United Nations Nations Unies

Assesses the impacts of climate change on groundwater resource use and availability in the Eocene Aquifer in Palestine

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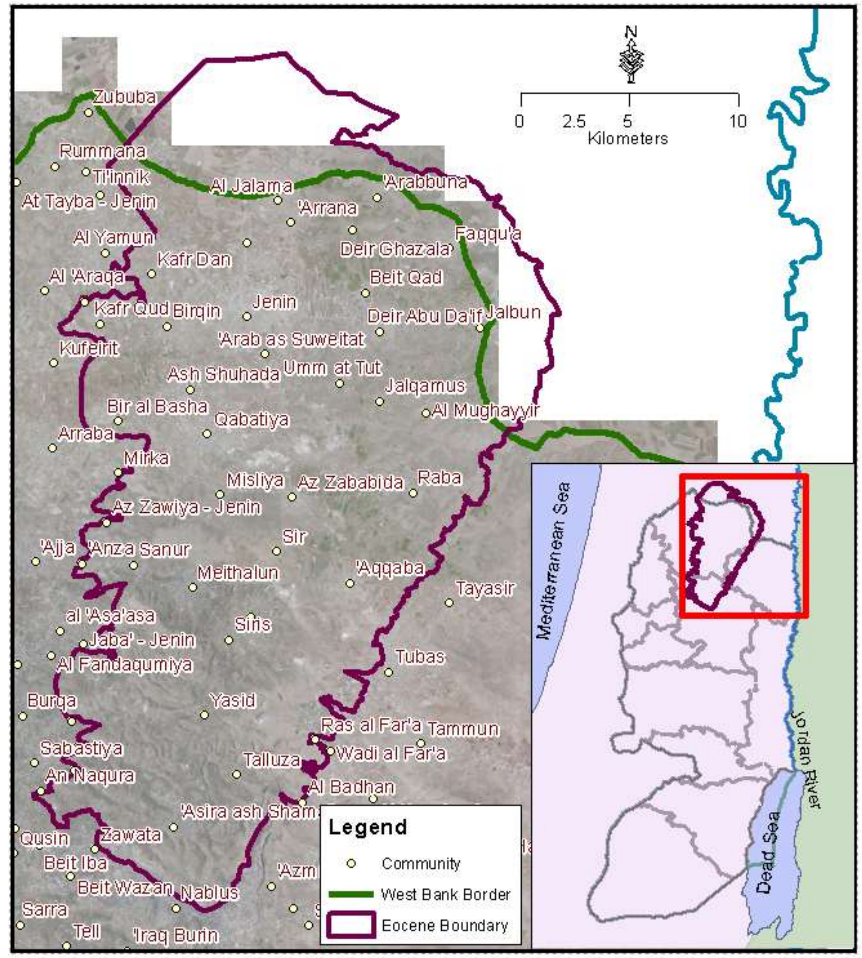
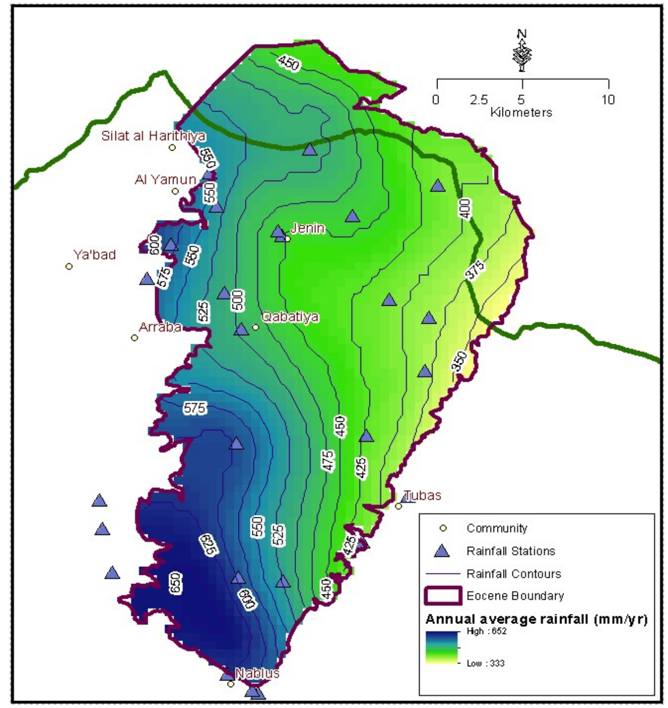
Study Area: Eocene Aquifer

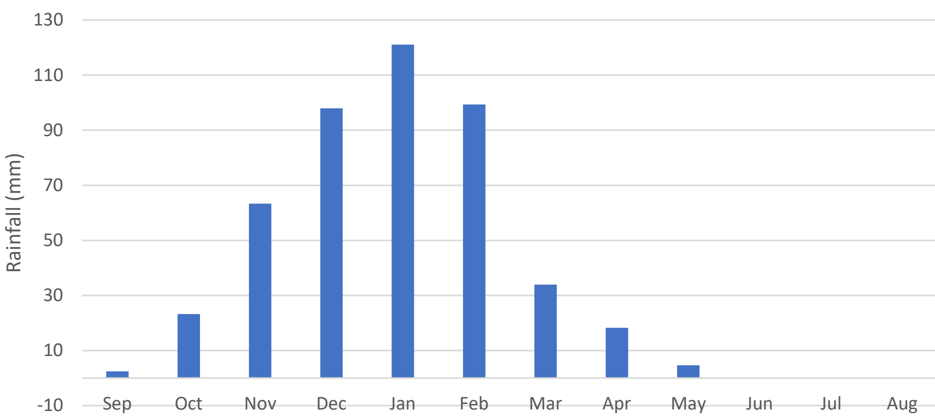
- Location: Northern part of the West Bank and extend to the north of the Green Line (Armistice Line).
- Area: 543 km^2, 459 (84.5%) of which is located within the boundary of the West Bank
- Population: high populated with more than 220,000 inhabitants living in 57 communities (PWA database 2020).
- Communities are located in three governorates Nablus, Jenin and Tubas.
- Agriculture is common in all communities and the type of agriculture (irrigated or rainfed)
- The main source of water is groundwater from wells owned by the farmer or water purchased from wells owned by other farmers in the area.



Climate Characteristics (Precipitation)

- 26 rainfall stations
- The long-term annual average rainfall ranges between 650 mm/year in the south-west to 330 mm/year in the north-east, with an annual average of 463 mm/year. (2008-2019)
- rainfall occurs between November and March, during October and April, precipitation usually is very low, while in May and September rainfall are rare.
- the rainfall distribution is varying from year to year in terms of rainfall quantity, intensity, frequency and number of storms.





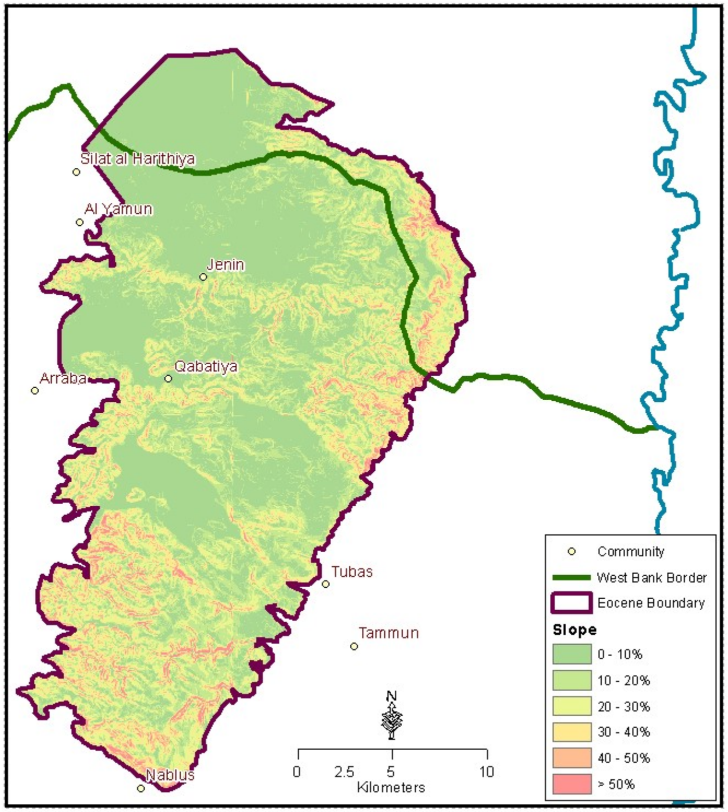
Item		Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Total
Total Monthly Rainfall (mm)	Avg	3	23	63	98	121	99	34	18	5	0	0	0	464
	Max	21	60	222	184	267	215	93	61	23	0	0	0	na
	MIN	0	0	0	21	7	6	4	0	0	0	0	0	na
	SD	6	21	66	56	79	61	27	22	7	0	0	0	
	%	0.5%	5.0%	13.6%	21.1%	26.1%	21.4%	7.3%	3.9%	1.0%	0.0%	0.0%	0.0%	100%

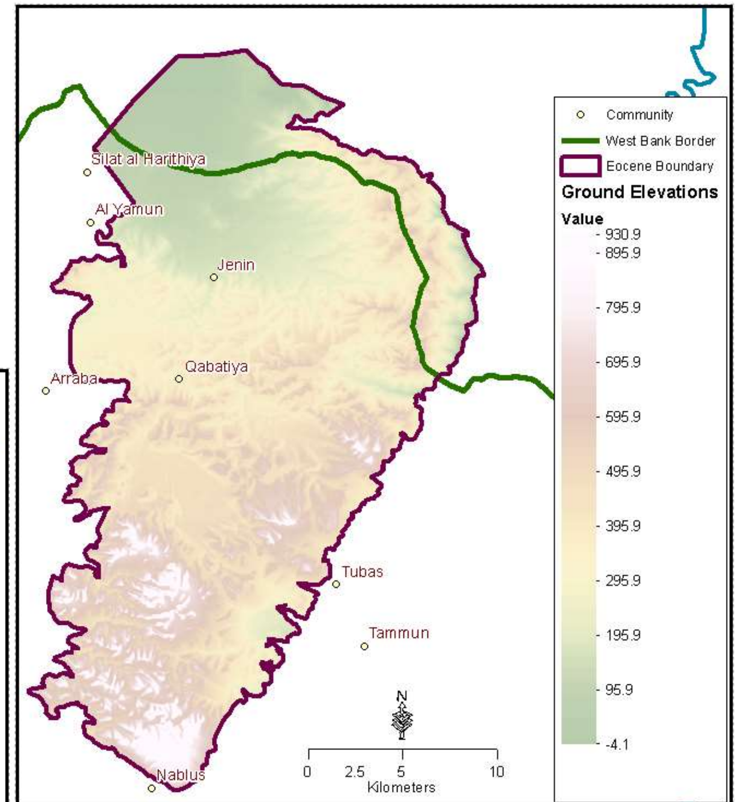
Physical Characteristics (Topography)

- Characterized by high slopes in the south and north-East sides to gentle slopes in the northwestern side.

