Increasing Water Availability with **Managed Aquifer Recharge**

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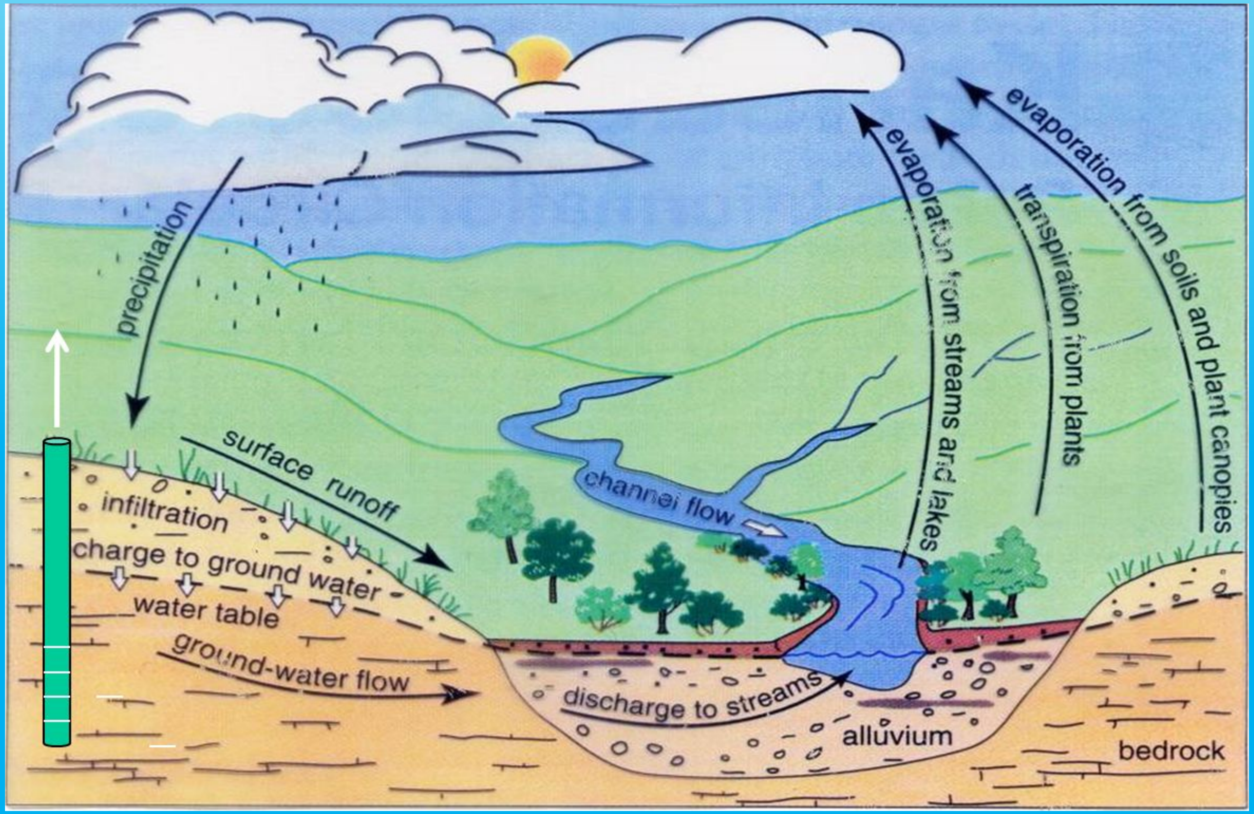
Advantages of Groundwater

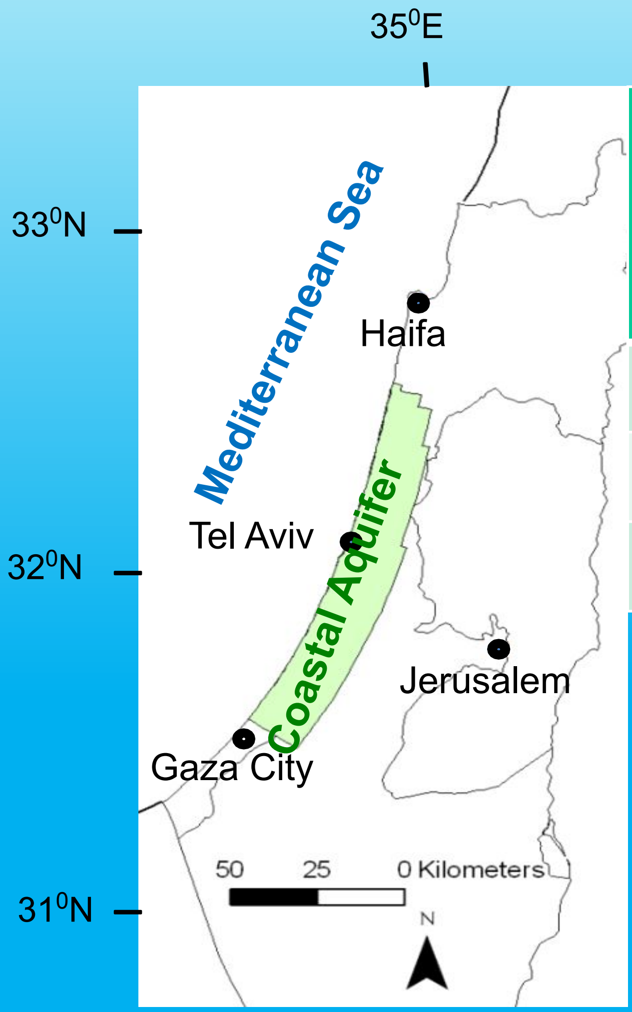
- Groundwater flows slow
- Groundwater are usually not exposed to evaporation
- Groundwater reservoirs sprawl over large areas
- Groundwater is less vulnerable to contamination

