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Climate change and development impacts using WEAP modeling to assess Natural resources in the oum zessar watershed, tunisia

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INTRODUCTION

In dry Area where soils and water resources are limited we used a new approach for modeling at regional scale to evaluate the effects of Climatic change and development impacts,. The WEAP model is a user-friendly software tool that takes an integrated approach to water resources planning, making use of supply, demand, water quality and ecological considerations. Simulations are based on Calculates water demand, supply, runoff, infiltration, crop requirements, flows, and storage, and pollution generation, treatment, discharge and instream water quality under varying hydrologic and policy scenarios.

STUDY SITE

The study site belongs to the region of south eastern Tunisia (Fig. 1). It is a transect which stretches out from the Great Oriental Erg and the Dahar plateau in he west, crosses the Matmata mountains between Béni Khdache and Toujane and the open Jeffara plain, then the saline depression (Sebkhat) of Oum Zessar before ending into the Gulf of Gabès (Mediterranean sea). The SS covers an area of 1226 km2 and the approximate coordinates of the central point are 33°16’ N and 10°08’ E.

The catchment area is drained by wadi Oum Zessar. In fact, it runs out since the mountainous chain of Béni Khédache crosses the Northern county of Médenine and reaches the county of Sidi Makhlouf to flow in Sebkhas Oum Zessar before reaching the sea. The highest point of the watershed reaches an altitude of 713 m on the level of Jbel Moggar

CLIMATE

.The climate in the study site is of the Mediterranean to Saharan type. The coldest months are December, January and February with occasional freezing (up to -3 °C). June-August is the warmest period of the year during which the temperature could reach as high as 48°C. The temperature in the study site is affected by the proximity to the sea and the altitude.