- The elevation ranges from 931 meter above sea level in the southern side to 400 meter above sea level in the north-eastern side, and then declines to less than 100 meter above sea level in the south.

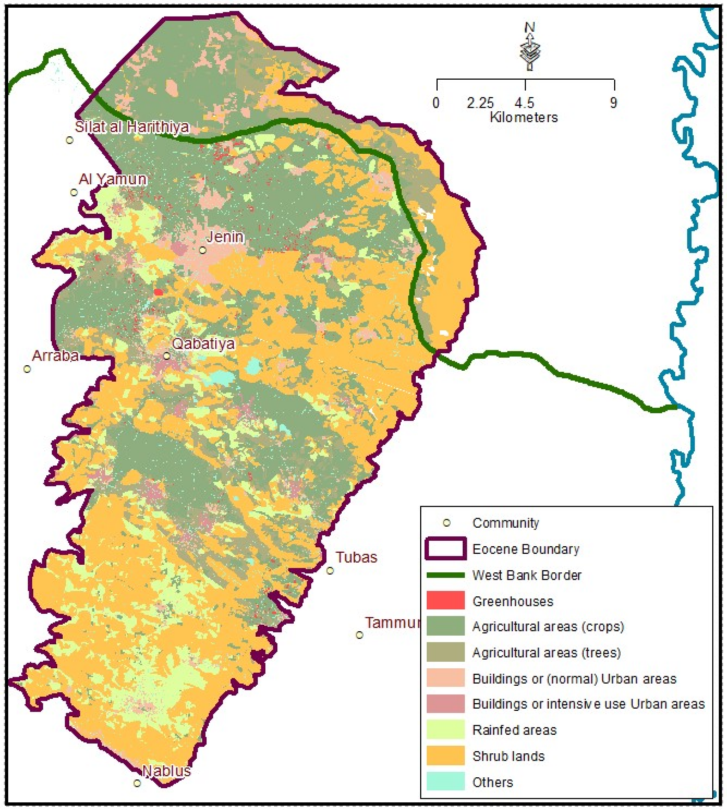
- Within the boundary of the Eocene aquifer, there are many flat areas classified as fertile such as Marj-Sanour.





Physical Characteristics (Land use)

- Classified into eight types
- Almost 50% of the total area (within the boundary of the West Bank) is classified as agricultural areas concentrated into 4-5 clusters.
- Noting that, not all agricultural areas are irrigated due the limited sources of water.
- Outside the boundary of the West Bank, agricultural areas and shrubs are the most dominants land use types (i.e., 94% of the total areas while urban and other types are limited to 6% only).



Inflows

- Inflow to Eocene Aquifer is limited to Recharge.
- <3% of recharge generated from urban and agricultural systems, while the remaining recharge generated from precipitation.
- Recharge from Precipitation can be estimated based in two methods:
  - Percentage of annual rainfall (Weiss et. al, 2007).

$$Rc = \begin{Bmatrix} 0.45(Rf - 180) & when & Rf < 600mm \\ 0.88(Rf - 410) & when & 600 < Rf < 1000mm \\ 0.97(Rf - 463) & when & Rf > 1000mm \end{Bmatrix}$$

Where:

Rc: annual recharge in mm

Rf: annual rainfall in mm

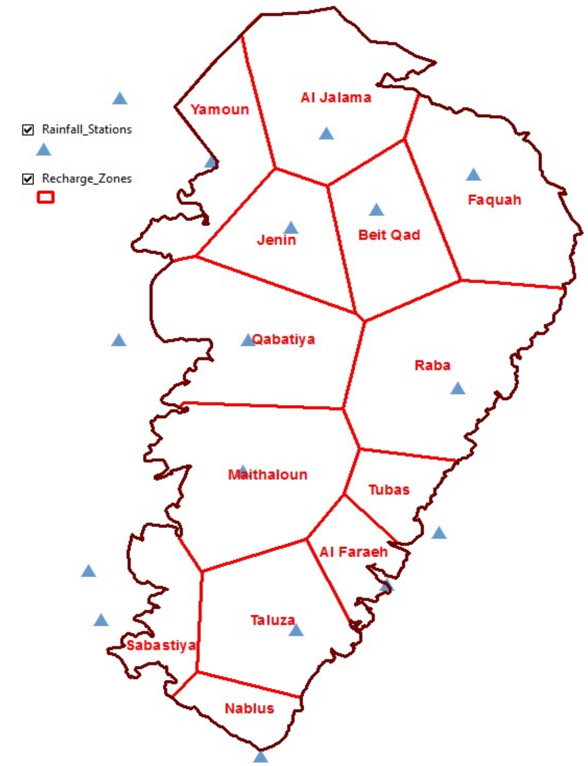
  - Based on water fluctuation technique: (Abu Sadah and Sauter 2011 and 2017)

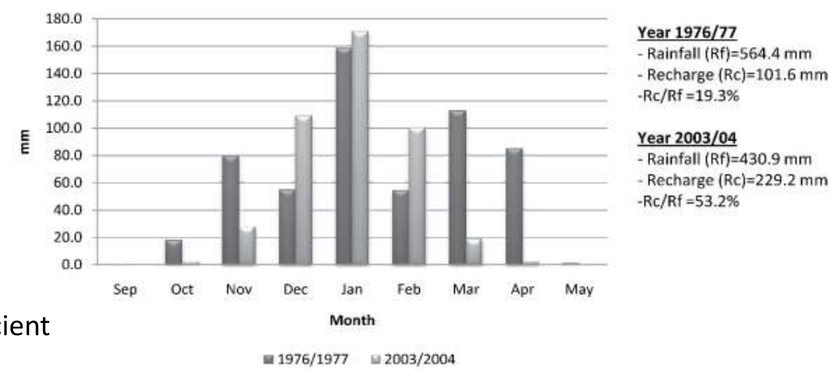
$$Rcof = \begin{bmatrix} 0.425 \times N + 0.105 & N \geq 0.2 \\ 0.95 \times N & N < 0.2 \end{bmatrix}$$

Where:

N: normality value

Rcof: annual recharge coefficient

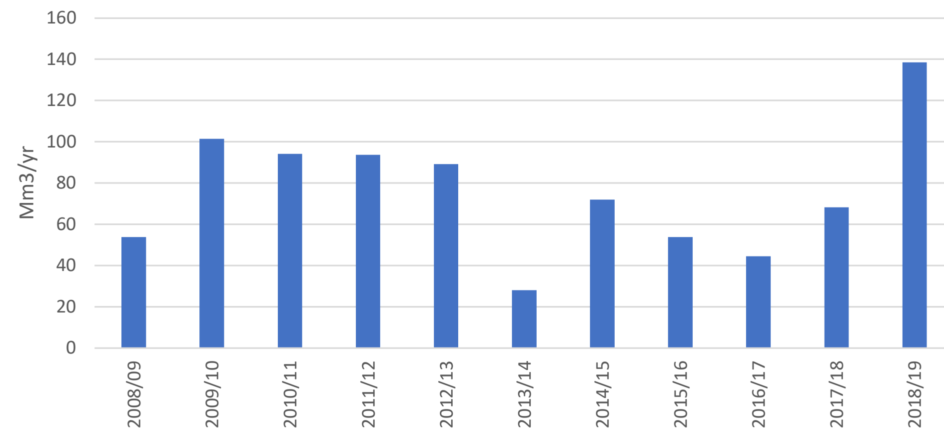


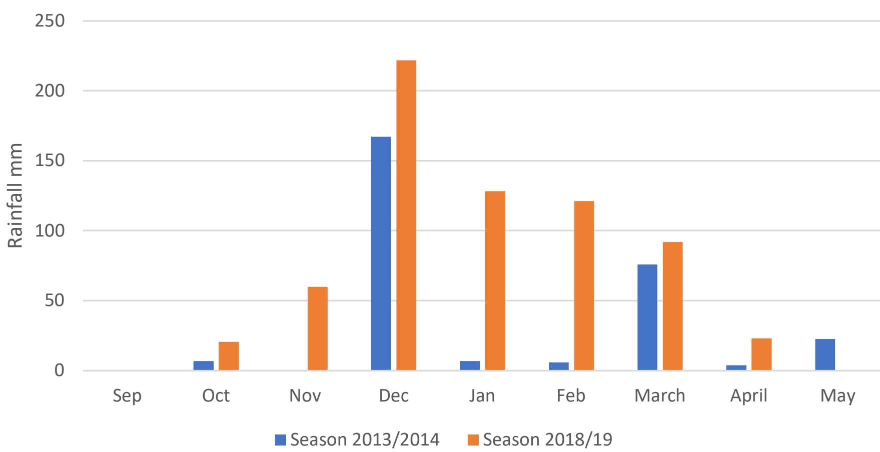


Inflows (2008 -2019)

- The average recharge coefficient was 29% (minimum is 16% while the maximum coefficient is 41%).

- The annual estimated recharge from Precipitation ranges between 28 Mm3 in 2013/14 to 138 Mm3 in 2018/19 with an average of 76 Mm3/yr.





