Climate Change and Natural Resources Sustainability Cluster
Water Resources Section

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Groundwater Modelling and Climate Change in Beni-Amir Aquifer, Tadla Complex, Morocco

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Workshop: Mashreq Waters Knowledge Series

Disruptive Technologies for Improved Groundwater Management in the Mashreq Region

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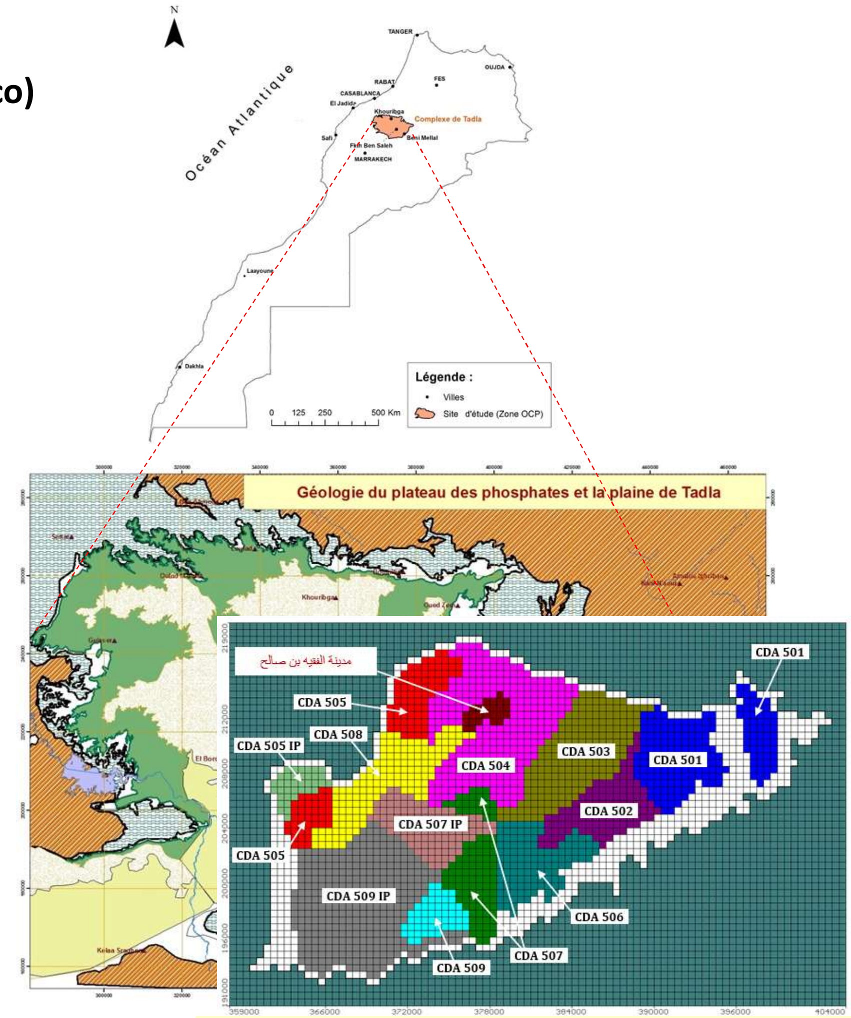
a) Objectives of the Study

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 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 of 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 the large irrigated perimeters of Tadla.



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

Purpose:

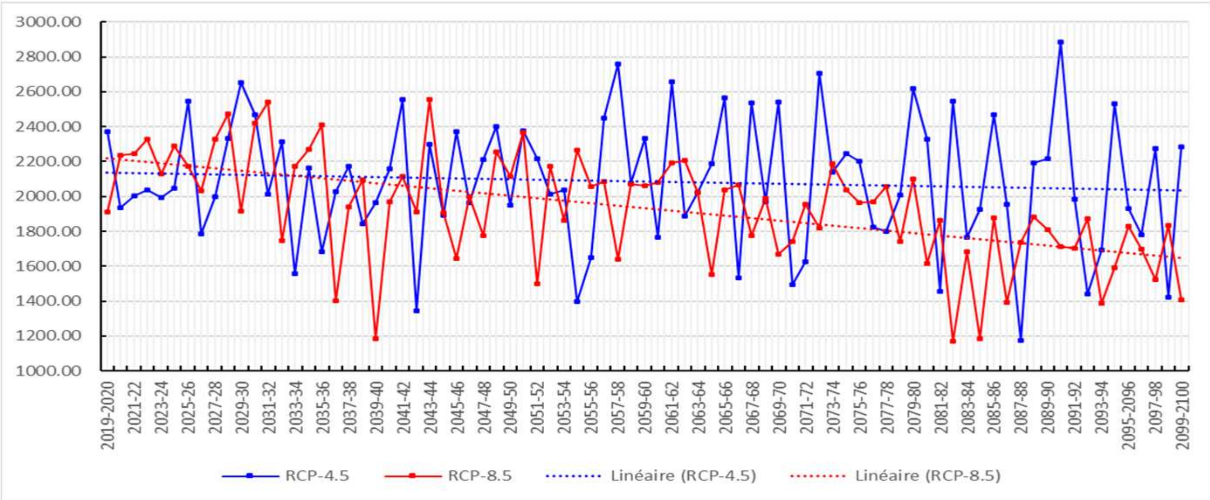
- **Assessment of climate change impacts on groundwater resource availability and use in Morocco, specifically on groundwater abstraction from the Tadla aquifer complex system that supplies domestic water as well as large irrigation schemes in the Beni Amir agricultural area.**