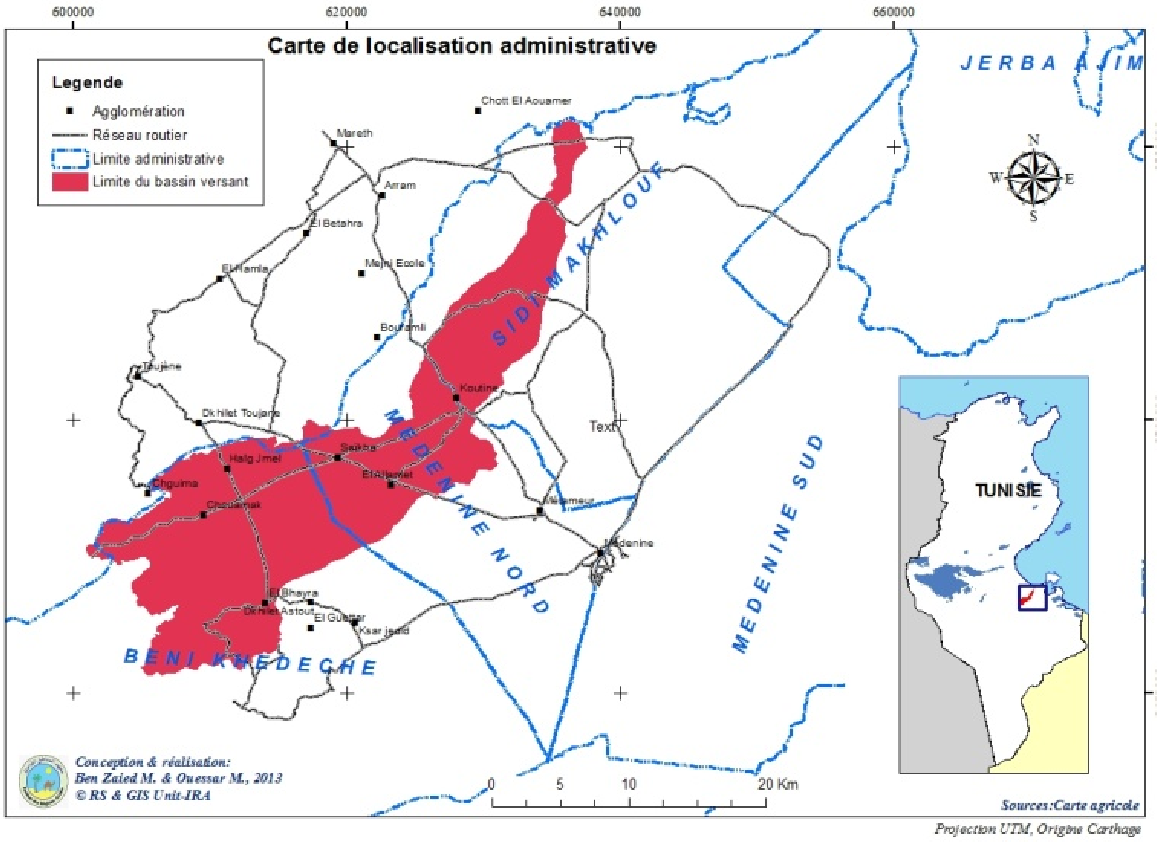

Figure 1. Study site location

Having an arid climate, the rainfall in the study site is characterized by low averages, high irregularity (both in time and space) and torrential characteristics. It receives, on annual average, between 150 and 240 mm in the mountains and eastern parts but this amount decreases rapidly to less than 100 mm in the zones close to the desert. The prevailing winds affecting the plain and the plateau are: in winter the cool and humid eastern/northeastern winds, and in summer the hot and dry southeastern winds, called *Chhili* or *Guebli*. With high temperature and low rainfall, the potential evapotranspiration (ETP) is very high (around 1321 mm/year) and the climatic water balance is negative almost around the year (Ouessar et al. 2009).

SOIL DATA

The soil classification of the study watershed was extracted from the soil map of the region (carte agricole de medenine 2002). It made by use, analyse and interpretation of provided imagery data (Taamallah 2003), the soil map was elaborated according to the French soil classification (CPCS, 1967).

The soils are developed on a calcareous substratum in the upstream area and gypsum or gypsum to calcareous in the downstream area. The soil horizons are generally shallow, stony, unstructured with sandy to fine sandy texture.

Six main classes have been identified: sols minéraux bruts (d'érosion)(lithosols), sols peu évolués (Fluvisols), sols calcimagnésiques (Calcimagnesic), sols isohumiques bruns calcaires tronqués (Isohumic) and sols halomorphes et hydromorphes (solonchak and solonetz).

WATER RESOURCES AND DEMANDS IN THE OUMZESSAR

The main source of water for the different users in and around the OumZessar catchment is groundwater. There are two main aquifers supplying water to the users with varying quality and quantity, the ZeussKoutine aquifer and the GresTrias aquifer supply domestic water use, tourism, industry and commercial uses. Shallow aquifers are the main source for the agricultural sector, supplemented by water from the ZeussKoutine aquifer and for a small amount the GresTrias aquifer. Recently a desalination plant was constructed purifying water from the brackish Jefara aquifer supplying water to Djerba/ Zarzis and for the tourism sector. An additional sea water desalination plant (capacity: 50.000 m^3/day) will be operational from 2016 to supply water to the same users.

With these developments pressure on the two aquifers is expected to diminishing and plans are made to develop additional irrigated areas using water from these aquifers.

WEAP MODEL

The WEAP model has been developed to operate in many capacities: Water balance database, Scenario generation tool and Policy analysis tool. We applied this model to simulate water balance (Fig.2) at the watershed scale.

Water sources in the OumZessar

Aquifers

The three aquifers are recharged through seepage in the river bed and infiltration into the landscape. As there is little information on these processes, the recharge of the aquifers, as a function of the rainfall was estimated based on the known natural recharge rates of the three aquifers