Recharge Component	Minimum Estimated Value (Mm3/yr)	Maximum Estimated Value (Mm3/yr)
Urban Recharge: Wastewater from un-isolated cesspits	0.49	0.88
Urban Recharge: Wastewater dumping in wadies	0.05	0.20
Urban Recharge: Network losses	0.34	0.91
Recharge from Agriculture	0	0.28
Recharge from Rainfall	28	138
Totals	**28.88**	**139.99**

Outflows (2008 -2019)

- There are three types of outflows of the Eocene Aquifer system; wells, springs and lateral flows.

- The outflows for agricultural use were estimated based on the irrigated areas and the agricultural survey conducted within the frame of this project, while, the outflows for domestic use were taken from the PWA database.

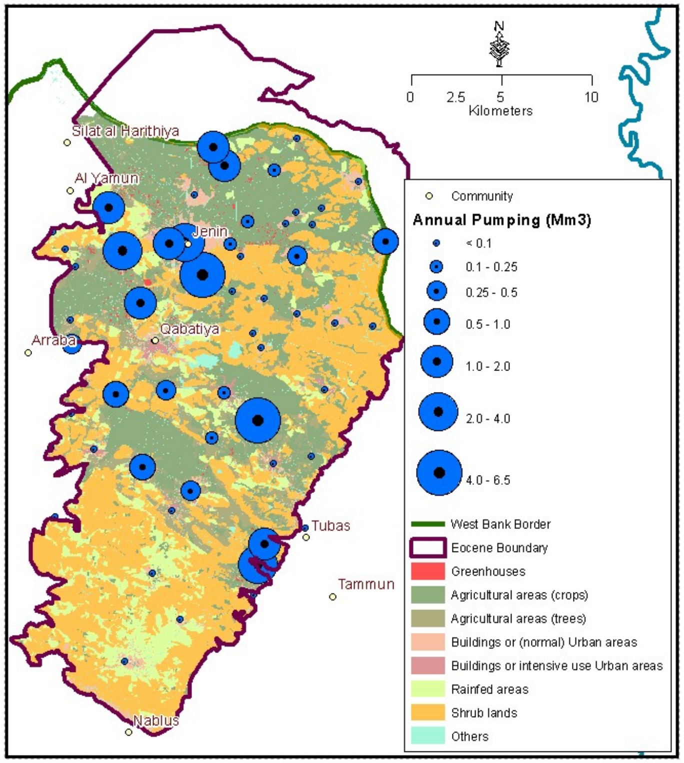
- The irrigated area within the Eocene boundary was taken from the agricultural statistics by MOA in year 2018 and concluded that the total irrigated areas were 40.5 km^2.

- The total agricultural outflow (within the West Bank) was estimated within the range of 31.8 Mm^3/yr in year 2018).

- The total annual pumping from domestic wells within the West Bank was 0.21 Mm2/yr,

- The Israeli abstraction was estimated based on historical data within the range of 5-6 Mm3/yr

- In total, 35-40 mm3/yr was pumped during period 2008-2019.



Model Development (2008 -2019)

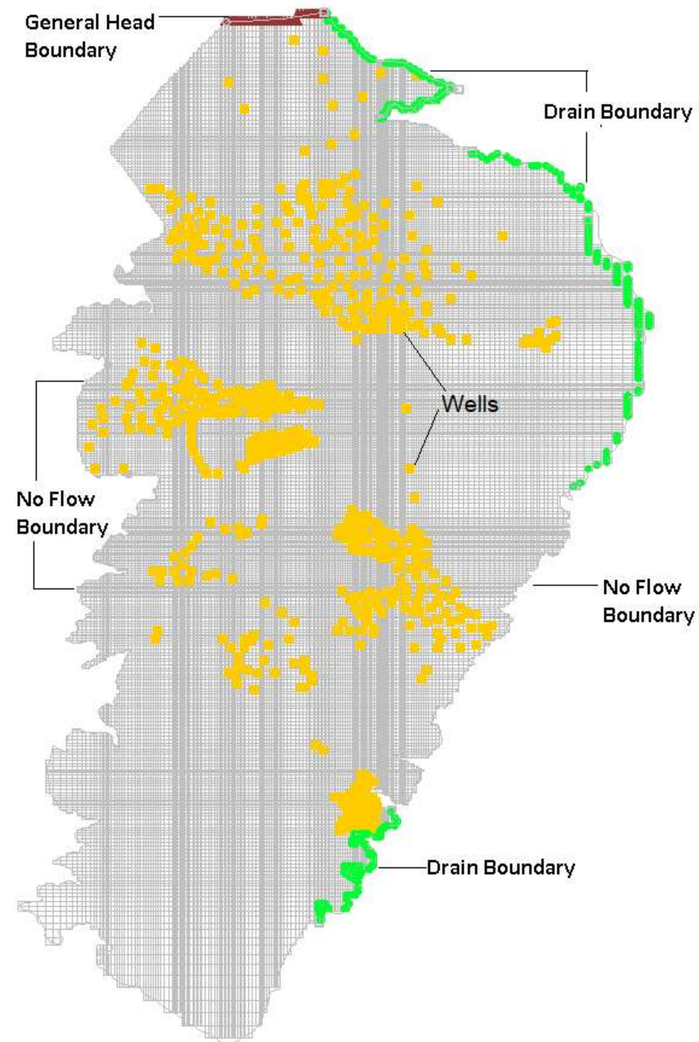
- The boundaries of the Eocene aquifer can be summarized as follows:

  1. No flow boundary: no flow is possible, meaning that the Eocene aquifer and other neighboring aquifer systems are totally disconnected.

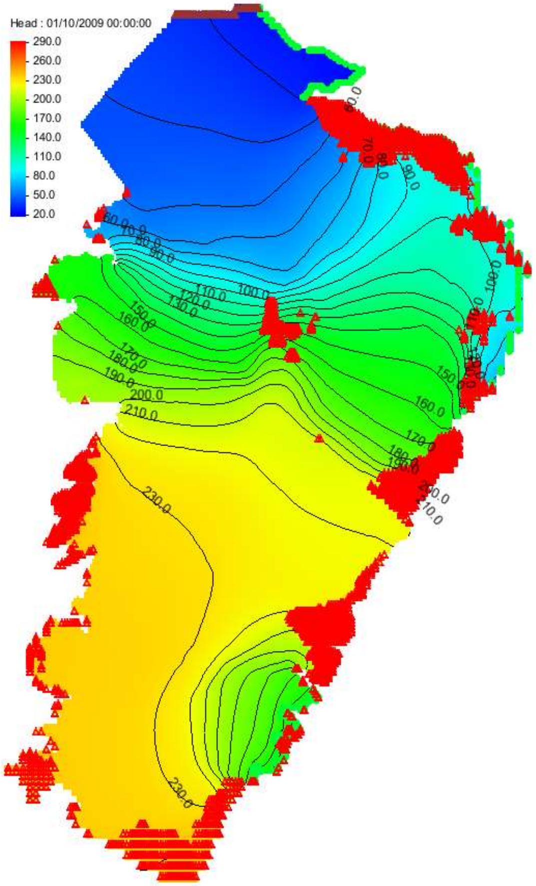
  2. General head boundary: water exchange between two aquifer systems depends on the water level in the two aquifer systems,

  3. Drain flow boundary: this boundary could be a set of springs or seepage zones where outflow from the aquifer will occur as a lateral flow.

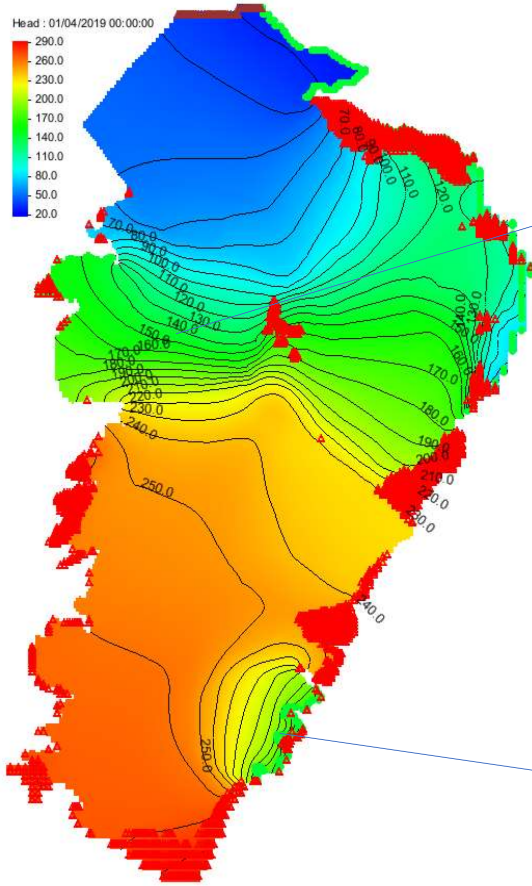
  4. Wells: represent the water abstractions