b) Key issue(s) and problem(s) addressed

- 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?**



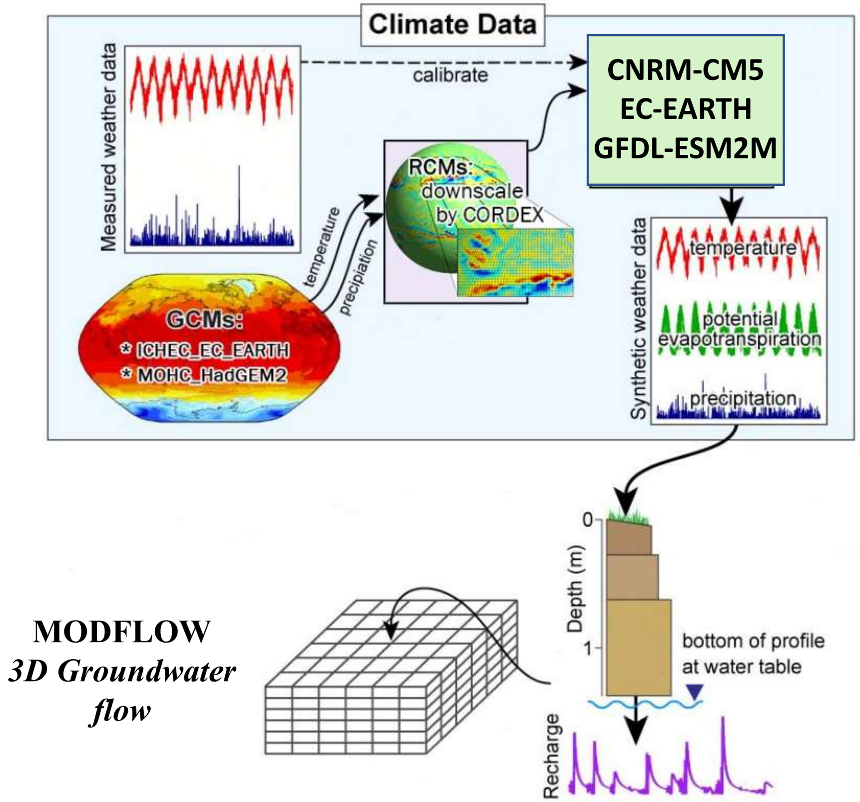
c) Methodology: Coupling Climate and Hydrological Modeling

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 Ribia basin;

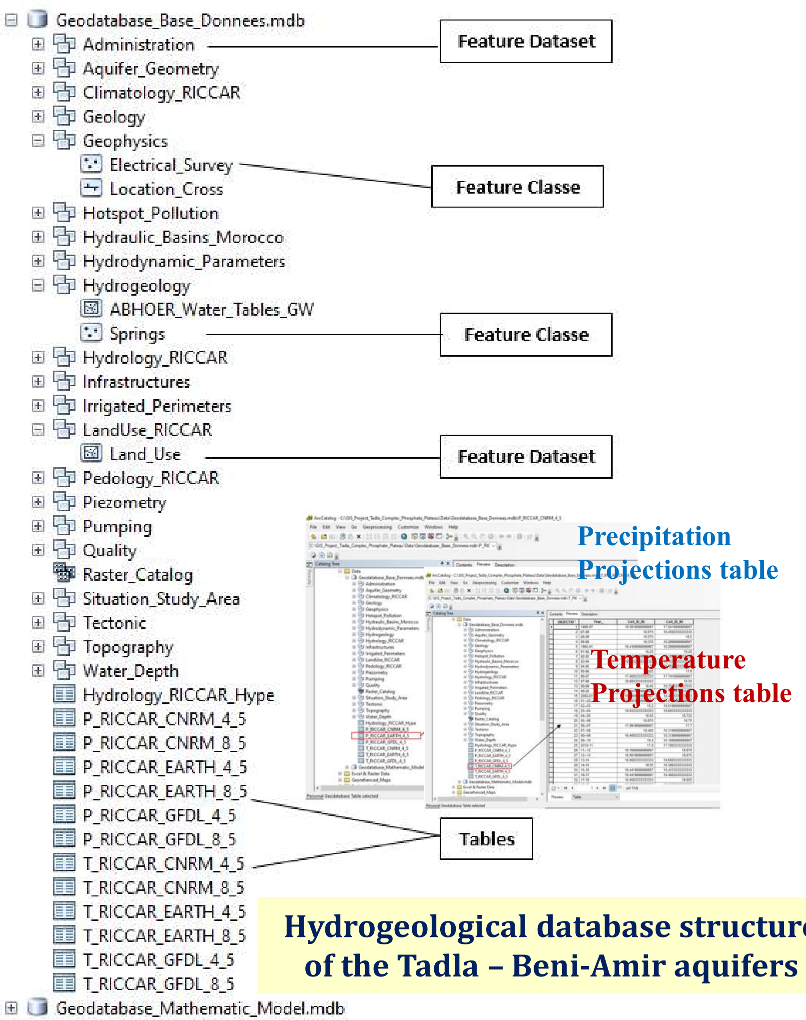
b. A three-dimensional conceptual groundwater model was designed and simulated a comprehensive set of physical processes and was compared, calibrated and verified with observations.

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).