- Groundwater can also be recharged in engineered systems, not only naturally

Managed Aquifer Recharge - MAR

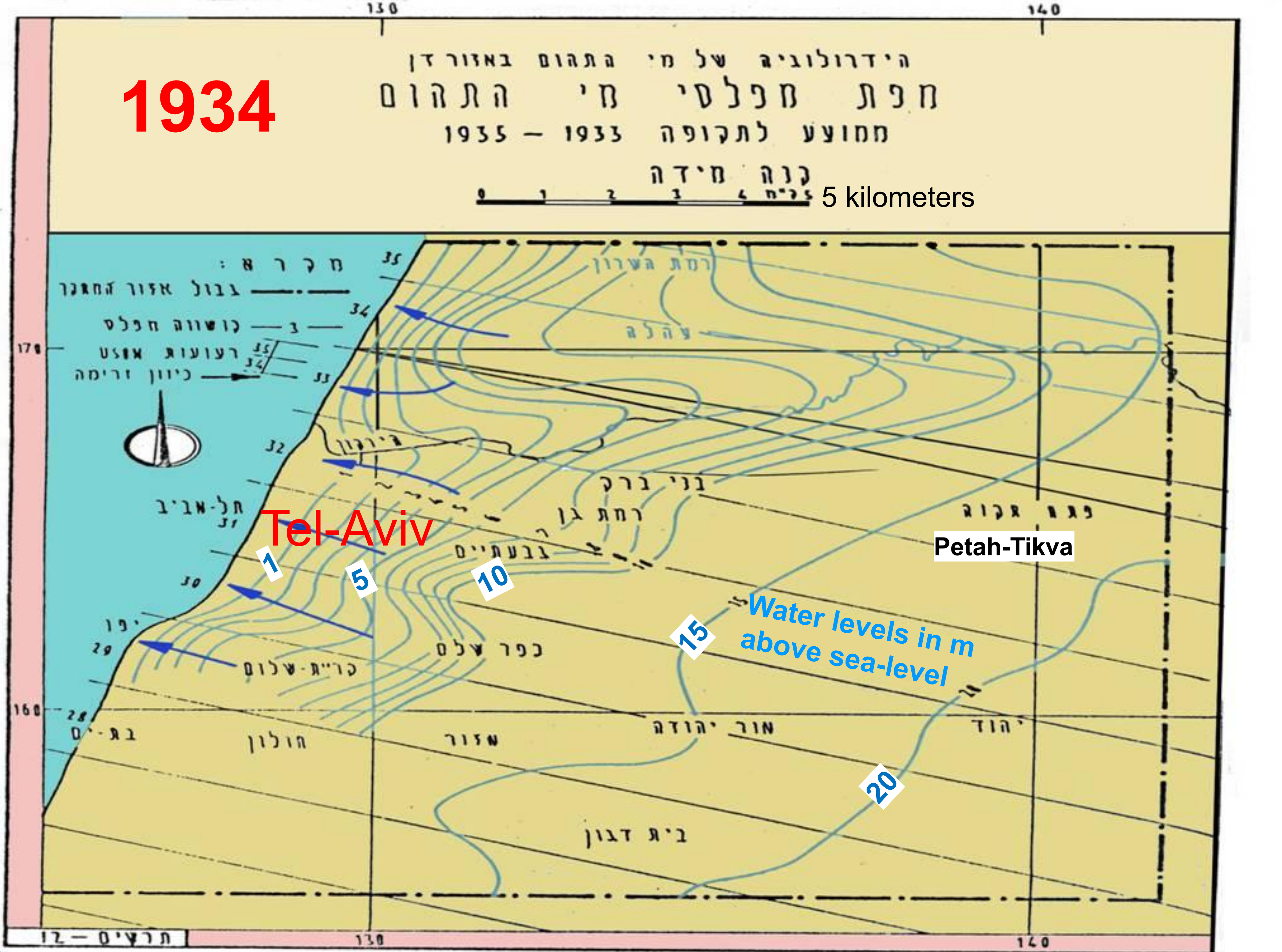


The Israeli Coastal Aquifer - 100 years of intensive use of the aquifer: first 50 years exploiting the natural recharge (and locally much beyond), second 50 years increasing recharge and pumping by Managed Aquifer Recharge (MAR)



Year	Population above aquifer (10^6)	Natural Recharge (+ irrigation returns) (10^6 m^3/yr)	Managed Recharge (10^6 m^3/yr)	Production (10^6 m^3/yr)
1915	0.15	250	0	10
1965	1.5	280	5	300
2015	4	270	150	400

Numbers reflect characteristic for the period and not the specific annual data


1934
הידרולוגיה של מי התהום באזור דן
מפת מפלסי מי התהום
ממוצע לתקופה 1933 — 1935
קנה מידה
5 kilometers
מקרא:
גבול אזור החקר
קו שווה מפלס
כיוון זרימה
רמת השרון
ירקון
בני ברק
רמת גן
גבעתיים
תל-אביב
Tel-Aviv
יפו
כפר שלם
פתח תקוה
Petah-Tikva
Water levels in m above sea-level
1
5
10
15
20
אור יהודה
יהוד
בת ים
חולון
אזור
בית דגון