Model Results (2008 -2019) - Heads

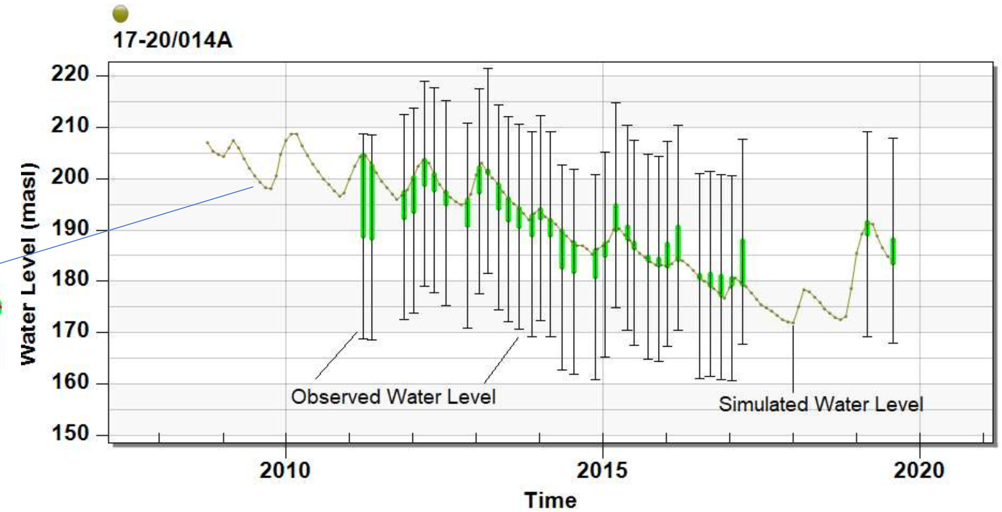


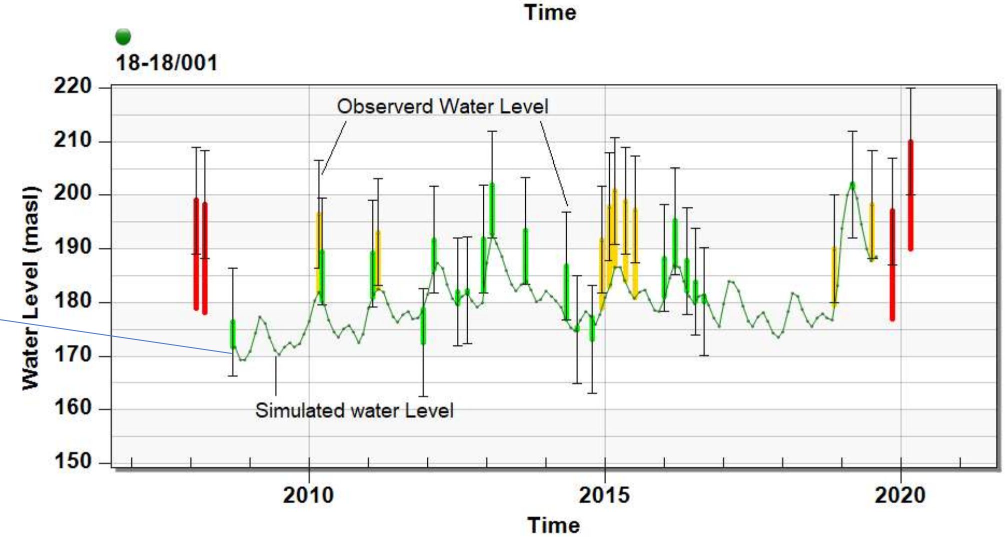
Summer 2009



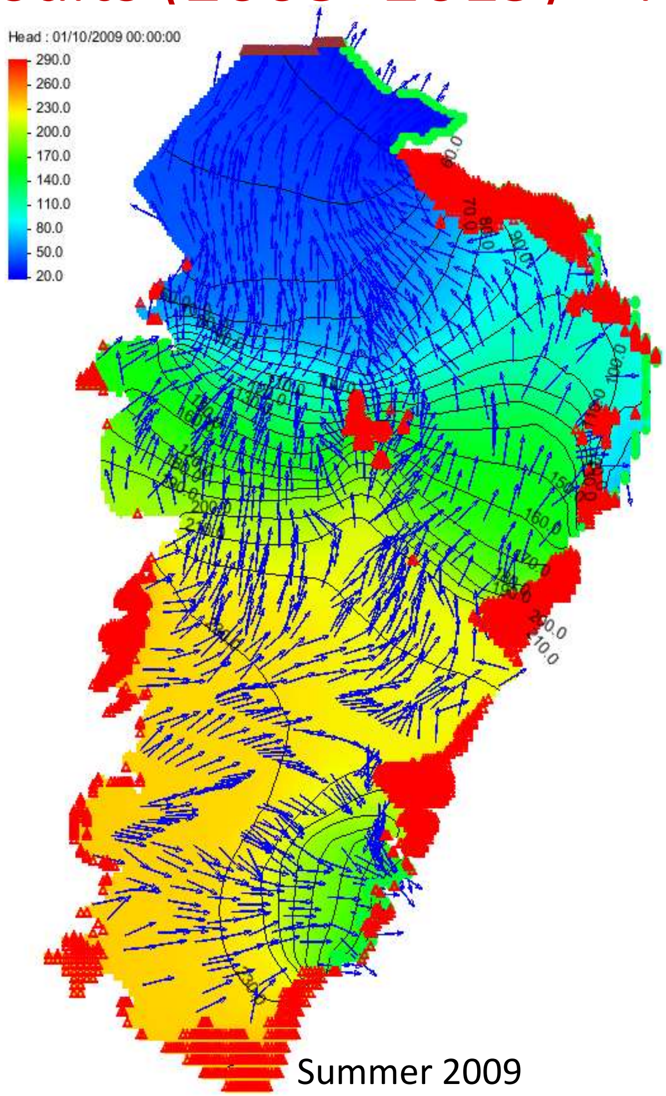
Winter 2019

* All red cells are dry.

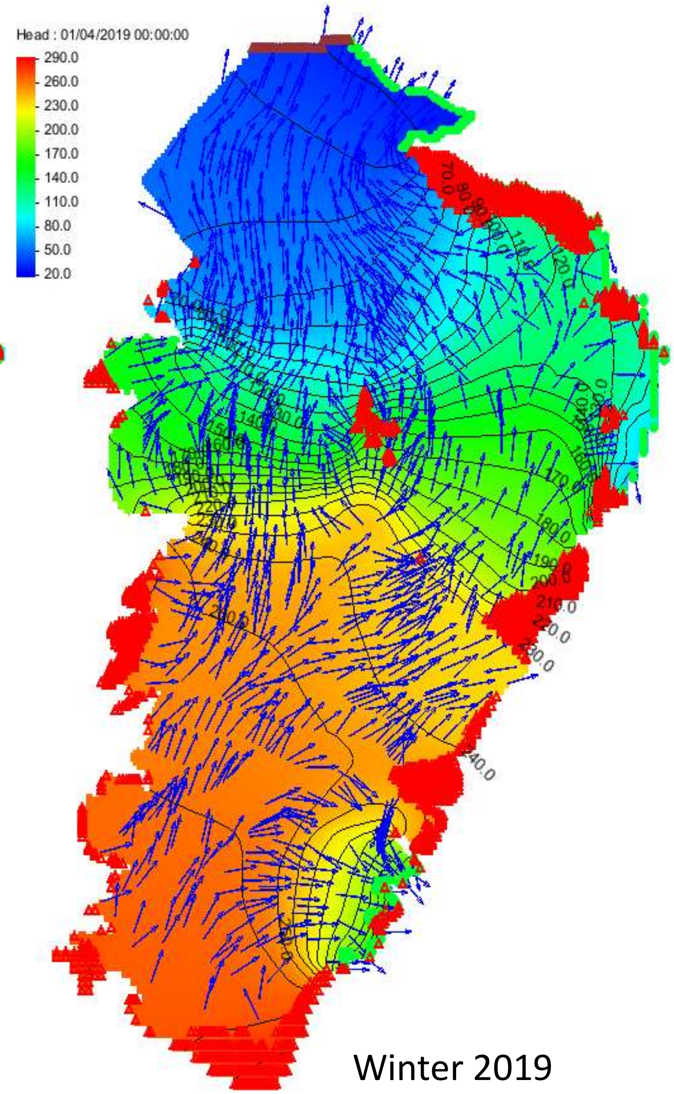




Model Results (2008 -2019) – Flow Directions



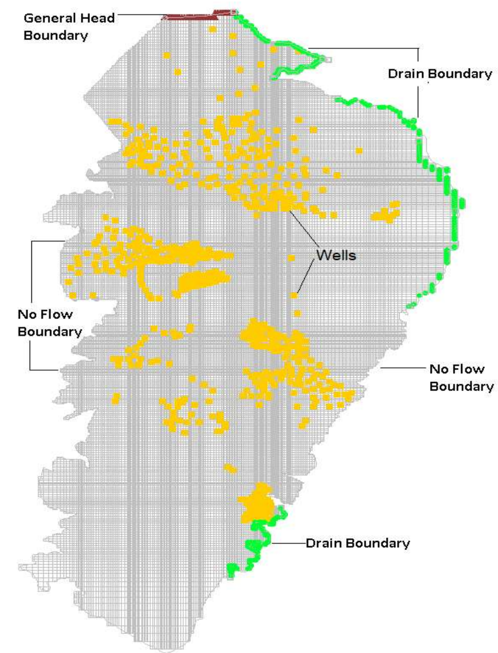
Summer 2009

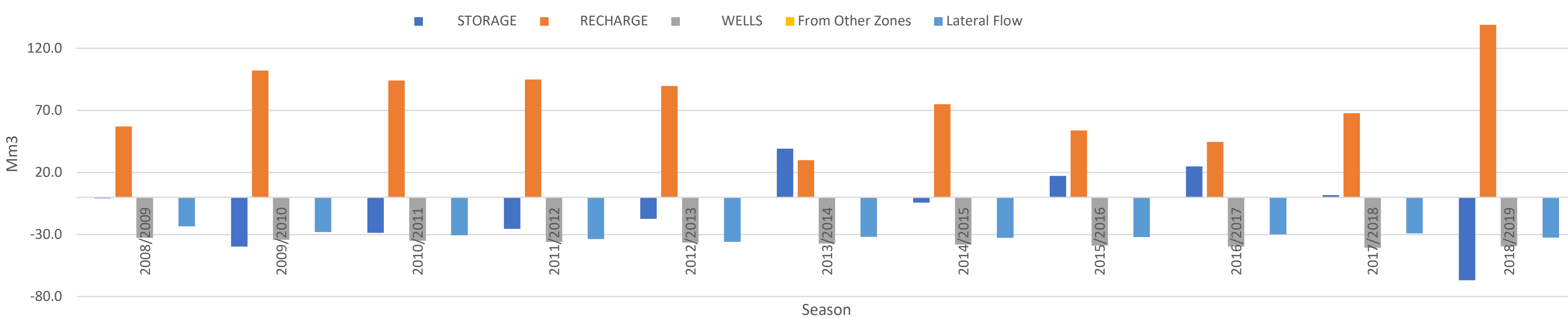


Winter 2019

Model Results (2008 -2019) – Budget

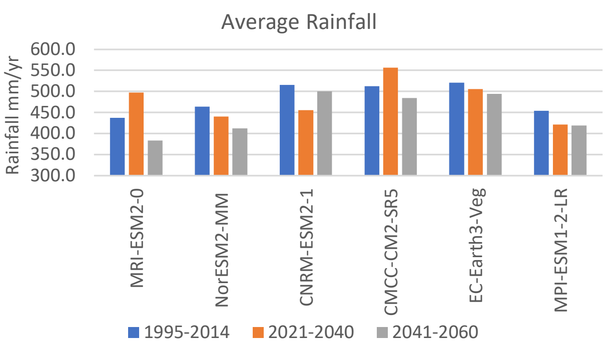
	Inflow	Outflow			Storage	Water exchange between areas inside and outside the West Bank
		WELLS (Pumping)	Lateral Flow (East: Al Faraah)	Lateral Flow (North and East North)		
	Mm3/yr					
Inside the West Bank	66	-28.9	-12.4	-1.1	-7.7	-17.4
Outside the West Bank	11.1	-8.2	0	-16.9	-1.9	17.4
Totals	**77.1**	**-37.1**	**-12.4**	**-18.0**	**-9.6**	**0**