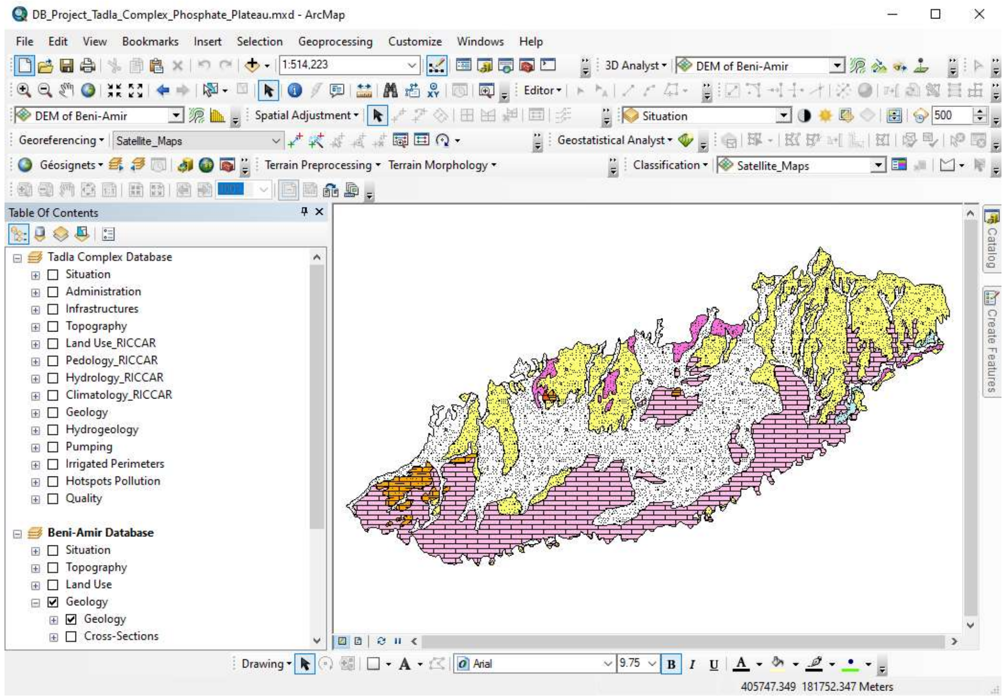


d) Results derived from the project: Geodatabase

Hydrogeological Database including RICCAR



Hydrogeological database structure of the Tadla – Beni-Amir aquifers



List of themes (ex: geology generated from the local data) selected on the left and their display on the right to view the geological map of the Beni-Amir aquifer system

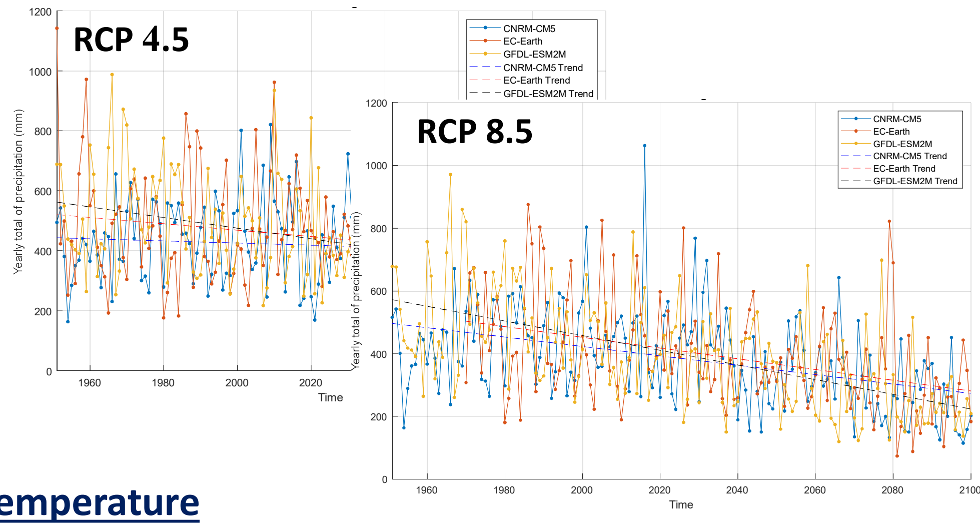
The data under which articulates this database, were collected from various local and regional organizations (ABHOER, DRPE, ORMVAT, ONEE-Khouribga and DPA-Khouribga and DPA-Settat, EMI and RICCAR)

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

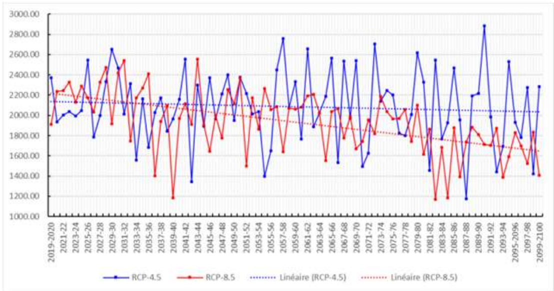
Local RICCAR Data Processing

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.