1950

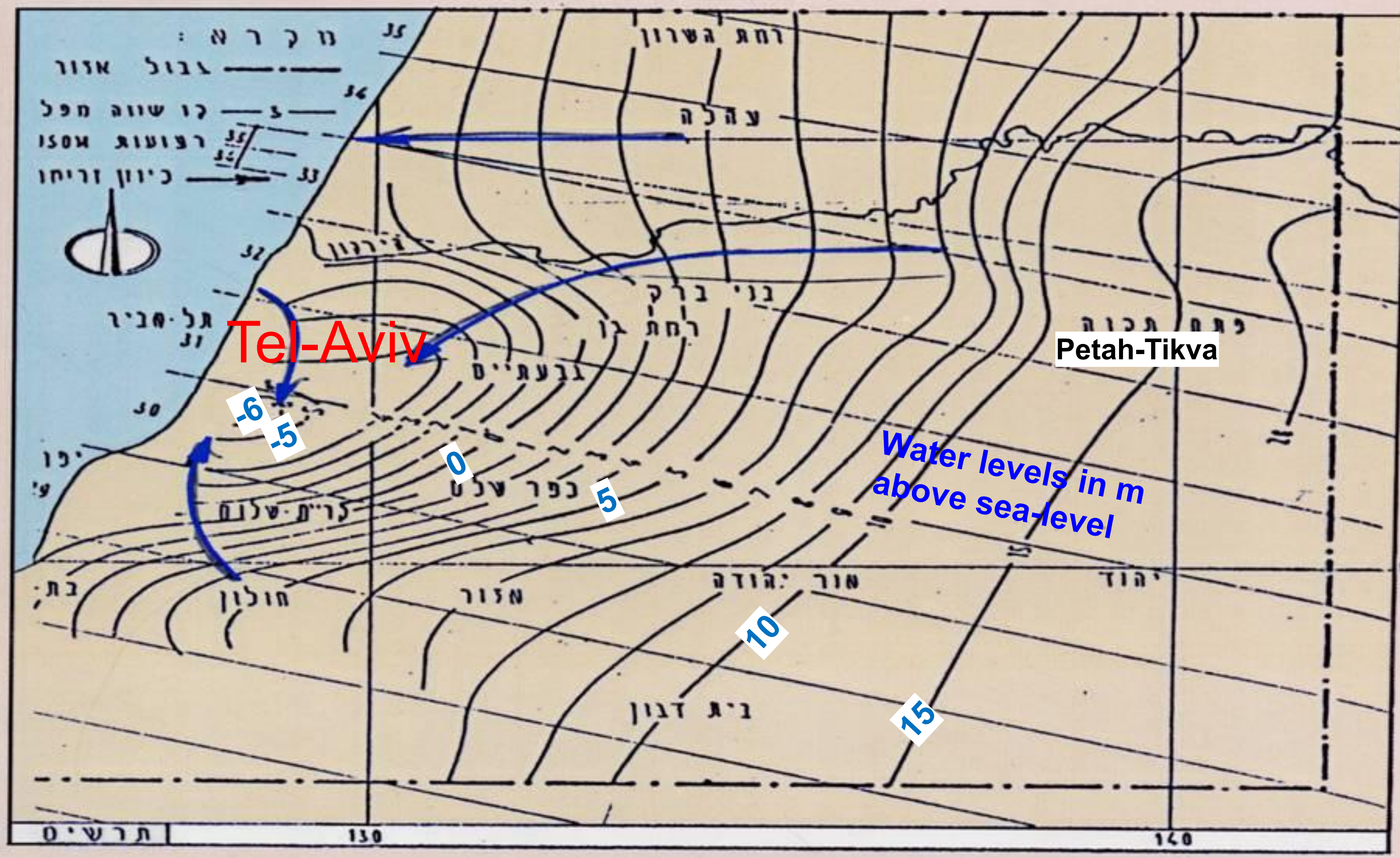
הידרולוגיה של מי התהום באזור דן

מפת המשטח הפריאטי

סתיו 1950

קנה מידה:

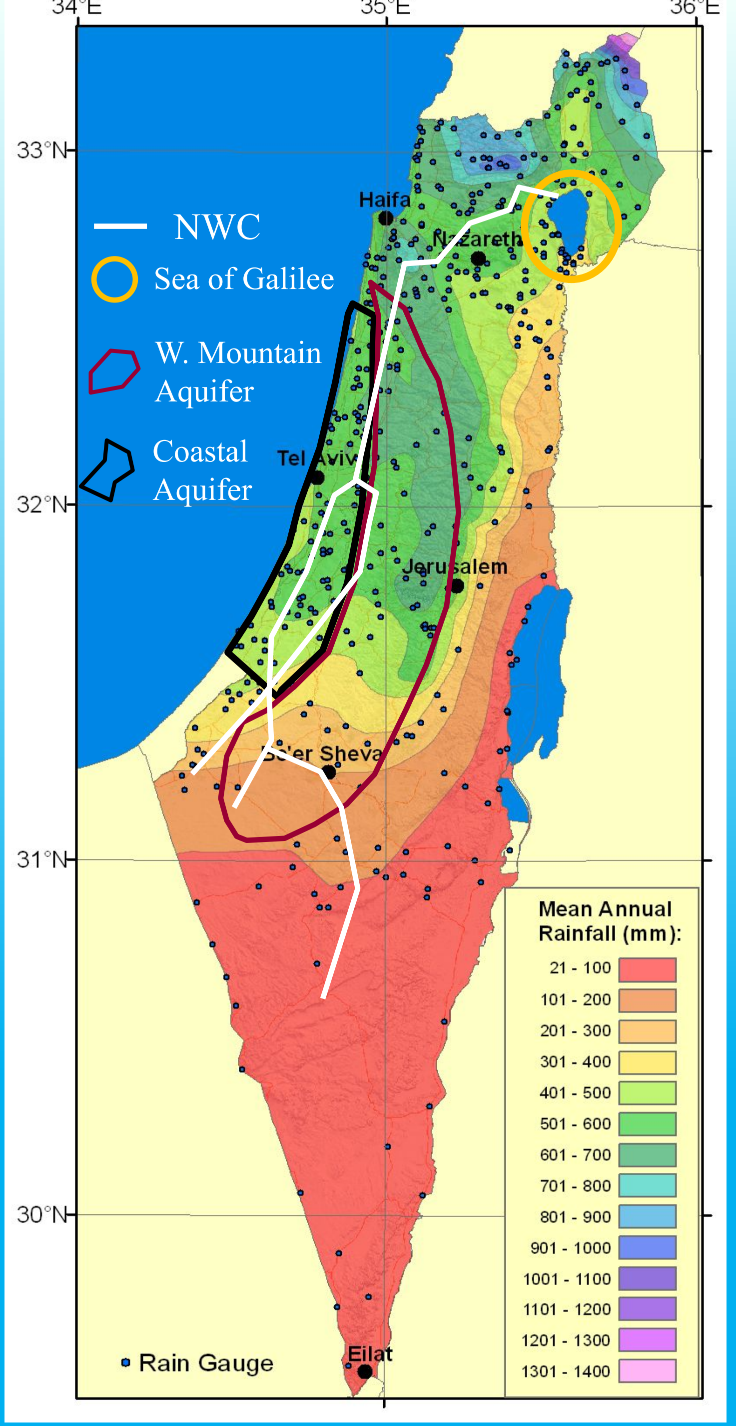
0 1 2 3 4 5 ק"מ 5 kilometers



1957
הידרולוגיה של מי התהום באזור דן
מפת המשטח הפריאטי
סתיו 1957
קנה מידה
0 1 2 3 4 5 קמ
5 kilometers
מקרא:
גבול אזור המחקר
קו שווה מפלס
רצועות USOM
כיוון זרימה
תל אביב
Tel-Aviv
פתח תקוה
Petah-Tikva
-10
-5
0
5
10
12
Water levels in m above sea-level
130
140
170
160
תרשים – 27

1965- 1945
Over pumping and developing new water resources & a National Water Carrier