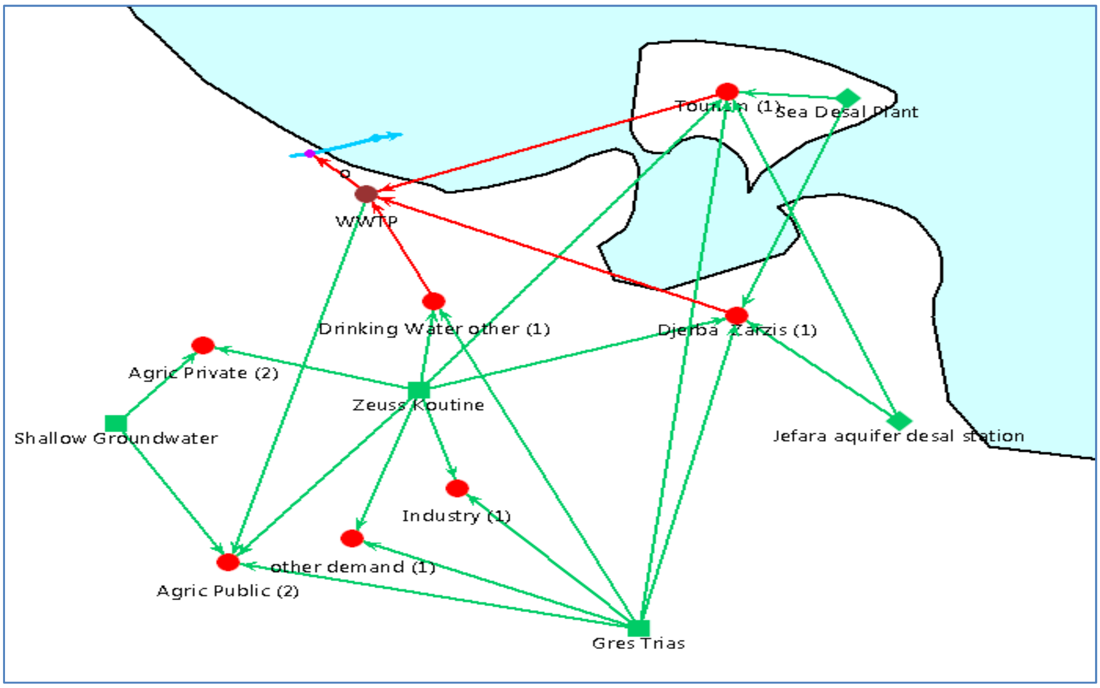

Figure 2. WEAP model setup

Table 1 Aquifer characteristics

	Capacity	Initial storage	Maximum withdrawal		R (known)	R (eq 1)	A	α
Aquifer	(Mm^3)	(Mm^3)	l/s	Mm^3/month	l/s	l/s	km^2	%
ZeussKoutine	10	5	350	0.92	350	329	461	12
TresGrias	22	11	150	0.41	150	142	200	12
Shallow aquifers	6	3	400	1.06	350	Same as ZK		

Other sources

The existing desalination plant pumps water from the brackish Jefara aquifer and supplies water to Djerba/ Zarzis and Tourism sectors. A sea water desalination plant will start operating in 2016. The capacities of the plants are provided in Table 2.

Table 2. capacity of desalination plants

	Source	capacity	
		m^3/day	m^3/s
Desal plant (existing: Djerba - Zarzis)	Brackish Jefara aquifer	15,000 + 12,000=17,000	0.197
Desal plant (2016)	Sea water	50,000	0.578

Demands

Supplied from current (and future) desalination plants: Djerba/Zarzis&Tourism

The largest water user in the area is Tourism and the domestic water demand from Djerba and Zarzis. These users are putting a lot of pressure on the groundwater resources and the construction of the two desalination plants is to alleviate this pressure. Table 3 and 4 present the calculation of the demands for these users.

Table 3. Population data for Djerba and Zarzis (source Office of Development South, 2004)

	Population		Actual water use		
	2004 (census)	2010		m^3/cap/year	l/cap/day
Djerba	139600	157560	7401000	47	129
Zarzis	73500	75569	3124500	42	114
Total	213100	233129	10525500	45	122

Table 4. Data on tourism (source: Office of Development South (ODS), 2010)

	Tourist nights spent	Water use (m^3/cap/night)
Tourism Djerba	4711984	0.8

Other domestic

The other domestic water use comprise of 4 delegations, see Table 5. The water use per capita is an average of the actual water use per capita.

Table 5. Population data for other domestic users (source ODS, 2004)

	Population		**Actual water use**		
	2004 (census)	2010	m3/year	m^3/cap/year	l/cap/day
Medenine north	48 100	54300	2688100	50	136
Medeninesouth	48 100	51882	616200	12	33
BeniKhedache	28 600	27410	419500	15	42
SidiMakhlouf	23 700	23120	552900	24	66
Total	148500	156712	4276700	25	89

Industry/ other demands

The industry and other demands (mainly commercial) are modelled as a bulk water use, based on the values for 2010 (Table 6).

Table 6. Industry and other water use demand (Office of Development South, 2010 figures)

	Bulk water demand (m^3/year)
Industry	240800
Other demands	18500

Agriculture

The agricultural sector can be split into two groups, public and private. Both groups primarily use water from the shallow aquifer for irrigation, as this is easier to access. The private companies do have some deeper wells, tapping into the Zeus Koutine aquifer during periods when the supply from the shallow aquifer is inadequate. The public agriculture also has limited access to the GresTrias aquifer. The two systems have 2,415 ha of full scale irrigation for different type of crops, using the majority of water for this sector. In addition, there are private companies growing olives and other types of trees that receive supplementary irrigation during periods of drought, these users use a smaller amount of water compared to the full irrigation (Table 7).

