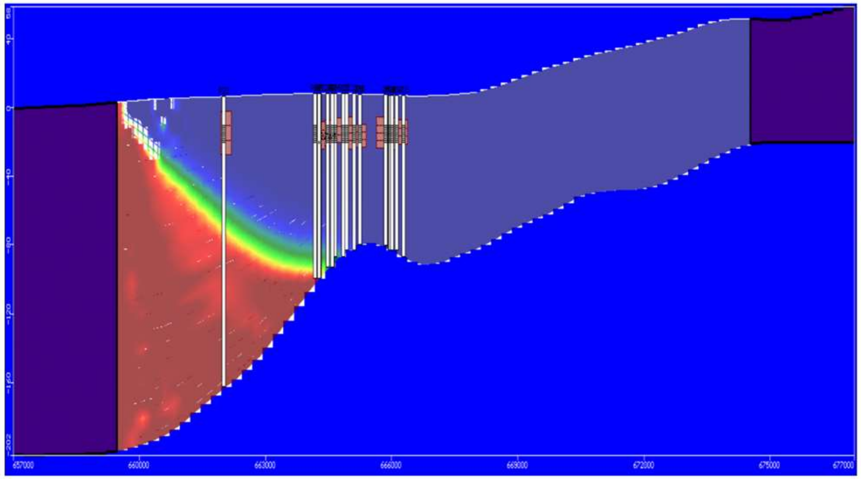
1976



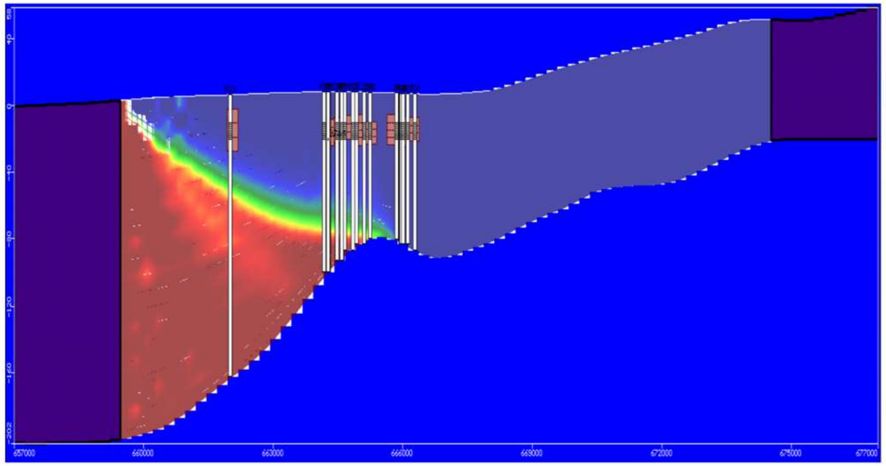
2020



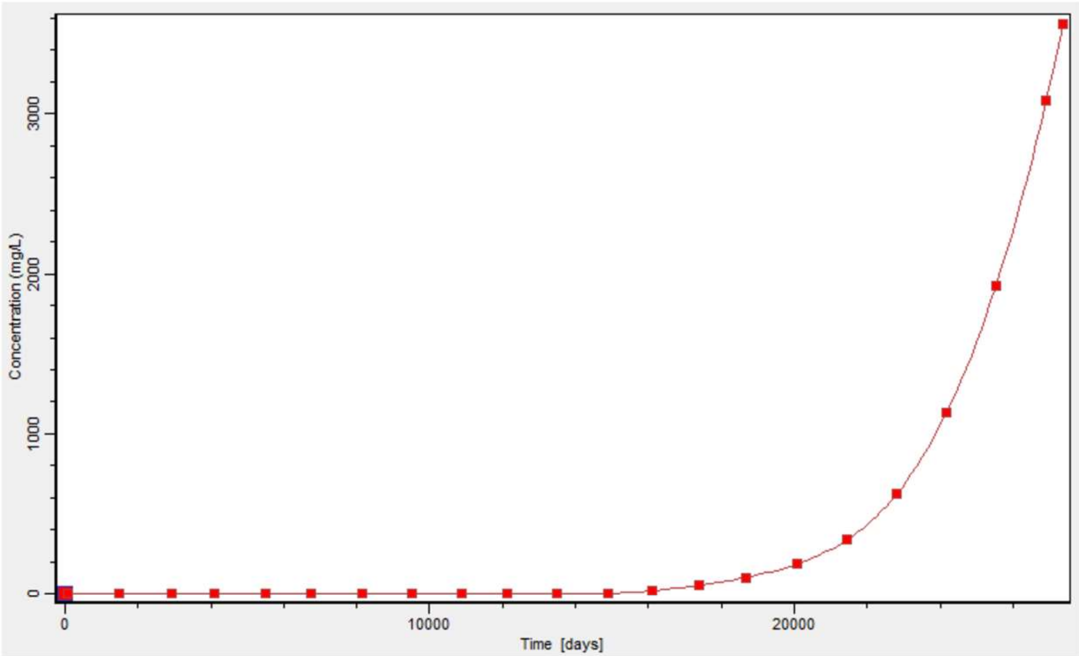




2030

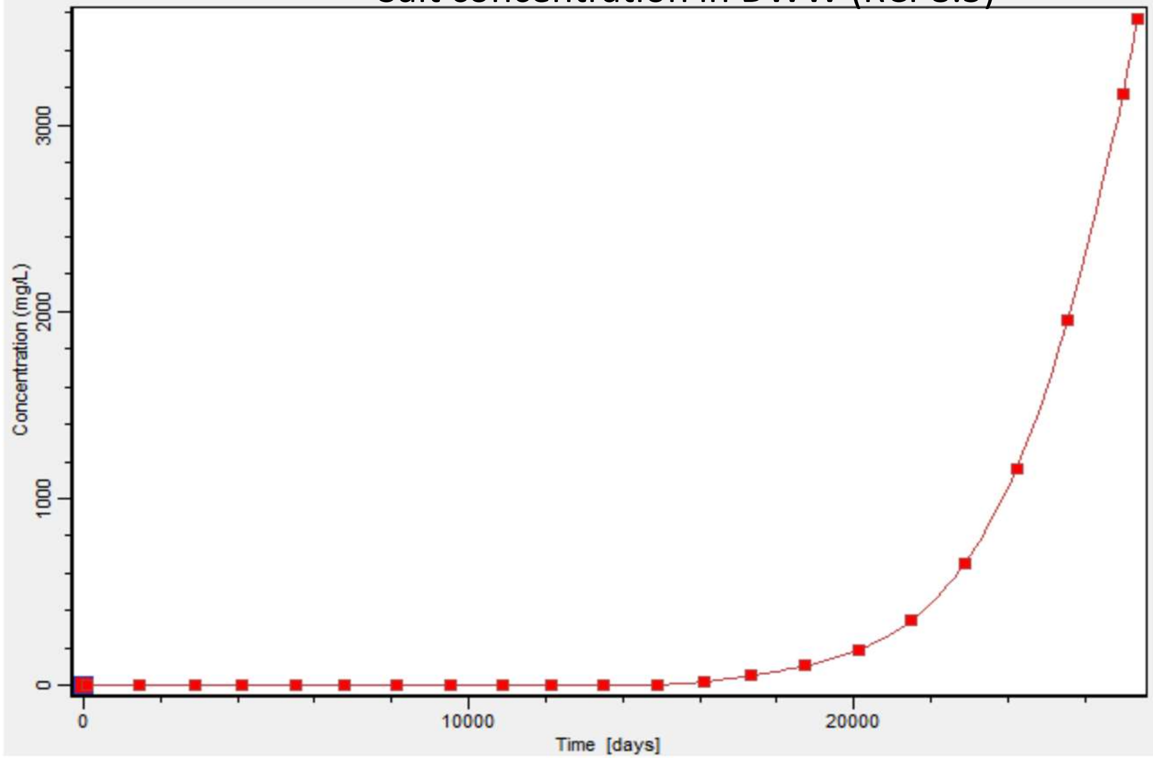


2050



Salt concentration in DWW (RCP4.5)

Salt concentration in DWW (RCP8.5)



d) Conclusions derived from the project and key recommendations for decision-makers

- **Groundwater resources** in the Tadla aquifer system will be affected by ***climate change*** due to a *reduction in natural recharge* from reduced precipitation (the mean will be 20% less at the end of the century for RCP 4.5; and 50% less for RCP 8.5) ;
- The *increase in evapotranspiration* caused in part by **higher temperatures** (the mean is about 2°C increase for RCP 4.5 and more than 4°C increase for RCP 8.5 at the end of the century).
- **Water availability** in the aquifer system will decrease for both scenarios, showing a severe situation for the RCP 8.5 scenario. This will result in groundwater table decrease for both scenarios varying from **10m** (RCP 4.5) to more than **25m** (RCP 8.5) which makes some aquifer areas completely dry.

❖ These results are of great importance as key information for **decision-makers** regarding the future of the sustainable exploitation of groundwater resources in the aquifer.

❖ The results of the RCP 8.5 scenario present a great concern for the future of irrigation agriculture in the study area since some **farms would be abandoned** due to the unavailability of groundwater. On the other hand, the results of the RCP 4.5 scenario are less severe but will **require rational and economical management** of water resources..

d) Conclusions derived from the project and key recommendations for decision-makers

Recommendations

The recommendations that the study can propose is mainly the adaptation to climate change impacts on groundwater resources in the study area by:

- Reconversion of gravity irrigation to **localized irrigation** (**drip**) throughout the irrigated perimeter, which would *save more than 50% of surface water* from the dam reservoir; the areas concerned by this action are **28,500 hectares** and cultivate mainly *market gardening products, beets, fodder, cereals, fruit growing*;

However, these actions will have a very **negative impact** on the ***aquifer recharge*** and will therefore endanger the irrigated perimeters by pumping, especially downstream and outside the study area:

- The irrigated areas at the level of the pumping perimeters inside the large hydraulic system are around 12,600 ha.
- For the 'Bour' perimeter (outside the irrigated perimeter) cultivated in the north and north-west, its area is estimated at 79,300 hectares, of which 69,000 hectares of crop rotations correspond to cereals while the rest is covered by fodder crops and legumes which constitute respectively 10.5 and 2.5% of the crop rotations. The latter, which generally has a total of 10,300 hectares, are irrigated by groundwater.
- Adaptation of current crops to crops that are water efficient and more resilient to climate change, both in the irrigated perimeter and outside this perimeter.

• Adaptation measures that account for these impacts of climate change on groundwater resources specifically in **improving productivity in the agriculture** sector are urgently needed, such as extensive reconversion of gravity irrigation to **drip irrigation** and **adapted crops** that are water efficient and more resilient to climate change.

• Assess Impact of CC on groundwater aquifers must be generalized in order to underline the consequences for the entire region and seek operational measures for the adaptation and management of groundwater systems in an adaptive and optimal manner.

Thank you for your attention