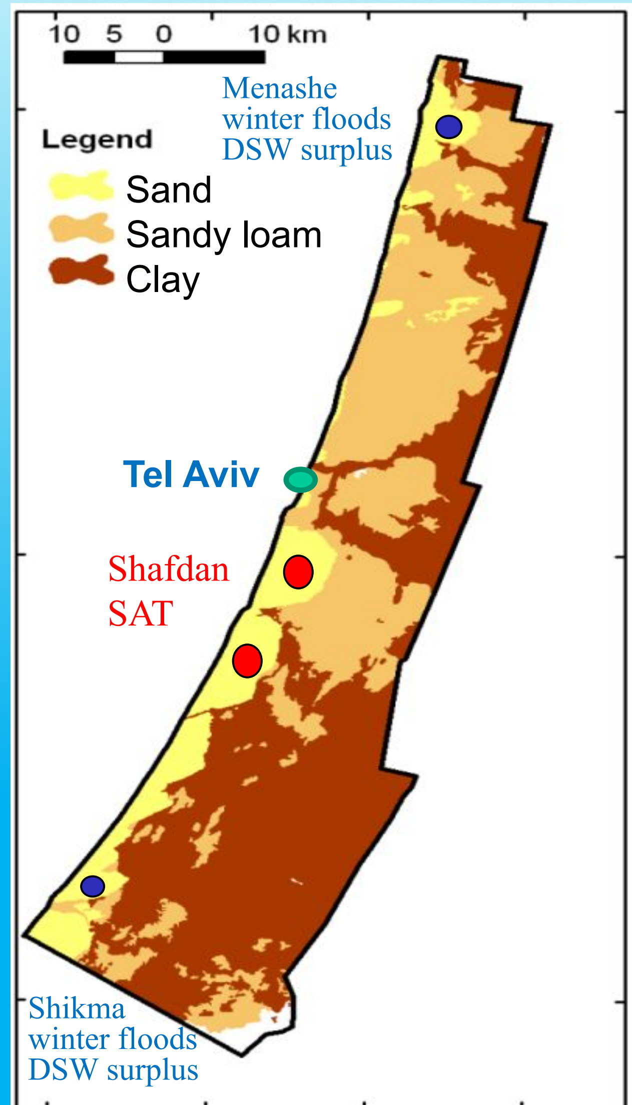
1965 – 1990
Using the pipes and wells of NWC not only to deliver water to consumers but also filling up the deficits that developed in the coastal aquifer



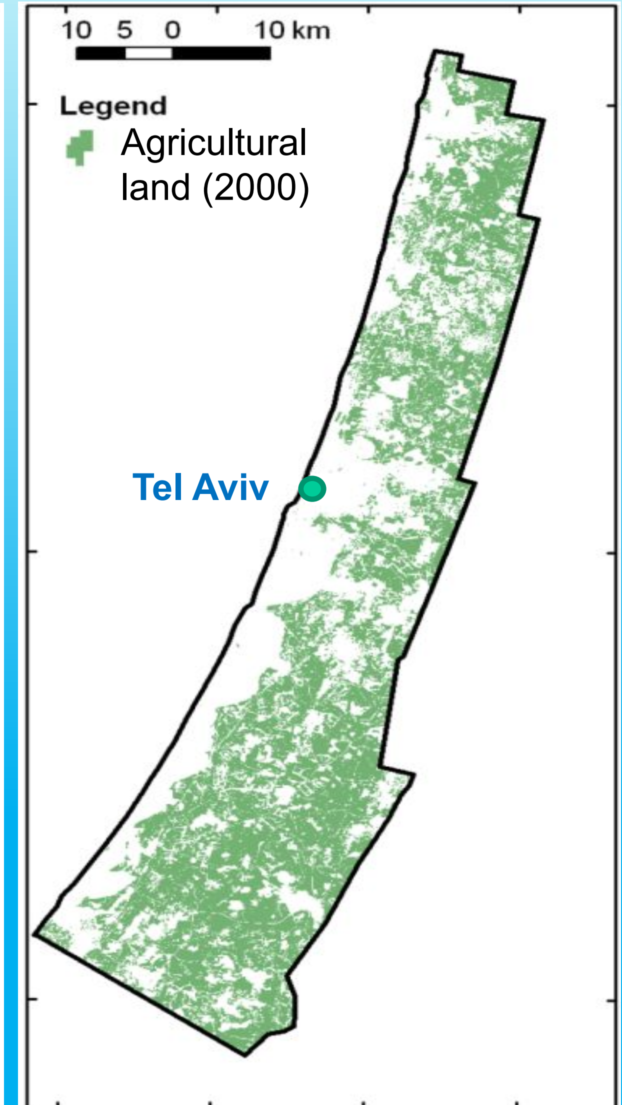
Using the sand dunes for MAR systems based on infiltration ponds

Sand dunes were not cultivated, hence the water company took significant areas for infiltration ponds in MAR systems.

Soils



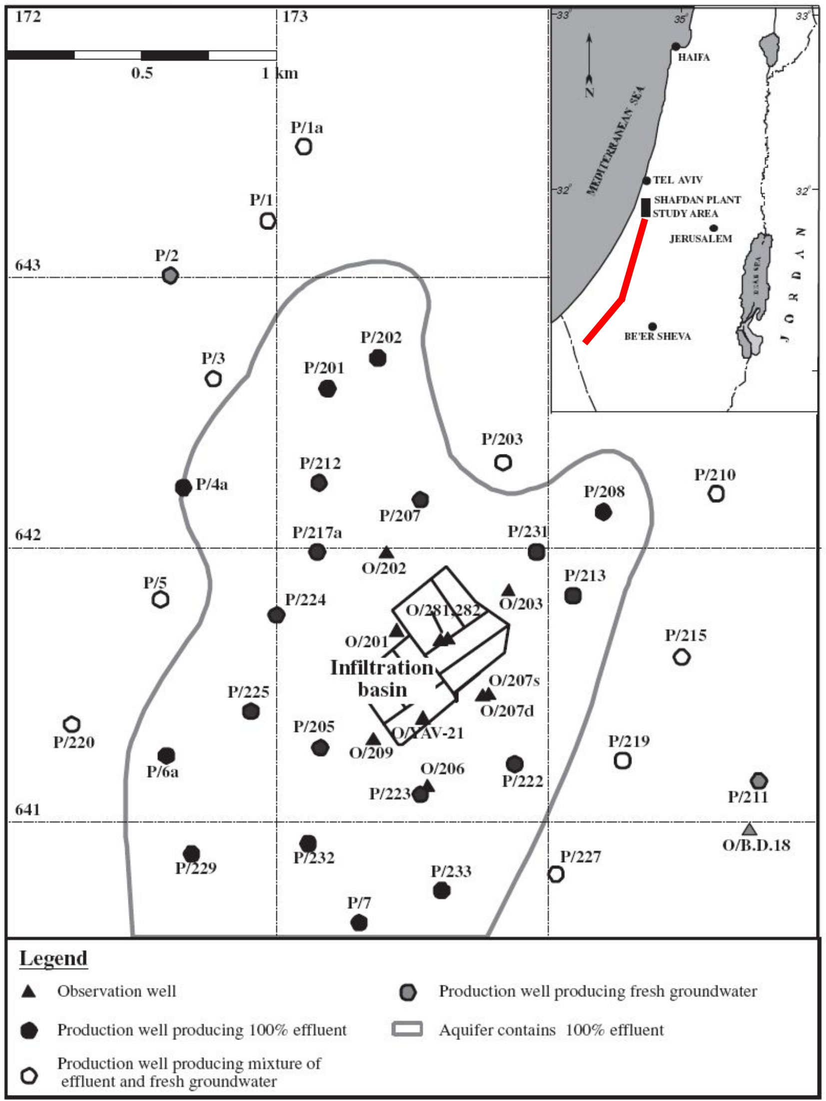
Cultivated land



Shafdan SAT - producing food in the desert with Tel-Aviv metropole's wastewater and an aquifer