Table 7. Agricultural water use (source of data on areas: ODS, water use is estimates)

	area	**Water use (m3/ha)**
Agriculture private		
Irrigated	1988	5000
Olives	188250	10
Other	9850	2
Agriculture public		
Irrigated	427	5000

Monthly variations

The water use of the different water users varies during the year, the monthly variations were used to spread the water demand between the different months.

Linkages

Finally for setting up the WEAP system priorities and constraints are assigned for each link (Table 8).

Table 8. Priorities and flow restrictions

To	From	Max flow	Preference
Tourism/ Djerba-Zarzis	Desal Plant (Jefara)		1
	Sea Desal Plant		1
	GresTrias		2
	Zeus Koutine		2
Agric Public	Shallow groundwater		1
	ZeussKoutine	2.88	2
	GresTrias	0.88	3
Agric Private	Shallow groundwater		1
	ZeussKoutine	12.97	2
Drinking water	ZeussKoutine	19.23	2
	GresTrias	5.87	1
Industry/ other	ZeussKoutine		1
	GresTrias		1

Scenario inputs

Three scenarios are used for the modelling. The inputs of these scenarios were quantified, based on the direction of change as provided by the scenarios and with additional consultation with stakeholders. The breakpoint in 2030 for the scenarios was incorporated for all three scenarios representing a crucial change of the main drivers around that time. For all scenarios, socio-economic growth is expected, this is translated into increasing water demands, as domestic water consumption and all other sectors, tourism, industry and agriculture are all expected to increase (at varying rates). Currently, there is unsustainable use of the groundwater resources to supply for all these users, therefore it is decided to supply the tourism sector and domestic water use for Djerba and Zarzis with water from a newly built desalination plant and a desalination plant planned to be operational by 2016.

Scenario 1 Liberalisation and Market orientation

This liberalization scenario predicts rapid growth in the near future with a breaking point around 2030 where government starts to intervene. The quantification of this scenario predicts the highest water demand for agriculture and industry. The tourism sector, the largest water user, on the other hand, grows compared to the base case scenario (scenario 3) but is much less than the other two scenarios. Total water demand increases from 65 Mm^3/yr to approximately 260 Mm^3/yr. Restriction on groundwater pumping is limited and slowly re-use of waste water introduced.

Scenario 2 Sustainable development and technological improvements

This scenario predicts increasing water demands throughout the period until 2050. The total water demand for this scenario is predicted to increase to 420 Mm^3/yr. In particular the tourism sector is expected to have the highest water demand and for the industry the demand is less than scenario 2 but higher than scenario 4. Groundwater pumping is being constricted, and re-use of waste water is quickly promoted.

Scenario 4 Corporate commitment for equity and sustainability

This scenario predicts slightly lower water demands than scenario 2, mostly related to a slower growth in water demand of the tourism sector. Total water demand is estimated to increase to 380 Mm^3/yr. Groundwater pumping is being constricted and slowly waste water is being reused in the second half of the period.

Modelling results

The WEAP model results show, that with these water demand projections the groundwater resources are depleted by 2030 (Figure 3). Across sectors water shortages are experienced (Figure 4).