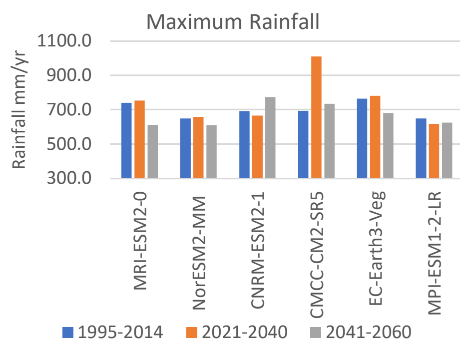


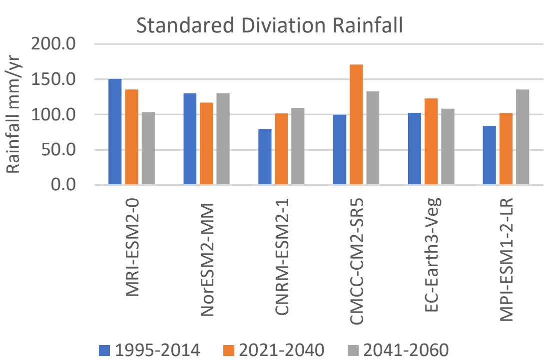


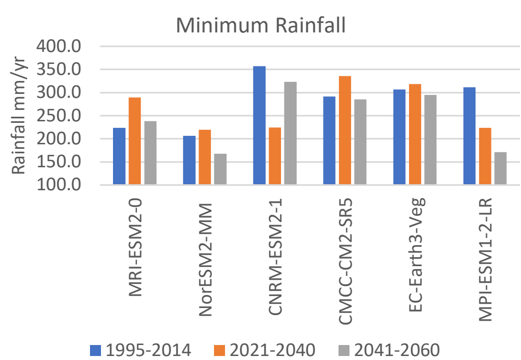
Climate Scenarios (2021 - 2060)

- 6 Precipitation Scenarios
- Reference Horizon: 1995-2014
- Analysed Horizons 2021-2040 and 2041-2060
- Pumping Scenario: No change in Pumping rates after 2019





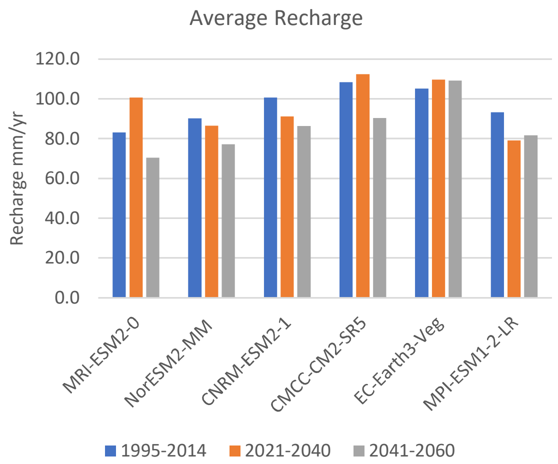


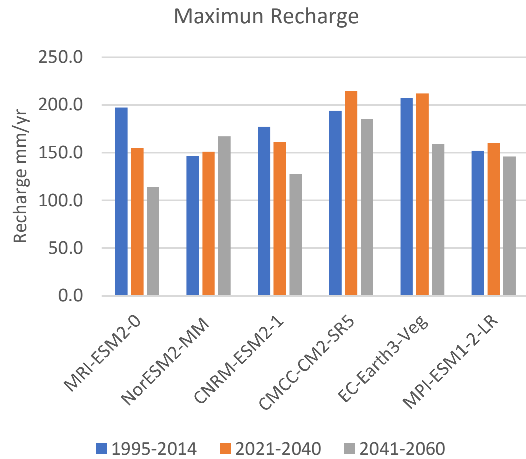


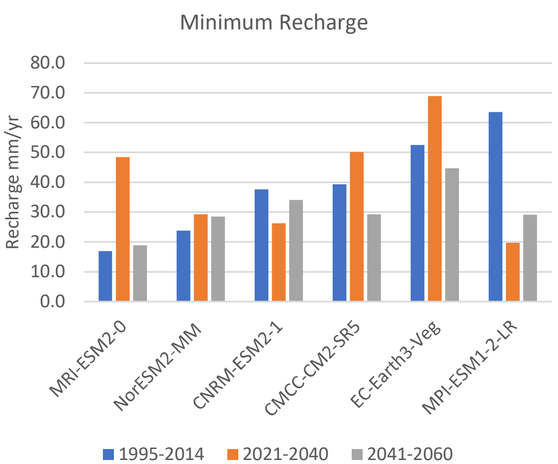
Scenario		1995-2014	2021-2040	2041-2060	2021-2040	2041-2060
		mm/yr			Change (%)	
MRI-ESM2-0	Averge	437.0	497.1	383.4	13.8%	-12.3%
Japan	Max	740.1	753.0	611.9	1.8%	-17.3%
	Min	223.8	289.6	238.2	29.4%	6.5%
	STD	150.7	135.7	103.4	-10.0%	-31.4%
NorESM2-MM	Averge	463.8	439.8	412.2	-5.2%	-11.1%
Norway	Max	648.6	658.2	609.1	1.5%	-6.1%
	Min	206.6	219.2	167.6	6.1%	-18.9%
	STD	130.3	116.9	130.1	-10.3%	-0.2%
CNRM-ESM2-1	Averge	515.1	455.6	500.2	-11.6%	-2.9%
France	Max	691.8	665.3	774.2	-3.8%	11.9%
	Min	356.9	224.6	323.1	-37.1%	-9.5%
	STD	79.2	101.6	109.1	28.4%	37.8%
CMCC-CM2-SR5	Averge	512.0	556.4	484.1	8.7%	-5.5%
Euro-Mediterranean	Max	692.5	1009.9	734.7	45.8%	6.1%
	Min	291.2	335.6	284.9	15.2%	-2.2%
	STD	99.7	171.0	132.9	71.5%	33.3%
EC-Earth3-Veg	Averge	520.5	505.7	494.2	-2.8%	-5.0%
European	Max	764.1	780.7	680.4	2.2%	-10.9%
	Min	306.3	318.0	294.8	3.8%	-3.7%
	STD	102.4	122.7	108.5	19.8%	6.0%
MPI-ESM1-2-LR	Averge	453.9	421.2	418.8	-7.2%	-7.7%
Germany	Max	649.2	618.1	625.3	-4.8%	-3.7%
	Min	311.8	223.8	171.3	-28.2%	-45.1%
	STD	84.1	101.8	135.4	21.1%	61.0%

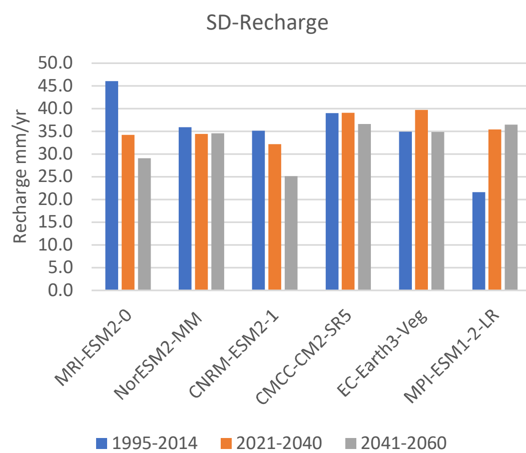
Recharge

Change compared with Reference Horizon (1994-2015)