SAT - Infiltration/abstraction fields

Goren et al., 2011 *J. of Hydrology*



The special red pipe-line from the abstraction wells to the Western Negev desert (130 km) for unlimited irrigation

In a fennel field

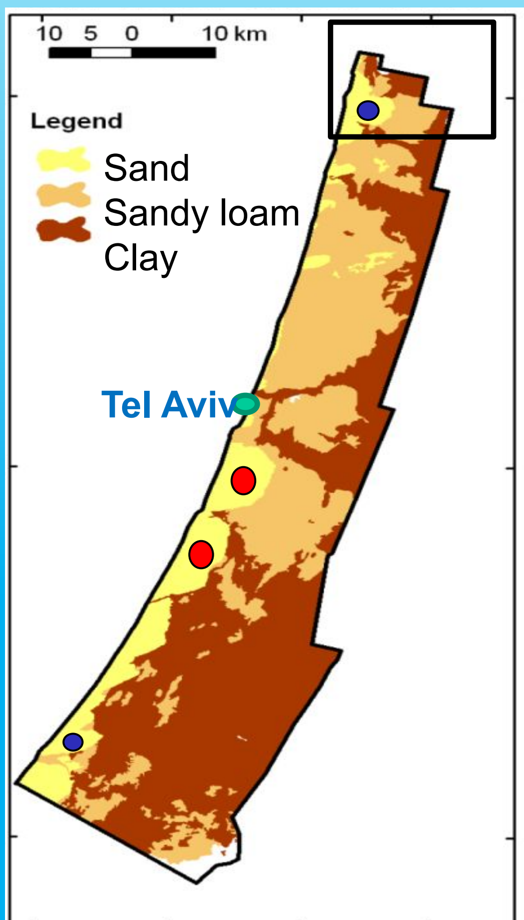
any pipe carrying treated wastewater for irrigation is either red or purple (rather than white for drinking water)

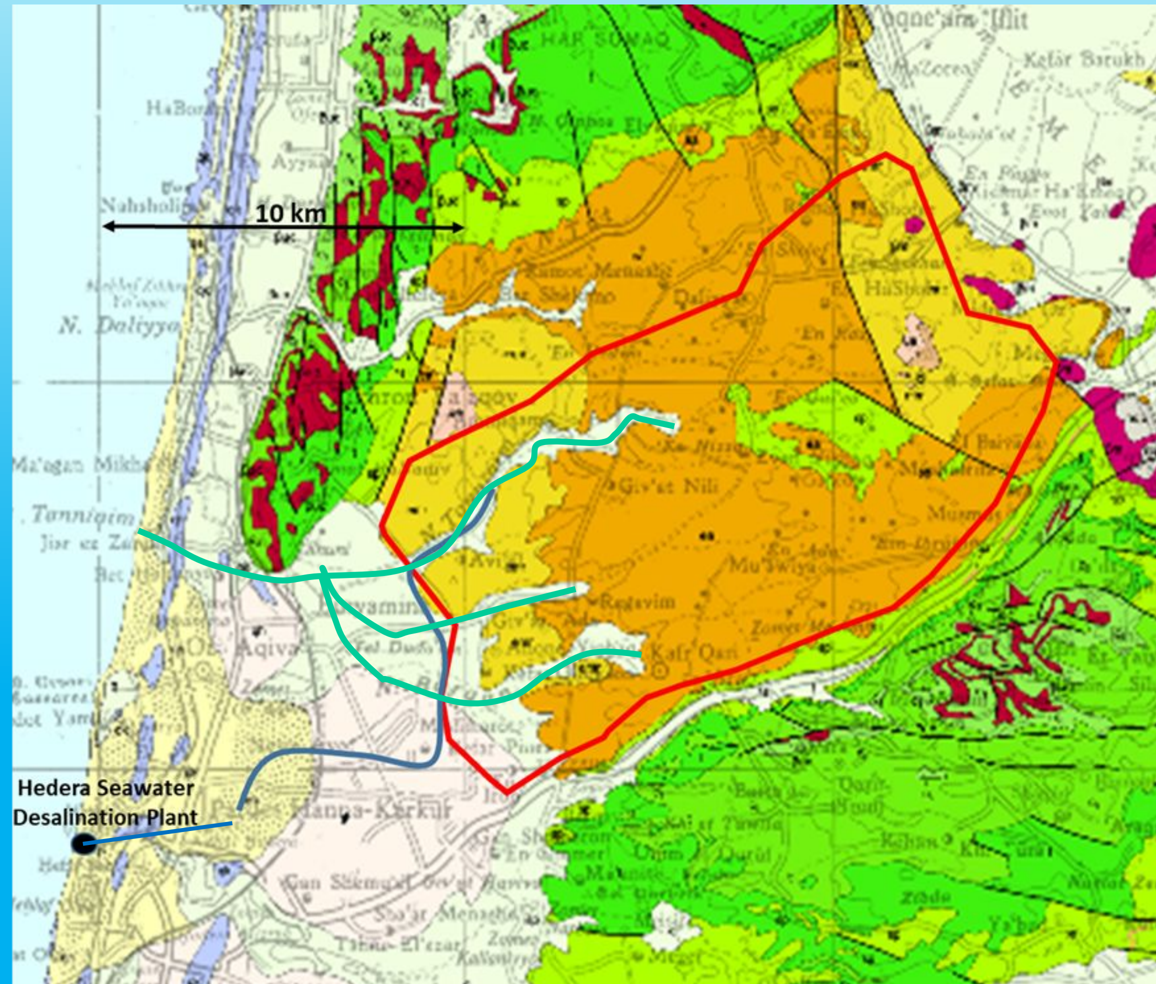
Collecting 55 ton/ha potatoes from desert land

The Menashe floodwater MAR system

<u>Hydrological rational</u>

Diverting ephemeral floodwater from the impermeable-high-runoff chalks of Menashe Hills to the sand dunes overlaying the northern coastal aquifer.