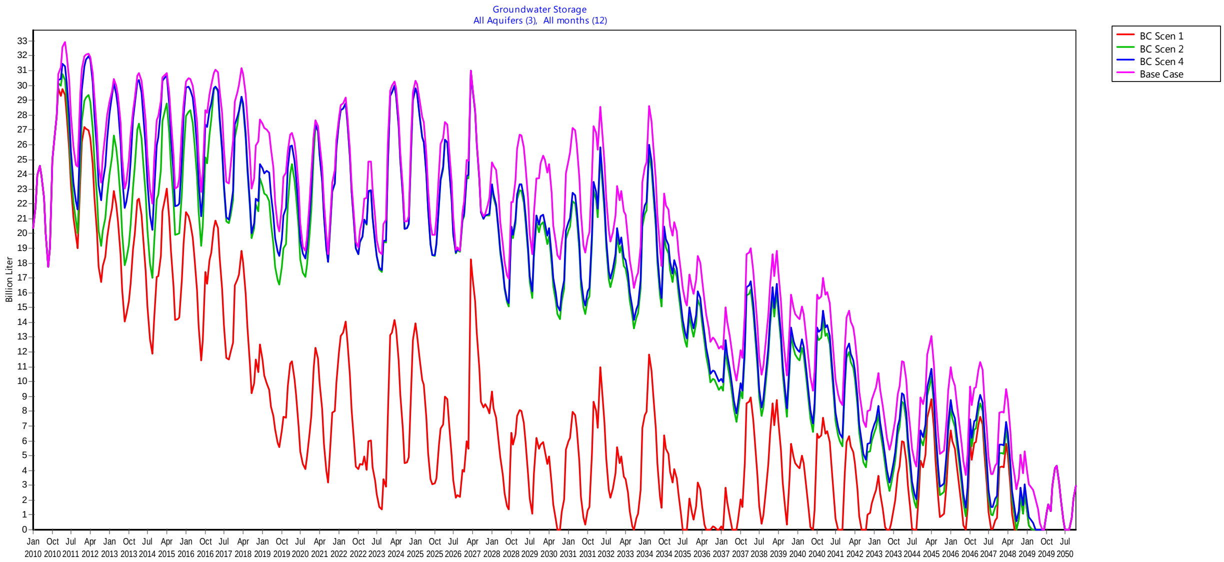

Figure 3 Groundwater storage under the three development scenarios

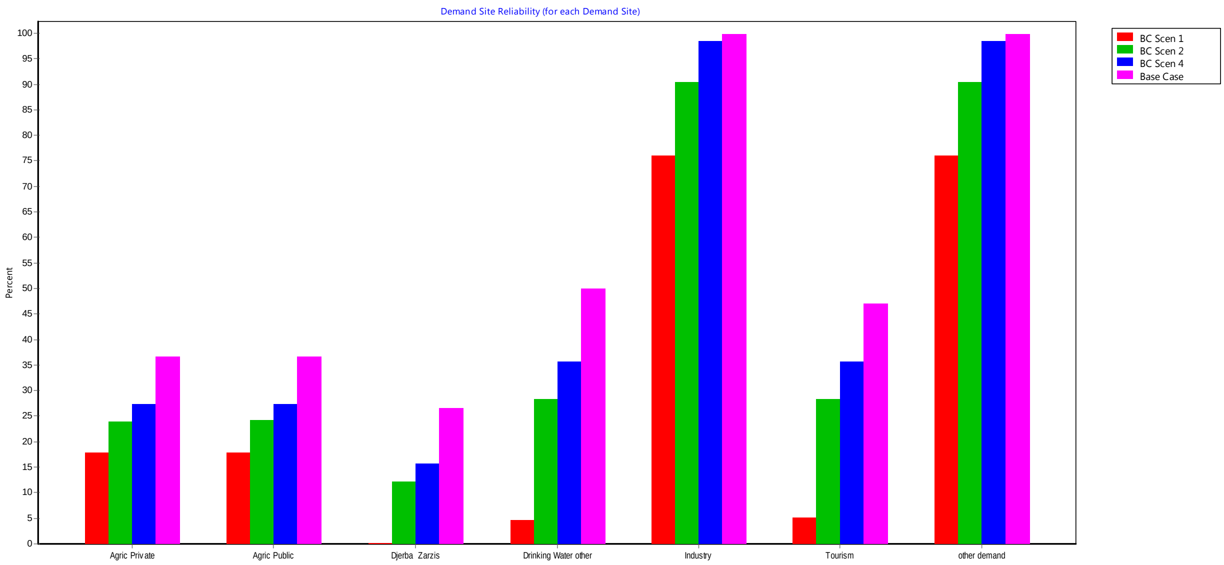

Figure 4 Unmet demand for the three development scenarios

While analyzing the results, the following becomes clear. Total annual water supply is a fraction of the projected water demands. Long term annual natural recharge to the three aquifers is between 20 and 30 Mm^3/yr, the two desalination plants add another 25 Mm^3/yr, this is far less than the projected total demand of 160 Mm^3/yr for the base case and 420 Mm^3/yr for scenario 2. It is clear that the input values for the scenarios are not realistic, and will have to be revised. For example in case of long term shortages this would affect growth and therefore demand would not increase according to these projections. Based on this assumption, the input values for scenario 2 (the most sustainable scenario) were revised accordingly (see next section), and used for identifying promising measures.