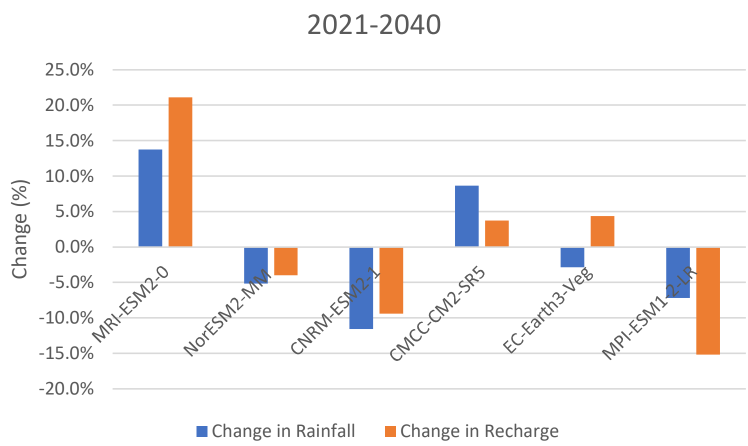


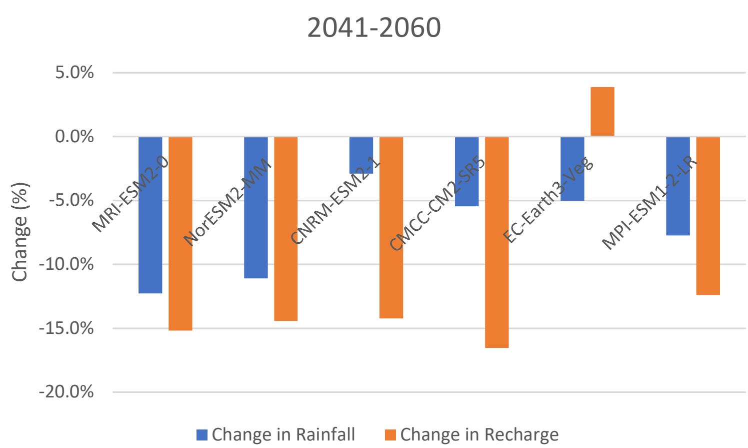


Scenario		1995-2014	2021-2040	2041-2060	2021-2040	2041-2060
		Mm3/yr			Change (%)	
MRI-ESM2-0	Averge	83.0	100.6	70.4	21.1%	-15.2%
Japan	Max	197.1	154.7	114.2	-21.5%	-42.1%
	Min	16.9	48.4	18.8	186.8%	11.5%
	STD	46.0	34.2	29.0	-25.6%	-36.9%
NorESM2-MM	Averge	90.1	86.5	77.1	-4.0%	-14.4%
Norway	Max	146.6	151.1	167.1	3.1%	14.0%
	Min	23.7	29.2	28.5	23.0%	19.9%
	STD	35.9	34.4	34.6	-4.2%	-3.7%
CNRM-ESM2-1	Averge	100.7	91.2	86.4	-9.4%	-14.2%
France	Max	176.9	161.0	127.7	-9.0%	-27.9%
	Min	37.6	26.3	34.0	-30.1%	-9.5%
	STD	35.1	32.2	25.1	-8.3%	-28.5%
CMCC-CM2-SR5	Averge	108.3	112.3	90.4	3.7%	-16.5%
Euro-Mediterranean	Max	193.9	214.4	185.2	10.6%	-4.5%
	Min	39.4	50.1	29.3	27.3%	-25.7%
	STD	39.0	39.1	36.6	0.3%	-6.1%
EC-Earth3-Veg	Averge	105.1	109.7	109.2	4.4%	3.9%
European	Max	207.2	211.8	158.8	2.2%	-23.4%
	Min	52.5	68.9	44.7	31.3%	-14.8%
	STD	34.9	39.7	34.9	13.7%	-0.1%
MPI-ESM1-2-LR	Averge	93.2	79.0	81.6	-15.2%	-12.4%
Germany	Max	152.0	159.8	145.7	5.2%	-4.1%
	Min	63.5	19.7	29.1	-69.0%	-54.2%
	STD	21.6	35.4	36.4	64.0%	68.9%

Precipitation VS Recharge

Change compared with Reference Horizon (1994-2015)



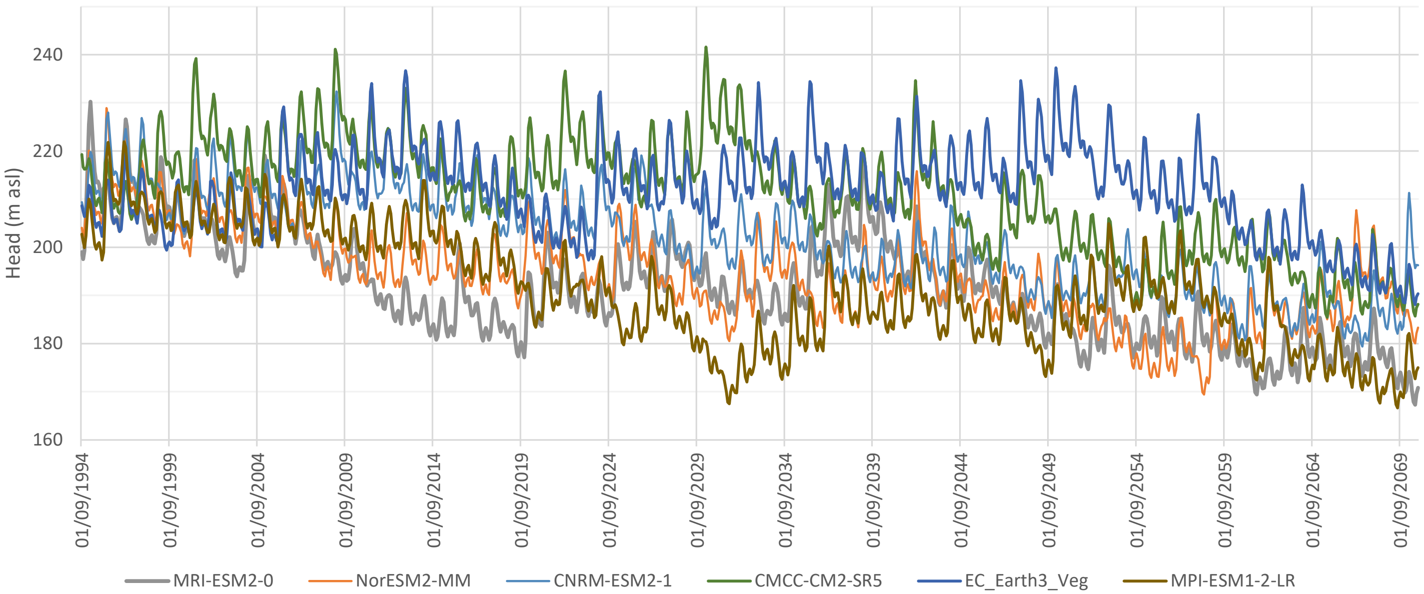


Scenario	1995-2014	2021-2040	2041-2060
	Recharge Coefficents		
MRI-ESM2-0	35.0%	37.3%	33.8%
NorESM2-MM	35.8%	36.2%	34.4%
CNRM-ESM2-1	36.0%	36.9%	31.8%
CMCC-CM2-SR5	39.0%	37.2%	34.4%
EC-Earth3-Veg	37.2%	39.9%	40.7%
MPI-ESM1-2-LR	37.8%	34.6%	35.9%

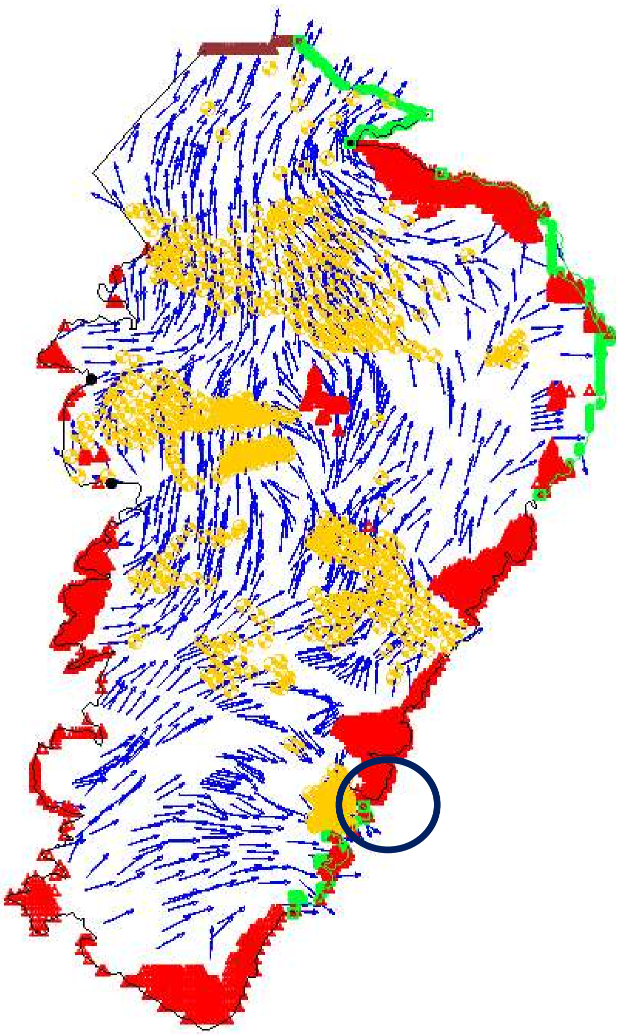
Scenario	1995-2014	2021-2040	2041-2060
	Change in Rainfall		
MRI-ESM2-0		13.8%	-12.3%
NorESM2-MM		-5.2%	-11.1%
CNRM-ESM2-1		-11.6%	-2.9%
CMCC-CM2-SR5		8.7%	-5.5%
EC-Earth3-Veg		-2.8%	-5.0%
MPI-ESM1-2-LR		-7.2%	-7.7%

Scenario	1995-2014	2021-2040	2041-2060
	Change in Recharge		
MRI-ESM2-0		21.1%	-15.2%
NorESM2-MM		-4.0%	-14.4%
CNRM-ESM2-1		-9.4%	-14.2%
CMCC-CM2-SR5		3.7%	-16.5%
EC-Earth3-Veg		4.4%	3.9%
MPI-ESM1-2-LR		-15.2%	-12.4%