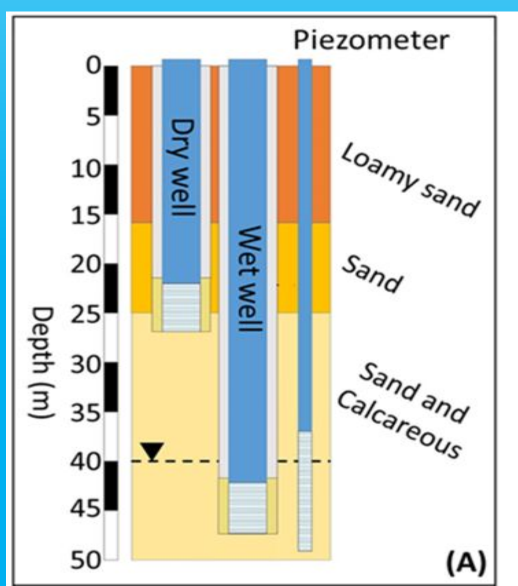


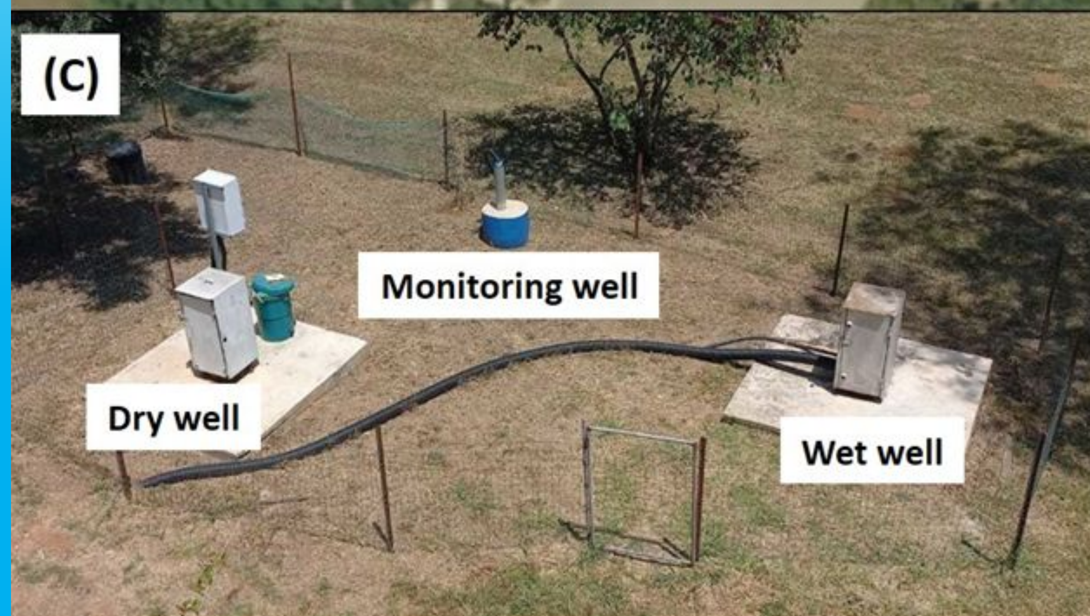
More methods of surface Recharge
Flooding agricultural areas - **Ag-MAR** (California, USA)

Figure 7 Application of stormwater on an almond orchard for groundwater recharge.

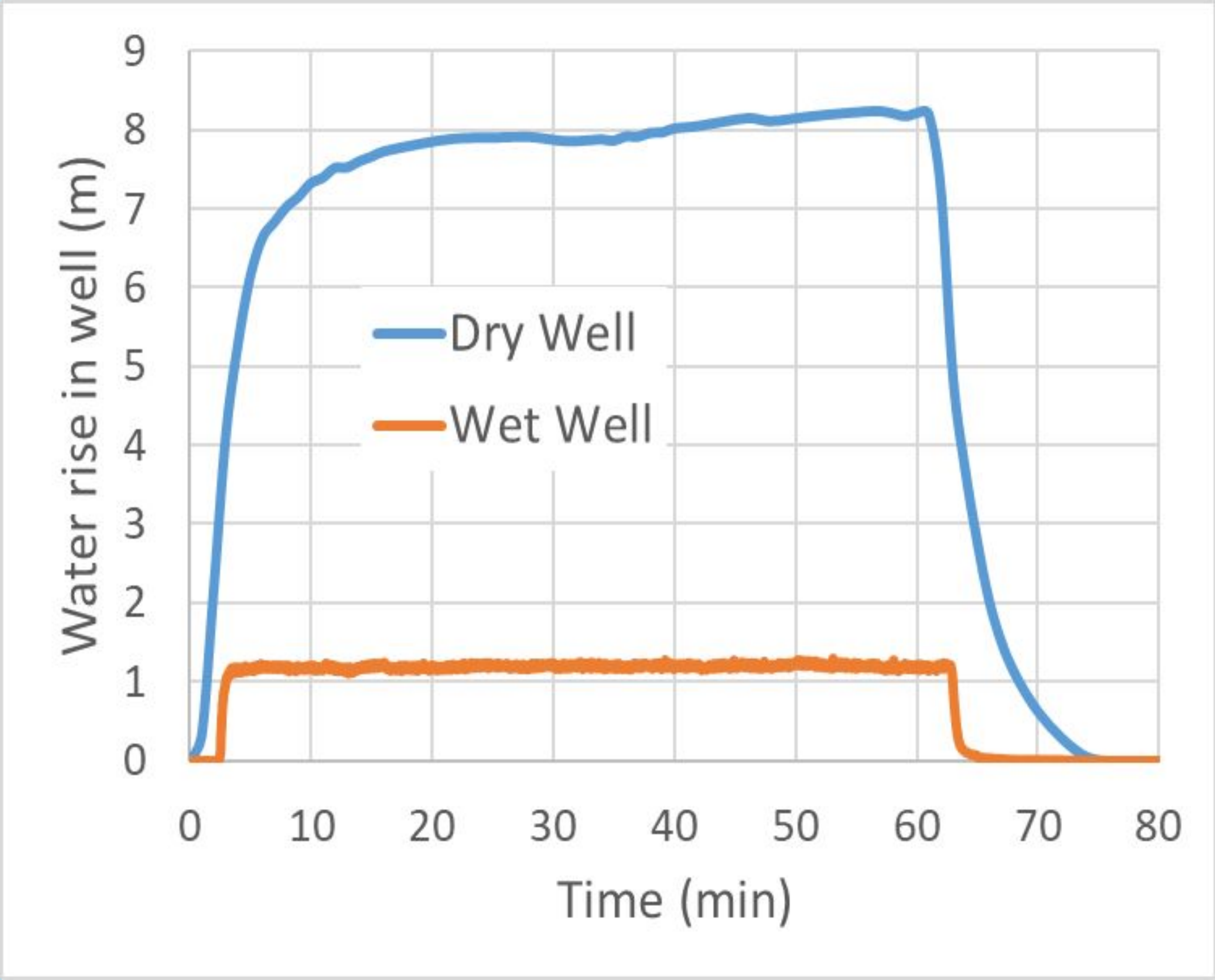
Helen E. **Dahlke**, Gabriel T. LaHue, Marina R.L. Mautner, Nicholas P. Murphy, Noelle K. Patterson, Hannah Waterhouse, Feifan Yang, Laura Foglia, 2018/
Chapter Eight - **Managed Aquifer Recharge as a Tool to Enhance Sustainable Groundwater Management in California: Examples From Field and Modeling Studies**,
Editor(s): Jan Friesen, Leonor Rodríguez-Sinobas, Elsevier