Revised sustainable scenario

The revised scenario assumes domestic water use to be similar to current water use and to grow slowly towards the national average. In addition, it is expected that the different sectors will grow, however the water demand will not grow at the same rate, as new water saving technologies will be applied. Finally the agriculture has not been included as a growth sector as this is dependent on the available water resources and will have to be determined afterwards. There is an efficiency gain projected for the agricultural by 2030 of 10% less water use. Table 9 shows the revised input used.

Table 9 revised inputs for the development scenario

Quantification of Scenarios	**Period**	**Unit**	**base case**	**Revised inputs**
households	2013-2020	Water consumption	165	120
	2020-2030	l/cap/day	149	150
	2030-2050		250	165
	2013-2020	population growth	1.14	1.14
	2020-2030	%	1.30	1.30
	2030-2050		1.51	1.51
Agriculture irrigation	2013-2020	area increase	3.0	3.0
	2020-2030	%/ year	4.0	0.0
	2030-2050		3.5	0.0
Tourism	2013-2020	consumption	3.0	3.0
	2020-2030	%/year	5.7	5.7
	2030-2050		7.9	7.9
Industry	2013-2020	consumption	5.0	3.0
	2020-2030	%/year	7.0	5.0
	2030-2050		10.0	7.0

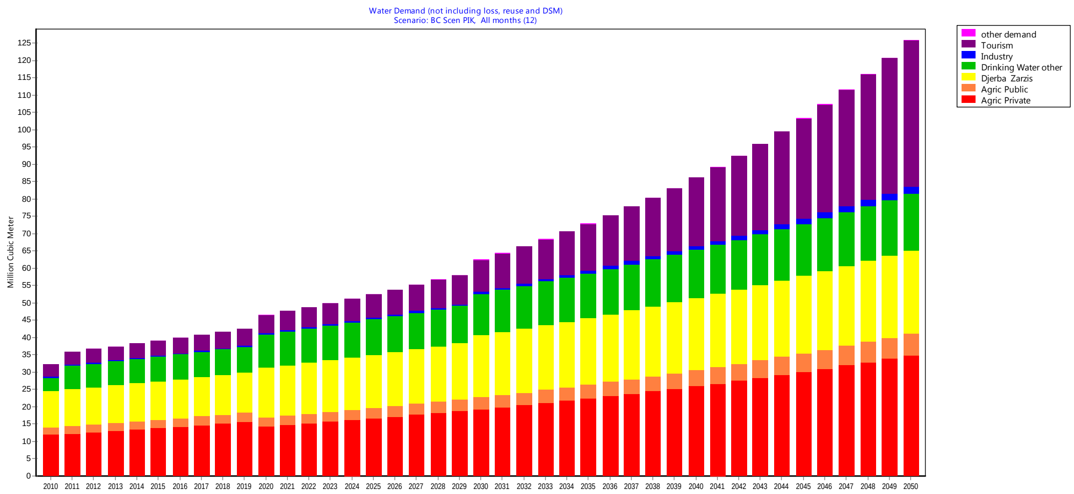

Figure 5. development of the demand for all sectors based on the revised inputs

This new scenario input reduces the total annual water demand by 2050 to approximately 125 Mm^3/yr. 50% of this demand is the tourism sector in Djerba and the domestic water use of Djerba and Zarzis. With a total capacity of 25 Mm^3/yr for the two desalination plants, this is insufficient to supply water for these users. In order to keep up with the expected growth, by 2030 additional treatment plants will have to be constructed, in particular to cope with the peak demands in July and August. In addition, demand for groundwater remains high (even without increasing agriculture), 60 Mm^3/y compared to the natural recharge of approximately 25 Mm^3/yr. Additional resources such as reusing of waste water is needed by 2020.

Water Resources Strategies

Based on the above analyses there is a disconnect between the water resources availability and the water requirements. Several strategies are proposed to alleviate the situation, agricultural water use is expected to become more efficient (10% reduction of water use), transfer from the aquifer to Djerba/Zarzis and the tourism is reduced to zero in the final period. In addition, more sustainable groundwater use is incorporated by restricting the groundwater abstraction rates. Finally, reuse of domestic waste water is promoted to augment supply to the agricultural sector.