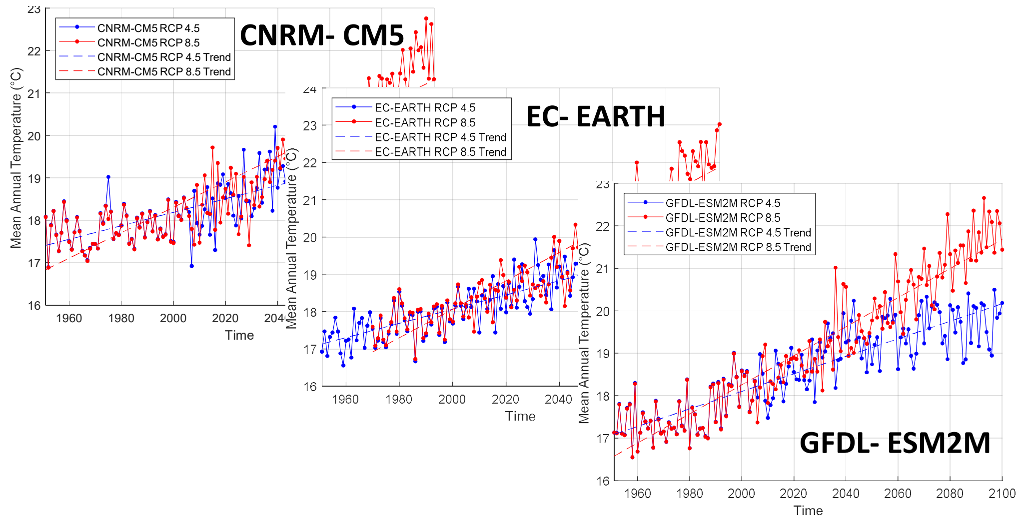
Precipitation



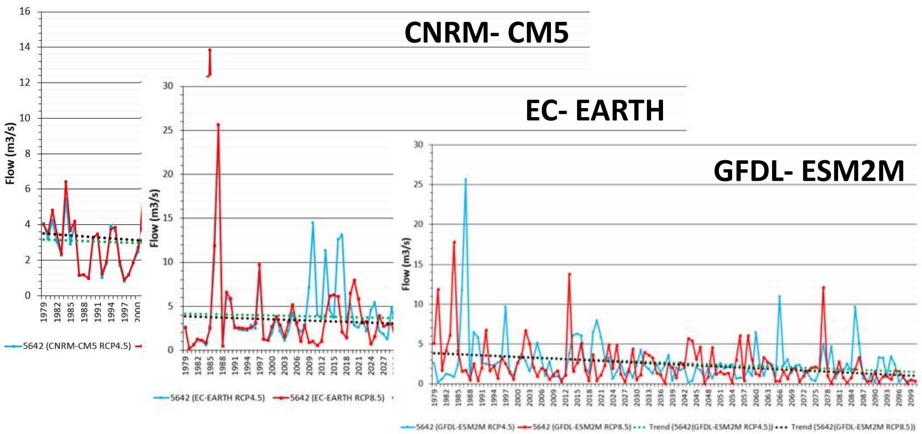
Recharge



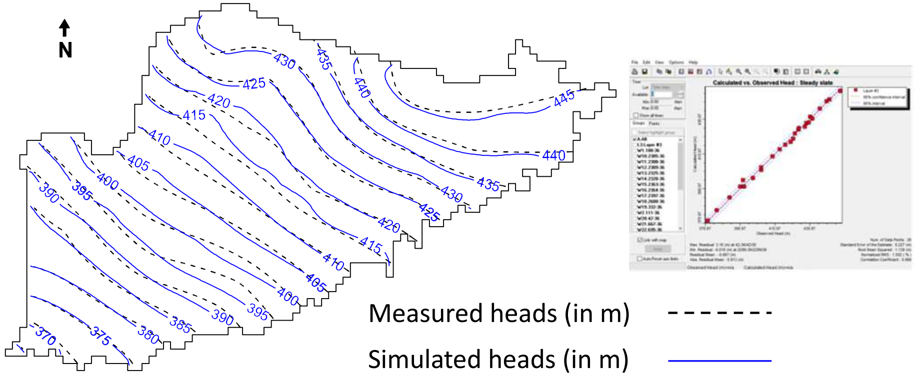
Temperature



Hydrology



d) Steady-state model

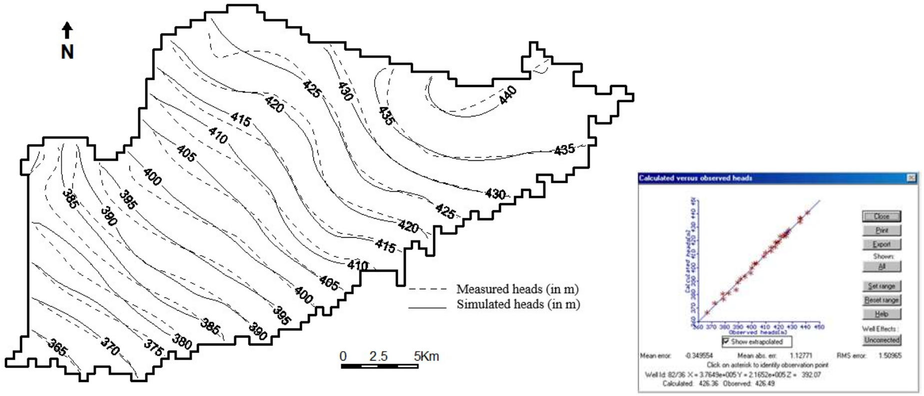


Calibration of the steady-state model on piezometry in 1978

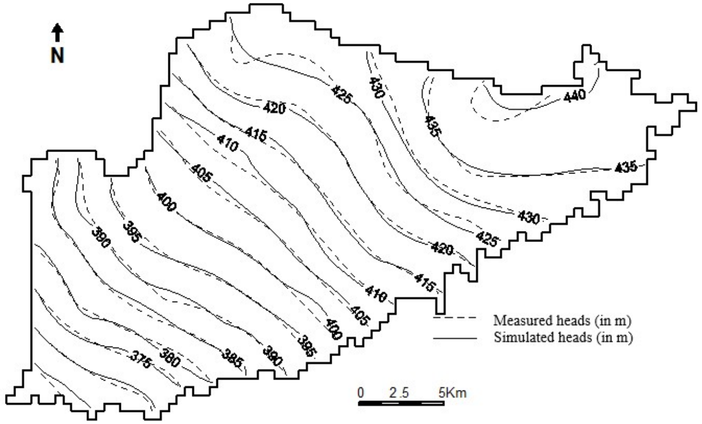
Inputs (in Mm³/an)		Outputs (in Mm³/an)	
Rain	56.4	Agricultural pumping	25.3
		DWSI pumping	15.2
Irrigation	130.6	Natural drainage (OER)	136.8
Boundary inputs	43.8	Boundary outputs	47.9
		Evaporation	5.6
Total	**230.8**	**Total**	**230.8**

Water balance of the aquifer system calculated after calibration in steady state.

Verification of the model in steady state



Verification of steady-state model on average piezometry 1994-95



Initial piezometry of August 1994.

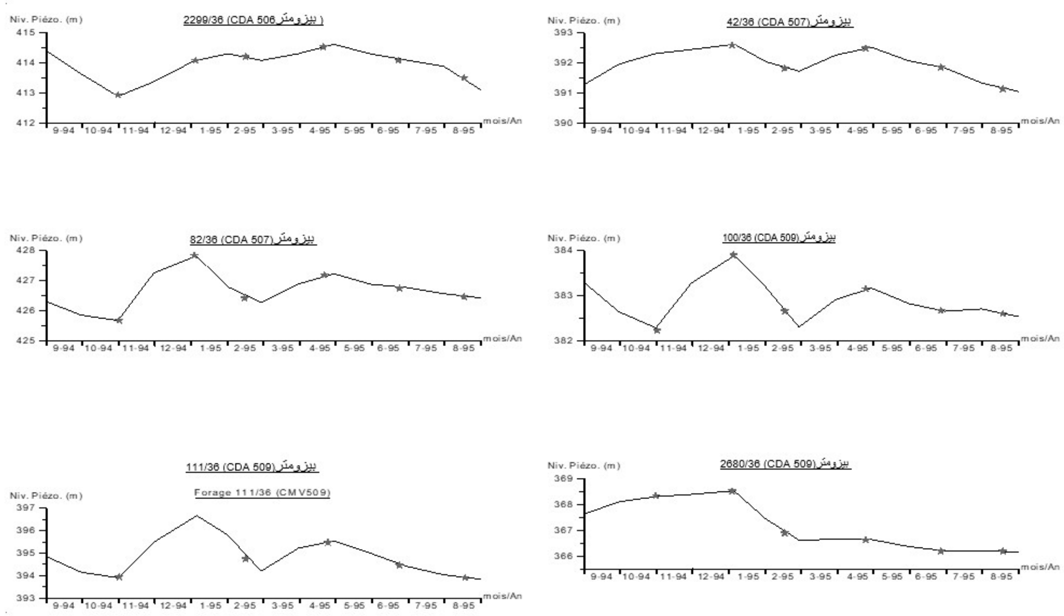
d) Simulations of the model in unsteady state

Inputs (in Mm^3/an)		Outputs (in Mm^3/an)	
Storage	76.6	Storage	72.2
		Natural drainage	45.5
Precipitation	31.3	Agricultural pumping	91.5
Irrigation	120.4	DWSI pumping	7.9
Boundary inputs	10.1	Boundary outputs	18.6
		Evaporation	3.5
Total	234	Total	234

Water balance of the aquifer calculated in transient regime.