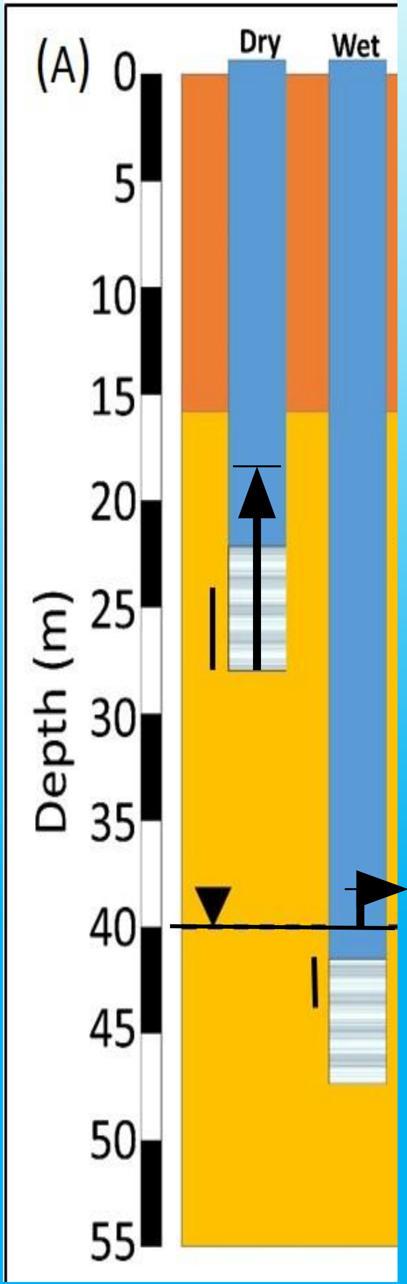
Small Scale MAR catching rain from roofs and directing them to the subsurface though wells





Moving rainwater to the subsurface, dry or wet well?





Conclusions

- If you develop water use from an aquifer, production wells is a must, but if you look at longer times think also of developing Managed Aquifer Recharge systems.
- Different sources of water of different quality can be thought of for Managed Aquifer Recharge (effluents, river, roof rain water …). Water end use is also a consideration (irrigation vs. drinking)
- Different methods of recharge are practiced (infiltration basins, wells (dual propose, wet, dry), flooding)

Thanks

- Volacni Institute (letting me make a living from hydrological research)
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- Israel Water Authority (Funding the Wells in Volcani Institute and collaboration)
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- Geological Survey of Israel (geological map)
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Some Shafdan SAT Numbers (2018, Aharoni et al., 2019)

(mg/l)	DOC	P	N	Org.-N	NH4-N	NO3-N	NO2-N	Ca	Cl
2nd effluent	10	0.5	10	1	4	3	2	55	200
After SAT	<1	<0.1	5	<0.2	<0.02	5	0.005	85	200

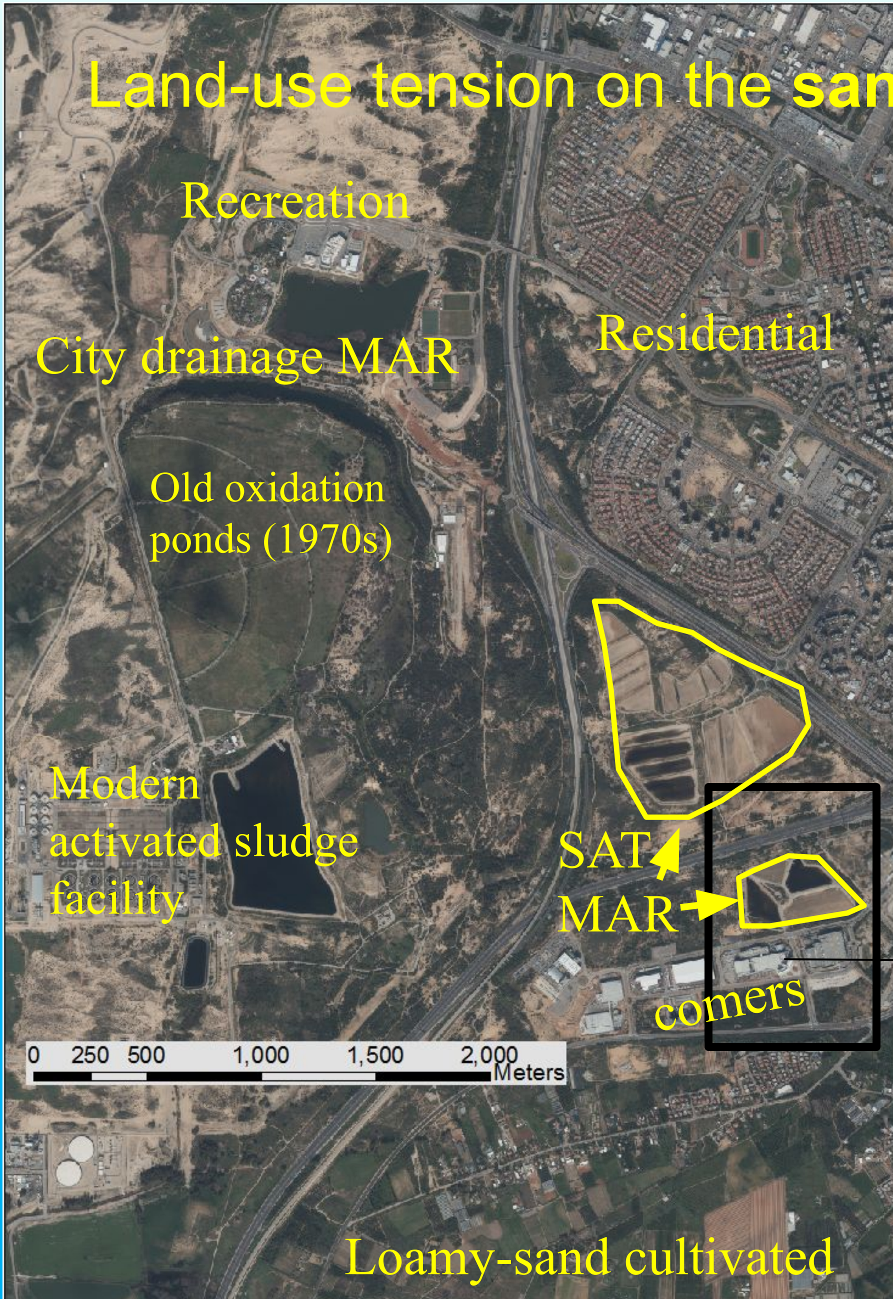
It is thought that keeping the total N input at 10 mg/l is essential for avoiding reduced forms of N in the aquifer (Mienis and Arye, 2018).