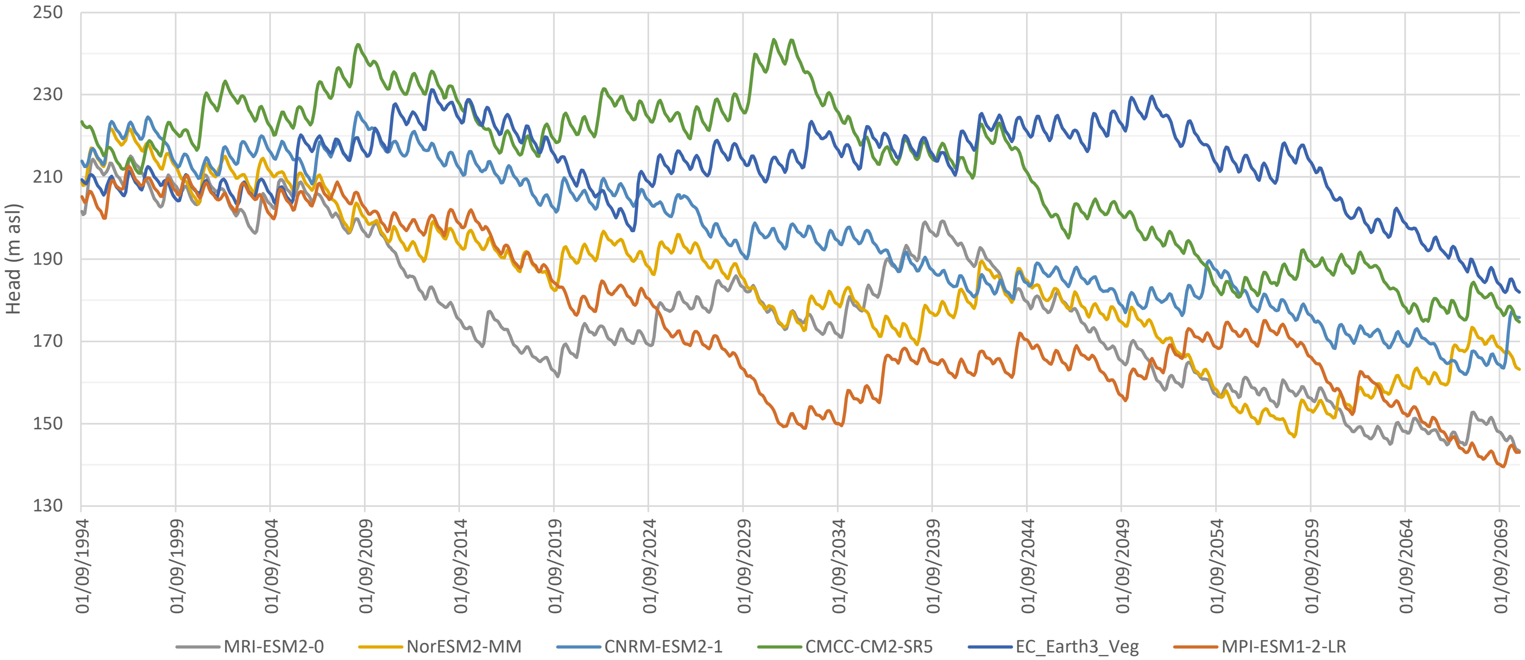
Simulated Heads: Al Faraáh Area

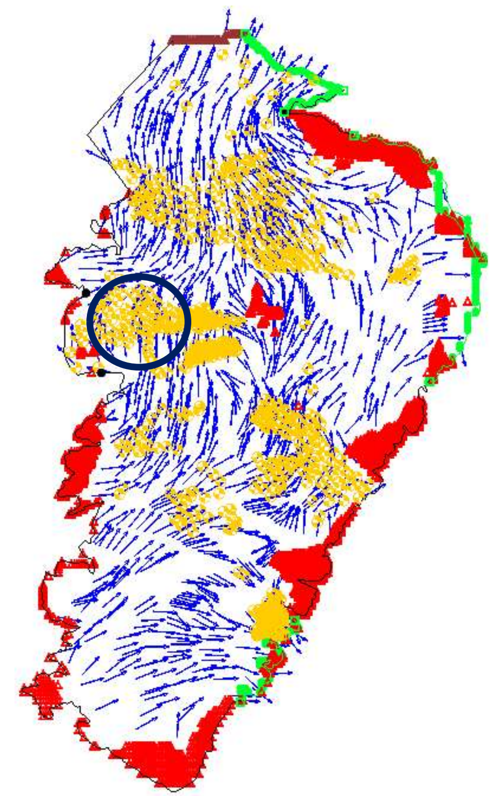


Scenario	Reference: Water Level in Sep 2014 (m)	Water Level in Sep 2040 (m)	Water Level in Sep 2060 (m)	Drawdown (m): Reference Sep 2014 Sep-40	Sep-60
MRI-ESM2-0	184.1	201.3	178.3	**-17.2**	**5.8**
NorESM2-MM	194.1	191.0	180.2	**3.1**	**13.9**
CNRM-ESM2-1	208.9	194.5	184.1	**14.4**	**24.8**
CMCC-CM2-SR5	216.6	210.2	198.0	**6.4**	**18.5**
EC_Earth3_Veg	215.5	208.9	204.0	**6.6**	**11.5**
MPI-ESM1-2-LR	203.4	184.9	180.9	**18.5**	**22.5**



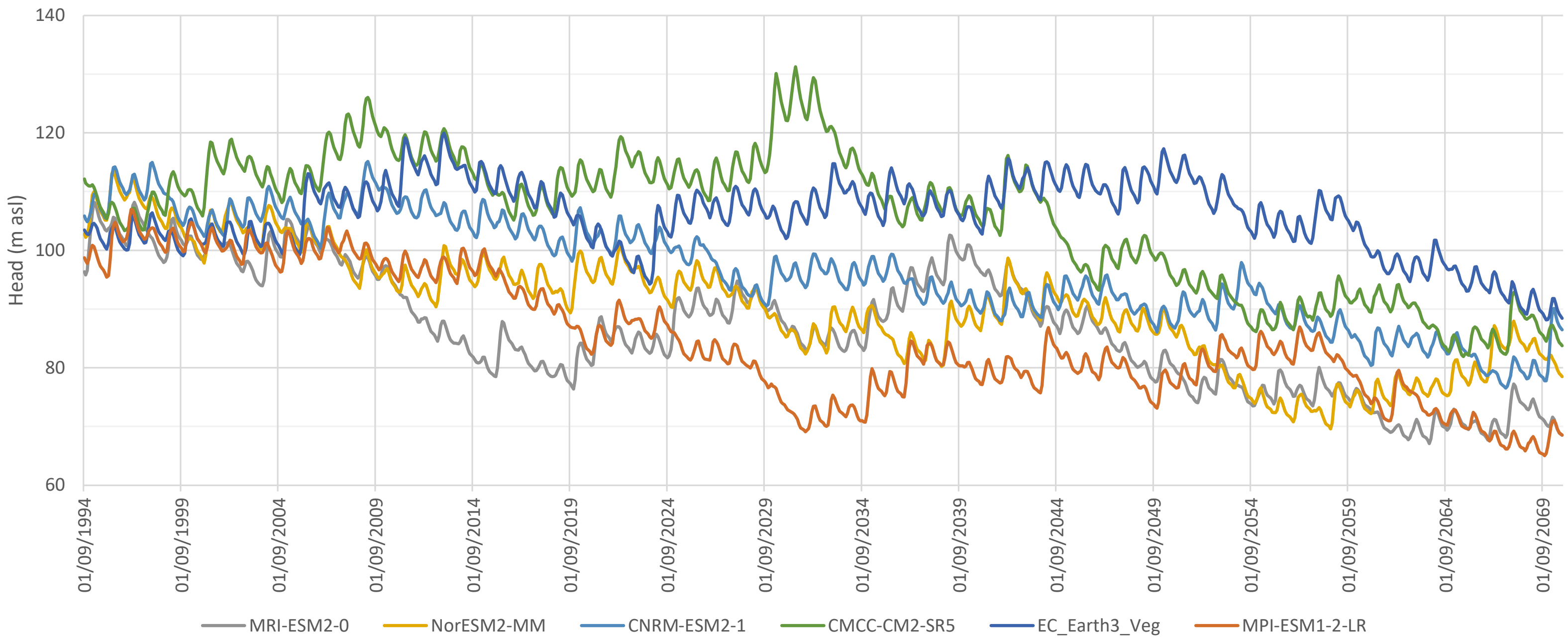
Simulated Heads: Qabatiya Area



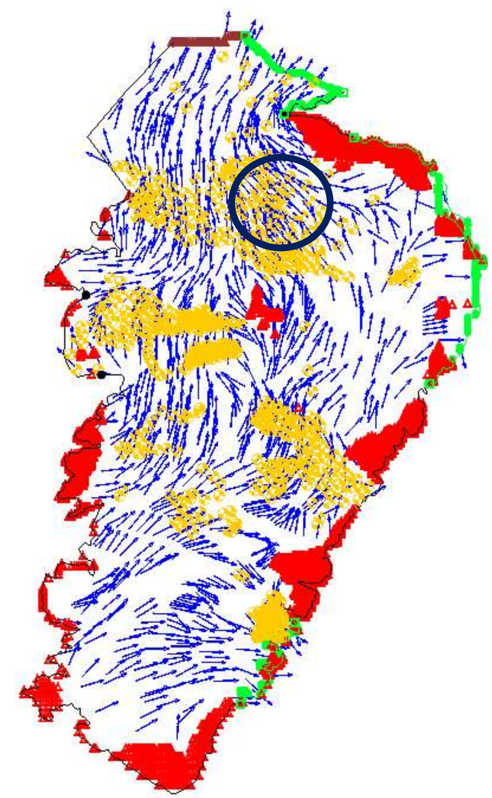


Scenario	Reference: Water Level in Sep 2014 (m)	Water Level in Sep 2040 (m)	Water Level in Sep 2060 (m)	Drawdown (m): Reference Sep 2014	
				Sep-40	Sep-60
MRI-ESM2-0	175.1	195.4	155.3	-20.3	19.8
NorESM2-MM	193.3	176.2	152.2	17.1	41.1
CNRM-ESM2-1	211.9	183.6	170.0	28.2	41.9
CMCC-CM2-SR5	227.5	213.7	187.0	13.7	40.5
EC_Earth3_Veg	223.8	211.8	206.7	11.9	17.1
MPI-ESM1-2-LR	198.5	162.1	159.7	36.3	38.8