Period	Storage variation	Period	Storage variation
9-1994	0.018	3-1995	-0.064
10-1994	0.024	4-1995	0
11-1994	-0.016	5-1995	-0.16
12-1994	-0.032	6-1995	0.08
1-1995	-0.056	7-1995	0.096
2-1995	-0.064	8-1995	0.096

Storage variation of the model in transient state (1994-1995) (in x106 m3).

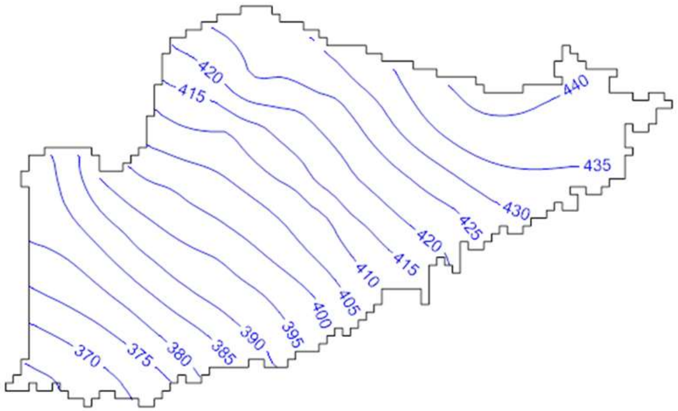


Calibration results for time series of piezometric levels in observation wells in transient state (Measured heads are in star symbol and simulated heads are in solid line).

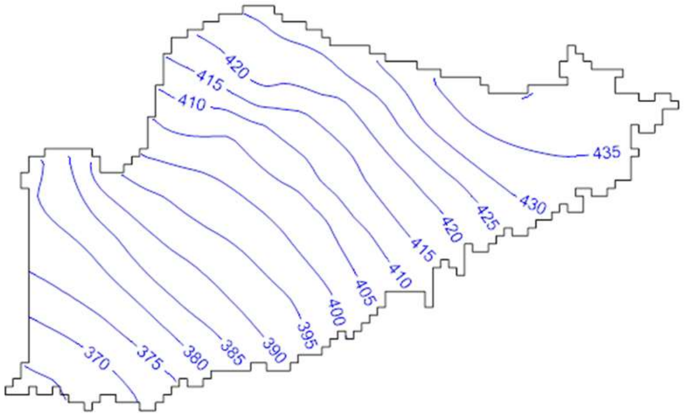
We also calculated the water balance for 1994-95 and shows that the results obtained agree with those of the balance of the model in steady state established for the same period. Furthermore, the intra-annual variation in the storage of the aquifer shows that on a regional scale the aquifer is characterized by a quasi-permanent regime.

d) Simulated the model for the year 2017-2019

Based on the model results for steady state and transient conditions, we have also simulated the model for the year 2017-2019



Simulated piezometry for 2018



Simulated piezometry for 2019

Inputs (in m³)		Outputs (in m³)	
Storage	60 809 336	Storage	16 739 039
Rainfall recharge	53 843 968	Agricole pumping	55 121 780
Irrigation recharge	47 880 000		
drainage from OER river	25 887 175	OER river drainage	102 792 978
Western inflow	6 762 968	Western outflow	34 333 290
Northern inflow	27 647 185	Northern outflow	13 843 556
Total	**222 830 632**	**Total**	**222 830 643**

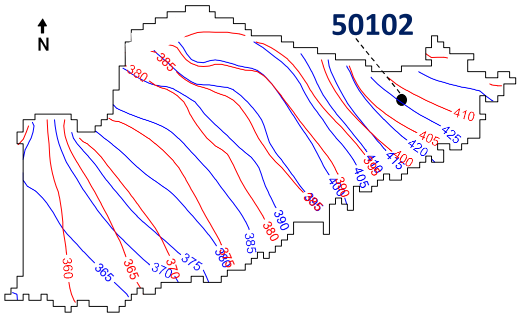
Inputs (in m³)		Outputs (in m³)	
Storage	75 217 368	Storage	159 925
Rainfall recharge	25 006 608	Agricole pumping	112 483 244
Irrigation recharge	39 480 000		
drainage from OER river	34 129 305	OER river drainage	85 790 101
Western inflow	8 430 883	Western outflow	23 138 378
Northern inflow	45 561 284	Northern outflow	6 253 921
Total	**227 825 448**	**Total**	**227 825 569**

The water balance does not vary much, which confirms the previous finding on the quasi-steady state regime at the yearly scale.