The WEAP model results show that to be able to sustain the growth in the Tourism and Djerba/Zarzis, the capacity of the desalination plants will have to be increased substantially. To reach acceptable reliability levels of more than 80% the capacity of the desalination plants will have to be triple the currently planned desalination plant by 2050. In addition, constraining the groundwater pumping does alleviate the pressure on the groundwater resources, however the supply to the users dependent on the groundwater resources (agriculture, other domestic use) is less and more shortages are experienced (Figure 6). Reusing of 10% of the waste water from the domestic sector increases the reliability of supply to the public agricultural sector (Figure 6).

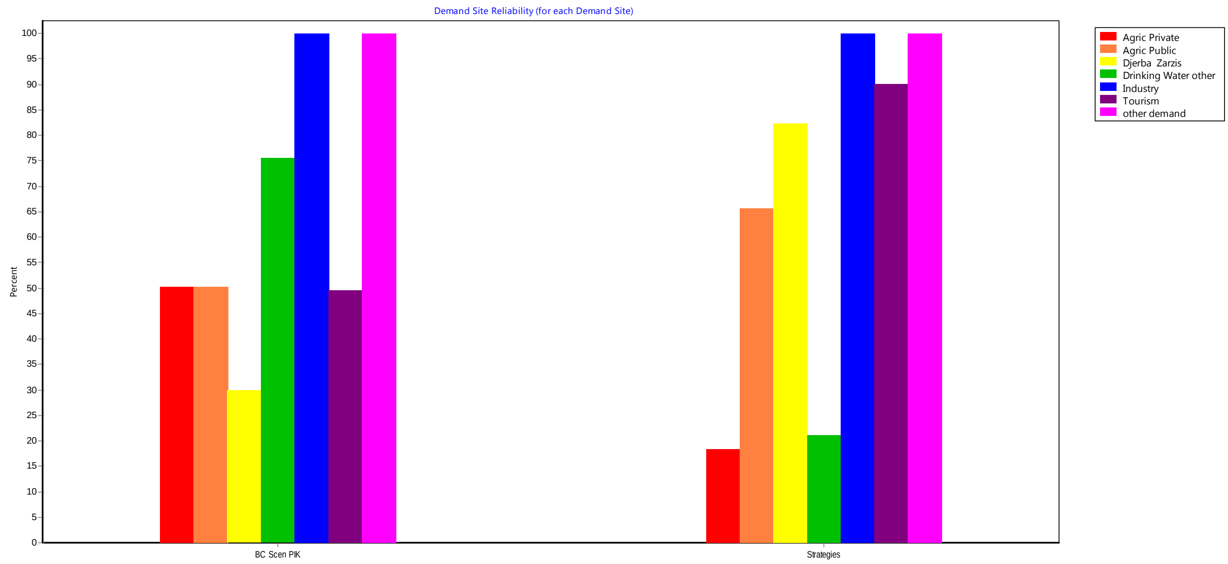

Figure 6. reliability of supply to the different users

Climate change impacts

The final scenario was also tested under different CC scenarios (RCP26 and RCP85). The established link between rainfall and groundwater recharge was use to incorporate the climate change scenarios as provided by PIK. The rainfall inputs are the following, average of the 5 GCM models (GFDL, HadGEM2, IPSL, MIROC, NorESM), key indicators are provided in the table:

Table 10 natural recharge time series used in the WEAP model (CC projections and calculated recharge estimates)

	Time period	**Average annual rainfall**	**Average annual recharge (l/s)**	
		mm/year	Zeus Koutine	GresTrias
Historical	1970-1999	185	329	142
RCP 26	2010-2029	178	315	137
RCP 85	2010-2029	171	304	131

The model currently focuses on a 20 year projection window (till 2030), in line with the short term projection of the INRM plans in the region. If there is time and resources available this can be expanded to 2050, updating the rainfall and other demands to the projections up to 2050. In addition, projected developments in the basin (eg large scale up scaling of rainwater harvesting technologies, such as Jessour and Tabia), can affect the percentage of rainfall recharging the aquifers, this is currently not include in the model.

CONCLUSIONS

The model results show that although the scenarios predict a reduction in rainfall (4-8%) and therefore a reduction in annual recharge, this is insignificant compared to the impact of the development scenarios (which predict a tripling of the total water demands). In addition, the constraining of the groundwater withdrawal from the aquifers reduces the influence of the rainfall on the water allocation. The climate change projections aggravate an existing fragile situation.

ACKNOWLEDGEMENTS

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