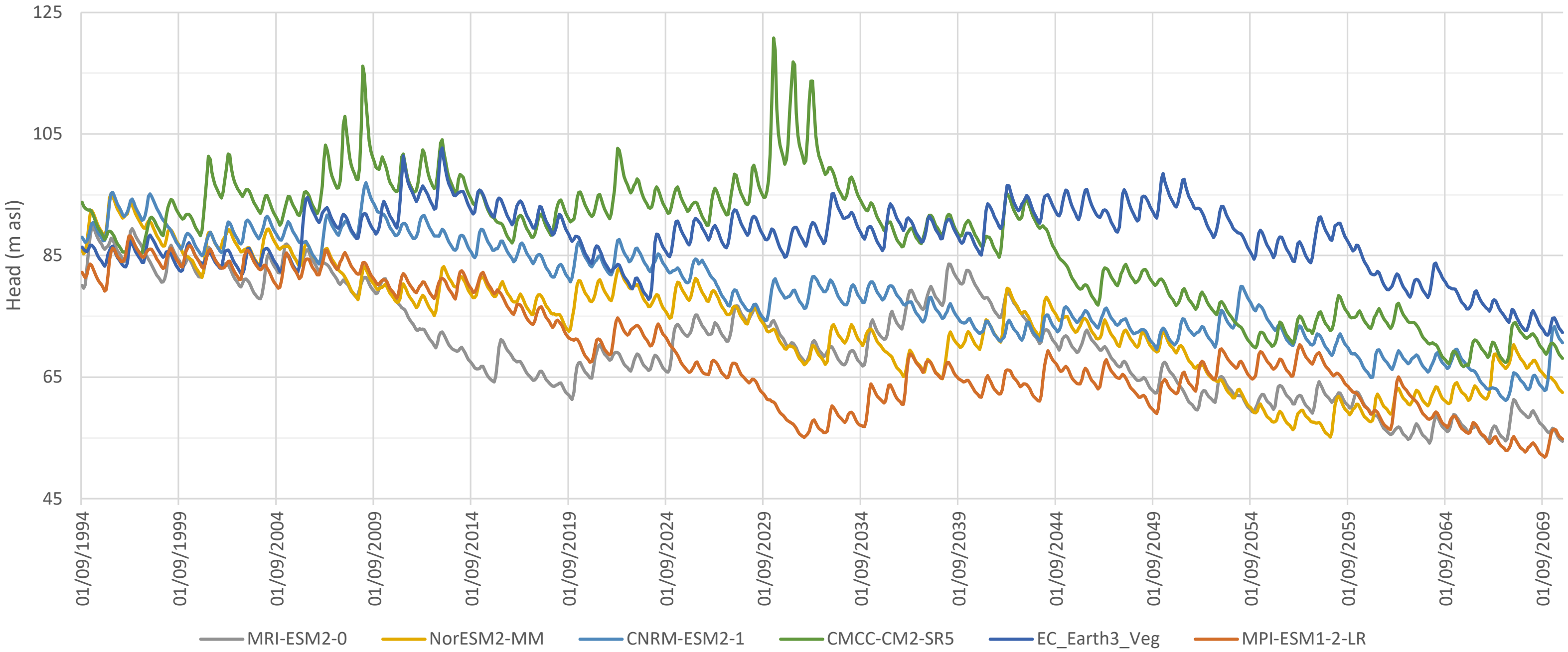
Simulated Heads: East Jenin Area



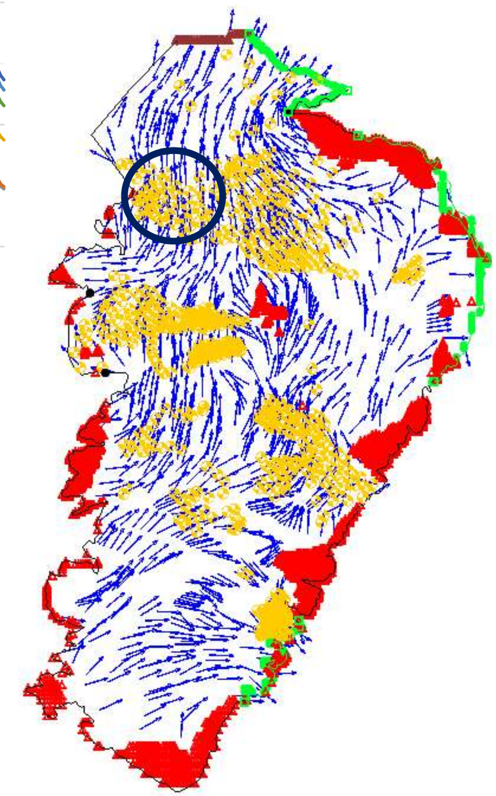
Scenario	Reference: Water Level in Sep 2014 (m)	Water Level in Sep 2040 (m)	Water Level in Sep 2060 (m)	Drawdown (m): Reference Sep 2014	
				Sep-40	Sep-60
MRI-ESM2-0	81.8	96.8	73.3	-15.0	8.5
NorESM2-MM	94.2	86.6	72.6	7.5	21.5
CNRM-ESM2-1	103.0	89.6	81.5	13.4	21.6
CMCC-CM2-SR5	112.9	105.2	90.1	7.7	22.8
EC_Earth3_Veg	110.5	103.7	100.2	6.8	10.3
MPI-ESM1-2-LR	96.3	77.7	75.0	18.6	21.3



Simulated Heads: West Jenin Area



Scenario	Reference: Water Level in Sep 2014 (m)	Water Level in Sep 2040 (m)	Water Level in Sep 2060 (m)	Drawdown (m): Reference Sep 2014	
				Sep-40	Sep-60
MRI-ESM2-0	67.3	79.4	59.8	-12.1	7.5
NorESM2-MM	78.5	69.8	58.0	8.6	20.4
CNRM-ESM2-1	85.5	72.4	65.8	13.1	19.7
CMCC-CM2-SR5	94.2	87.5	73.5	6.6	20.6
EC_Earth3_Veg	92.3	85.9	83.1	6.4	9.1
MPI-ESM1-2-LR	79.5	62.1	59.8	17.3	19.7

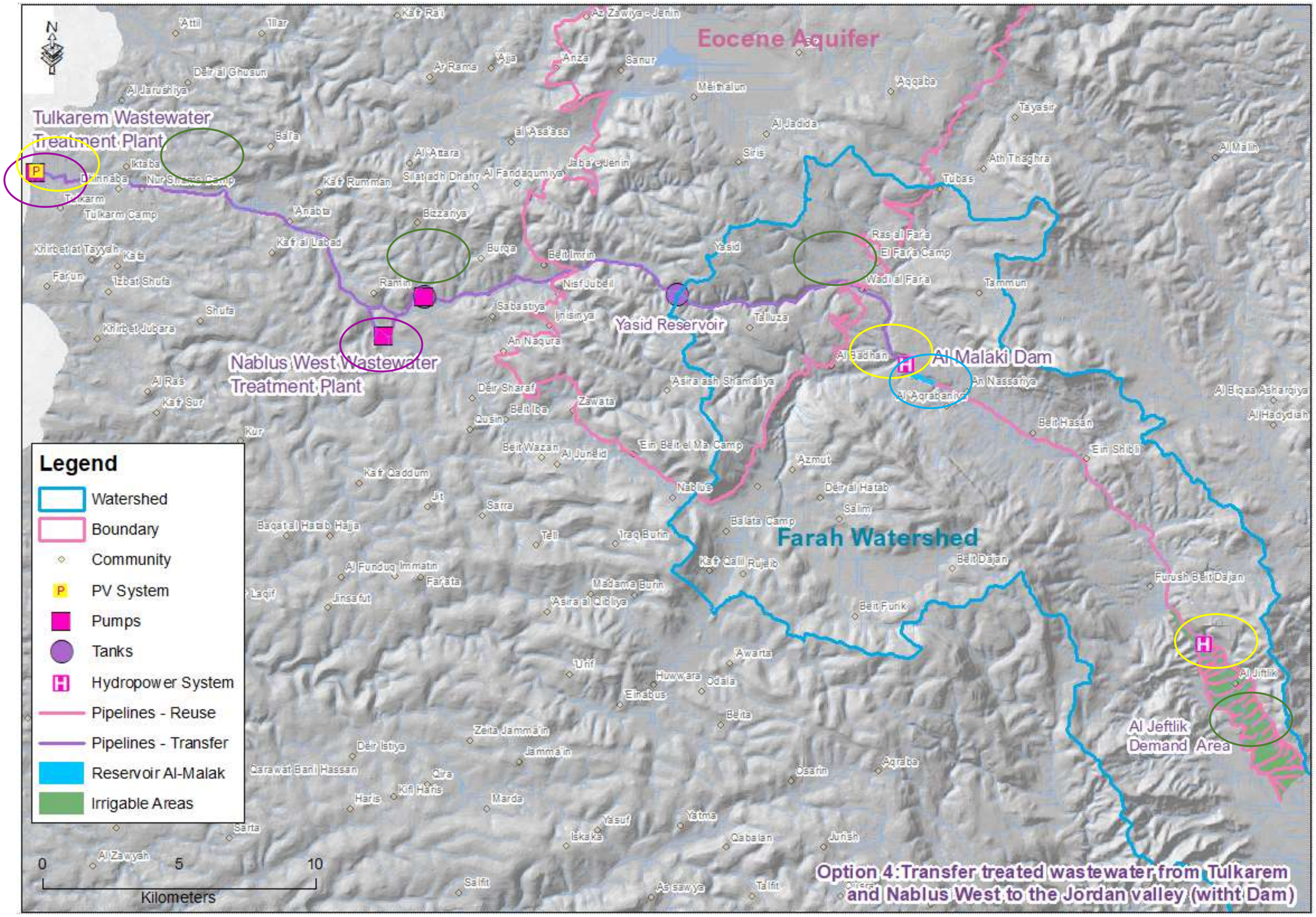


Conclusion

- Rainfall change:
  - Horizon 2021-2041: The average annual rainfall are ranging between 88.4% - 113.8% compared with the refence horizon.
  - Horizon 2041-2060: The average annual rainfall are ranging between 87.7% - 97.1% compared with the refence horizon.
- Recharge change:
  - Horizon 2021-2041: The average annual recharge are ranging between 84.8% - 121.3% compared with the refence horizon.
  - Horizon 2041-2060: The average annual recharge are ranging between 83.5% - 103.9% compared with the refence horizon.
- Drawdown:
  - Huge decline of water levels (drawdown) in Qabatiya area with drop ranges between 17-42 meter at the end of horizon 2060, less impact in Jenin and Al Faraáh Areas 6–25-meter drop.

Adaptation Measure/Integrated Solution

- Water-Energy-Food Nexus
  - WW treatment (Environment, financial, source of agricultural water)
  - Energy Production (Solar + Hydropower => Sustainability)
  - Water Harvesting (agricultural water, storage ➔ social acceptance)
  - Reuse (Food, socio-economic development, Resilience)



Discussion