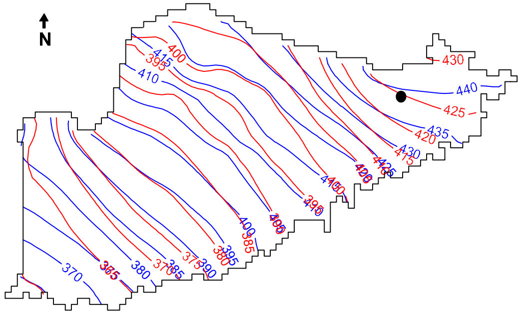
d) Results derived from the project (Piezometric maps & records and WB)

Simulations of the impacts of CC using RICCAR data

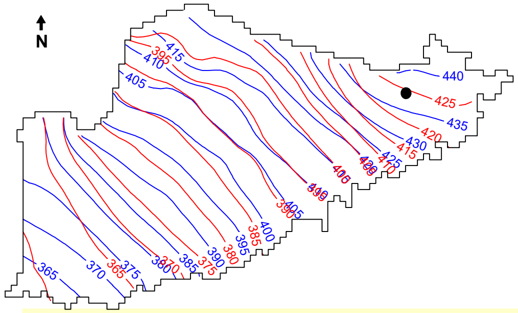
Climate Model CNRM- CM5



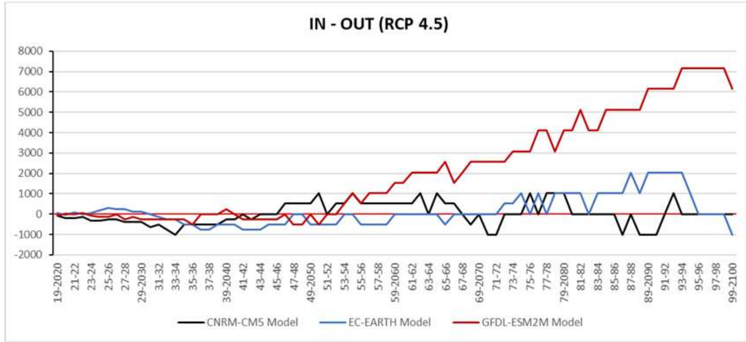
Climate Model EC-EARTH

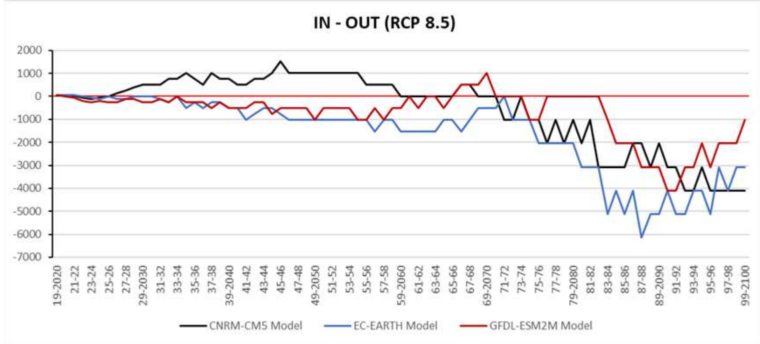


Climate Model GFDL- ESM2M



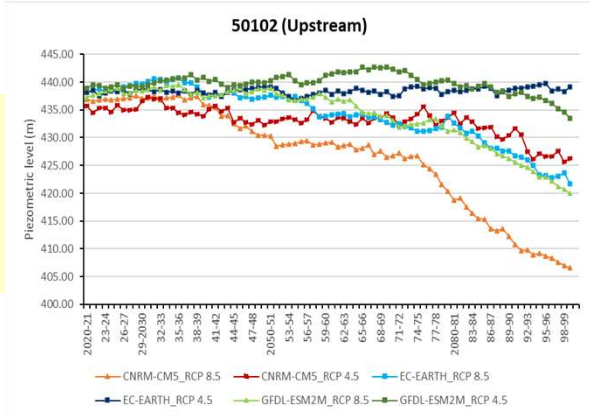
Piezometric maps in 2093/2094 (t = 27375 days)





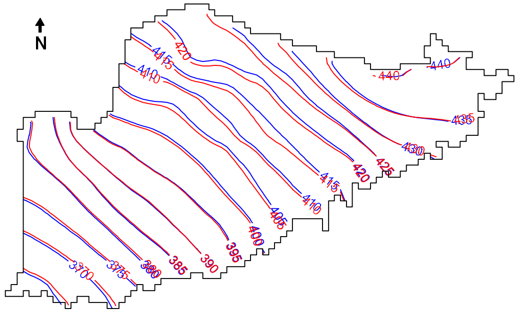
Storage and destocking of the aquifer reservoir (2020-2100)

Drawdowns variation in 50102 observation well (2020-2100)

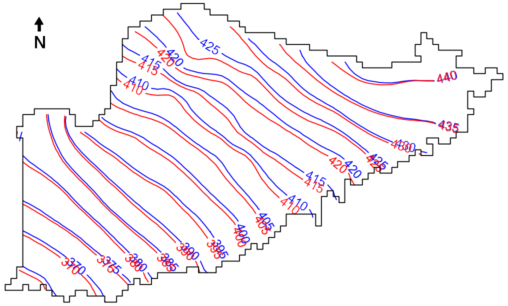


d) Simulations of the impacts of climate change using RICCAR data

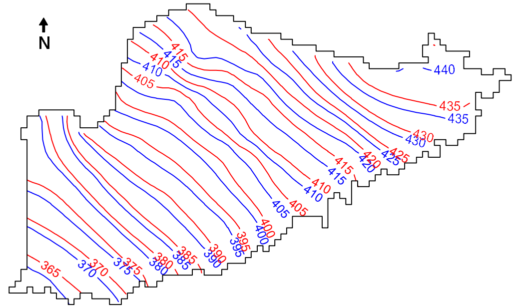
Average of CNRM-CM5, EC-EARTH, GFDL-ESM2M Models



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



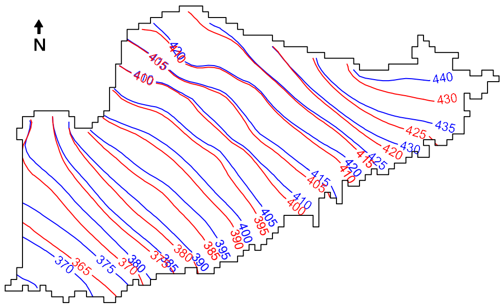
Piezometric maps in 2030/2031 (t = 4380 days)



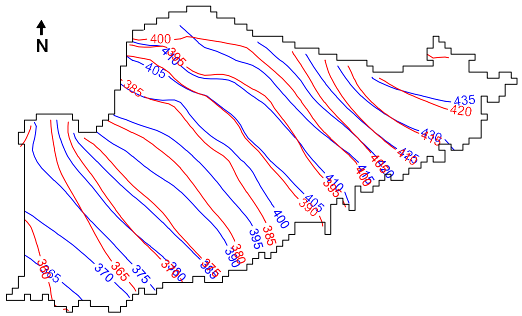
Piezometric maps in 2047/2048 (t = 10585 days)

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)

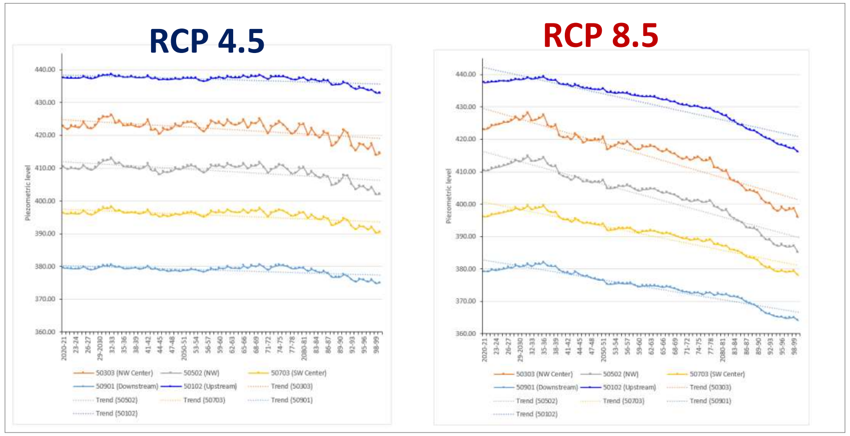
Piezometric maps selected for some years in the study area (Average of CNRM-CM5, EC-EARTH, GFDL-ESM2M Models for RCP 4.5 and RCP 8.5 Scenarios).

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

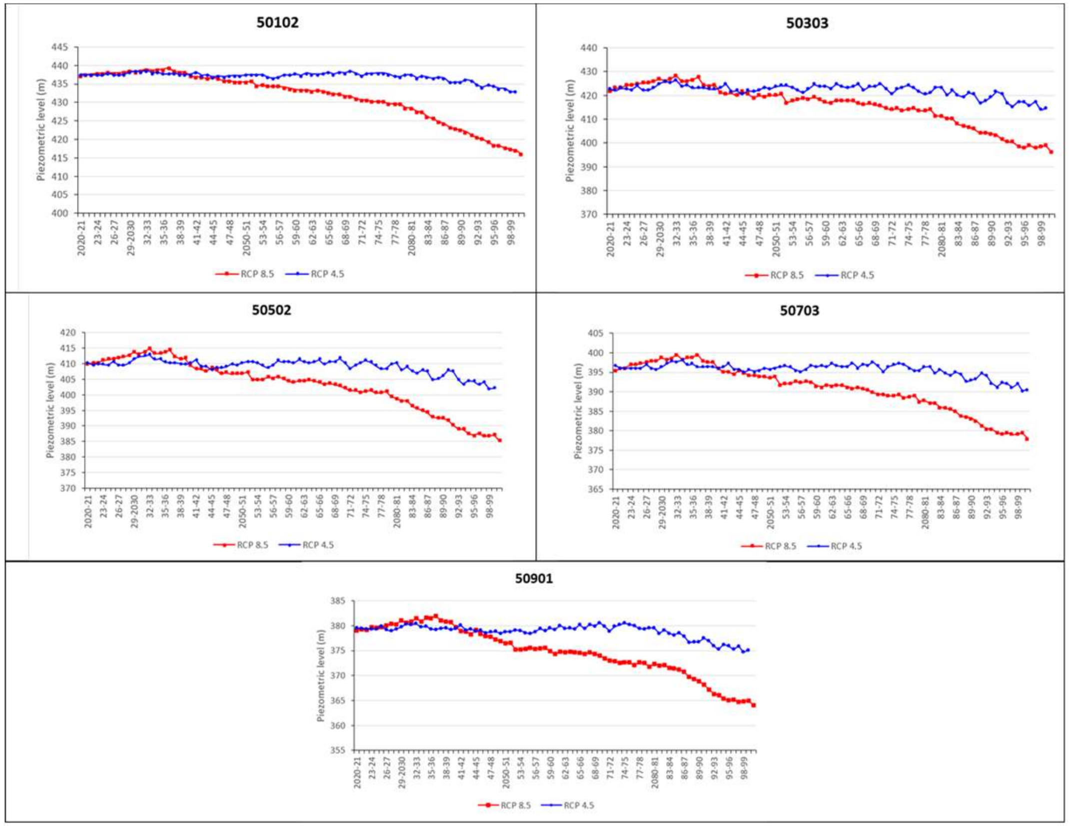
Average of the 3 RCM Models

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

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 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 3 RCM Models

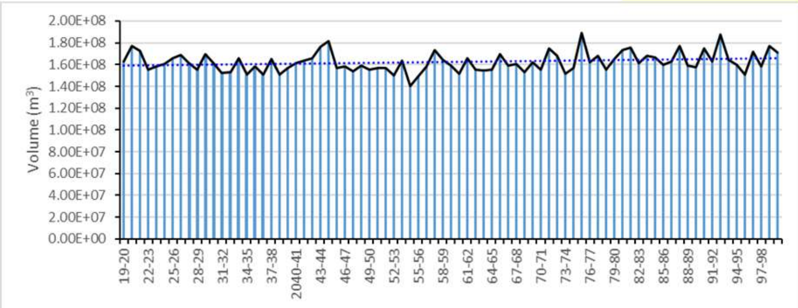
RCP 4.5 DWA = 140 210 347 m^3 ≅ 140 Mm^3 (2054-2055)

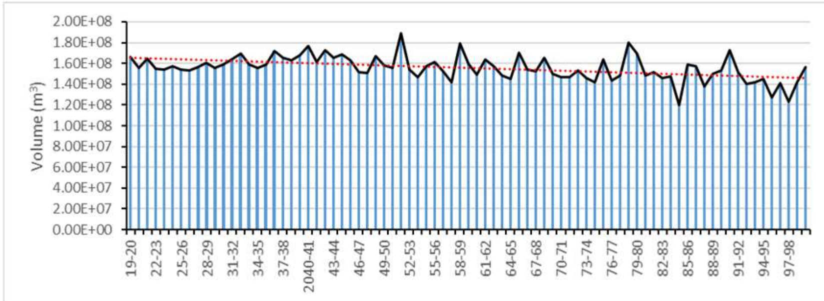
Time (Year)	2021/22	2030/31	2047/48	2075/76	2093/94	2095/96	2099/2100
STORAGE IN (m^3)	31 822 542	1 182 872	6 307 541	41 799 467	39 752 919	16 095 337	23 793 023
RECHARGE IN (m^3)	81 930 203	101 135 208	90 524 583	90 032 127	69 130 923	78 731 437	93 460 137
FLOW IN (m^3)	58 914 224	58 786 965	57 225 513	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**

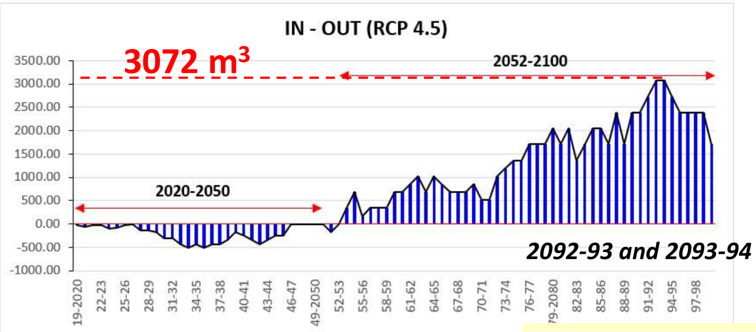
RCP 8.5 DWA = 119 911 067 m^3 ≅ 120 Mm^3 (2084-2085)

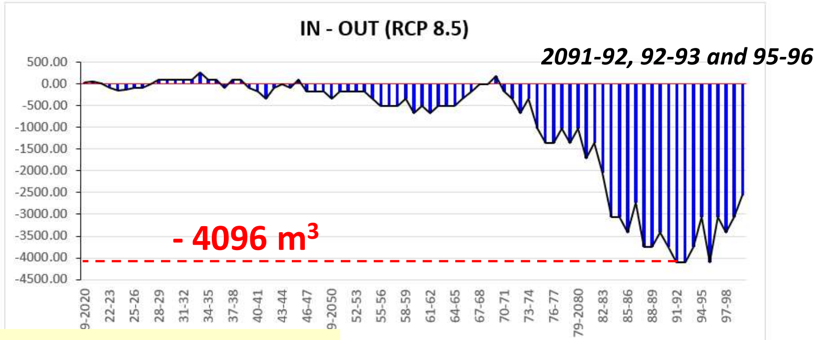
Time (Year)	2021/22	2030/31	2047/48	2075/76	2093/94	2097/98	2099/2100
STORAGE IN (m^3)	13 882 443	85	21 439 701	30 485 205	37 121 320	124 43 437	51 375 443
RECHARGE IN (m^3)	91 821 317	99 657 727	72 594 433	80 233 473	56 422 400	70 176 257	57 085 610
LAT FLOW IN (m^3)	59 127 336	59 127 339	56 822 483	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







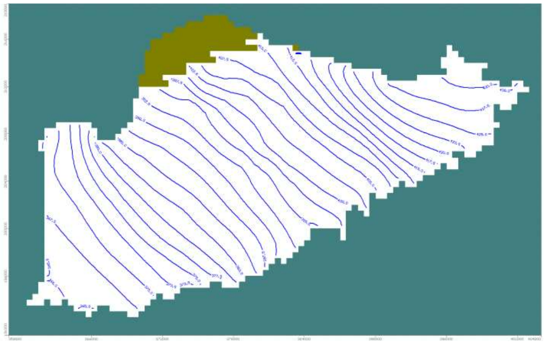


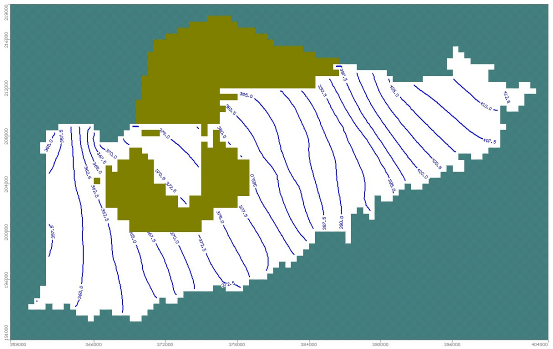
Storage and destocking of the aquifer reservoir (2020-2100)

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

❖ **2nd layer**

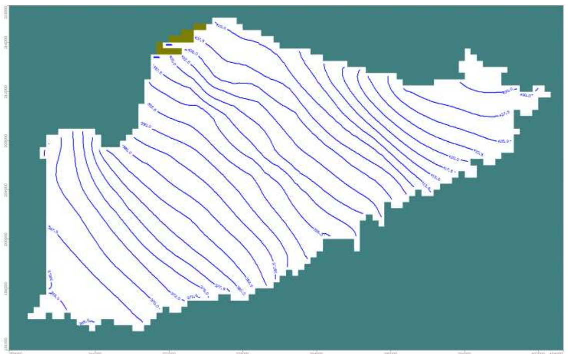
RCP 4.5	RCP 8.5
(Dry cells over 16.5 Km²)	(Dry cells over 68.5 Km²)



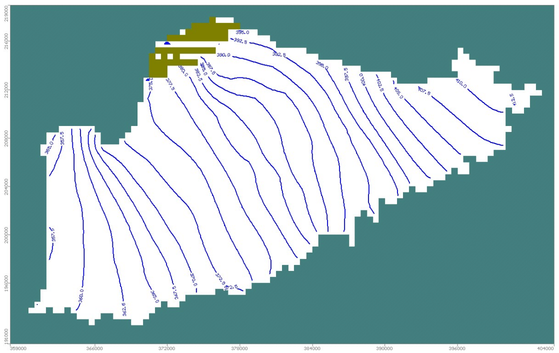


❖ **3rd layer**

(Dry cells over 1 Km²)



(Dry cells over 4.5 Km²)



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 km² of the 2nd and
- 13 km² of the last layer.

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

- ***the dried areas*** are relatively reduced to 4.5 km² on the 2nd layer and
- 1 km² on the 3rd layer located at the north of the study area.

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.

- 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.