Shafdan SAT is also an Ion Exchanger (Mg, Kurtzman and Guttman 2020)

	Mg before desalination	**Mg in desalination era**
2nd effluent	30	12
After SAT	24	20

Microbiology - Shafdan's SAT operates with no disinfection prior to infiltration (or after pumping). Nevertheless, no positive tests for fecal coliforms were recorded in any of the SAT reclamation wells for 20 years, and practically all enterovirus tests were negative (Elkayam et al, 2015, 2018).

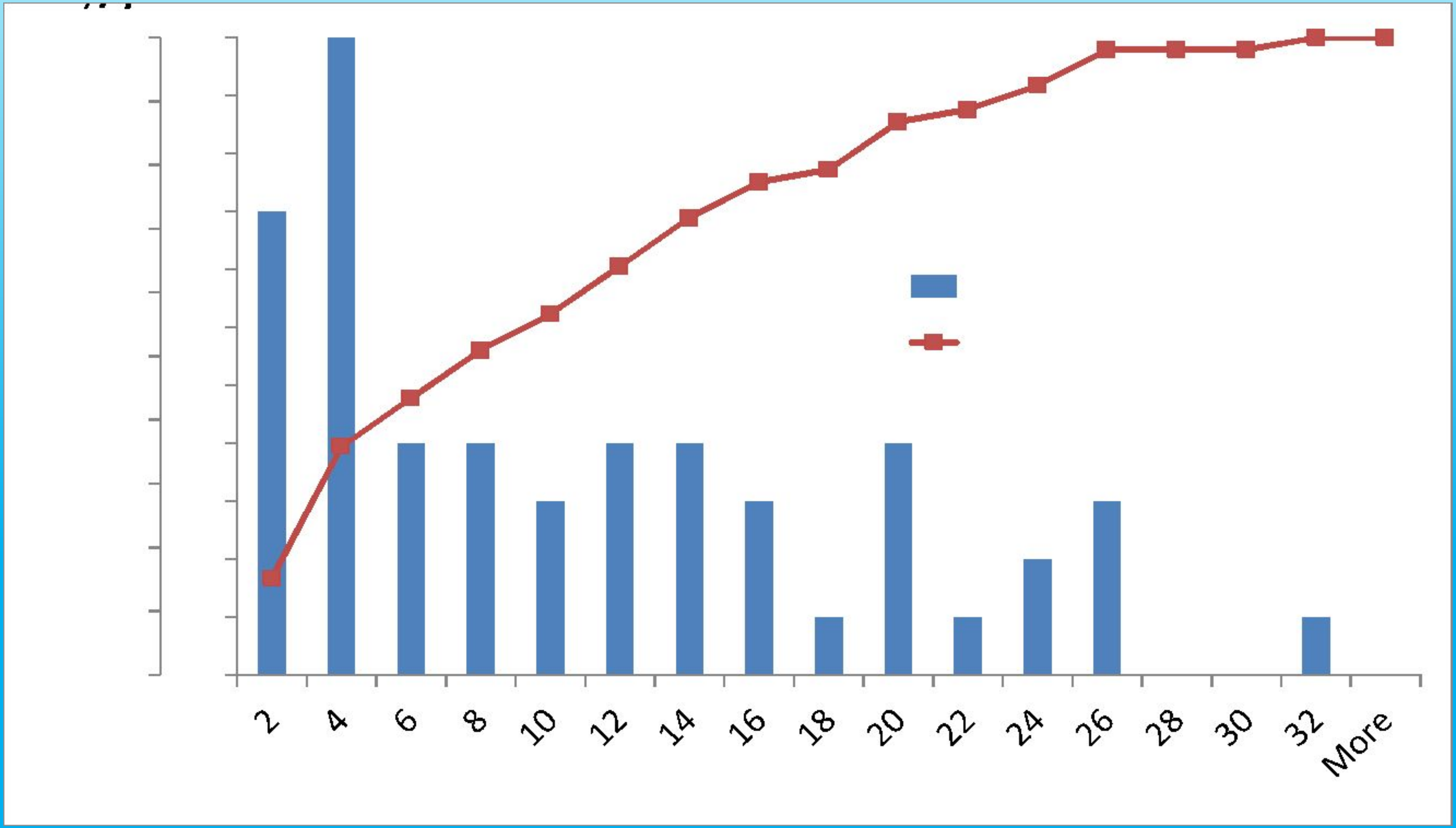
Land-use tension on the **sand-dunes** South west Rishon



Shafdan SAT basins are flooded for ~1 day than left to drain and dry for ~ 2 days. This sequence re-oxygenates the soil and maintains high infiltration rates. <u>A column of ~ 120 m of secondary effluents percolate through the soil surface of the infiltration basins each year.</u>

Variability in availability of floodwater for MAR in Menashe System

Histogram of annual volumes of flood-water that were diverted from the Menashe Streams towards the basins in the sand dunes for MAR in 53 years 1967-2019. Note that in ~ 2/3 of the years the volume is between 4 – 32 MCM. Average 10 MCM/yr; 3 out of 53 years with 0 stream-water for MAR (Kurtzman and Guttman 2020).



Historical log of the Israeli Coastal Aquifer

The history of man use of the Israeli Coastal Aquifer in the last century is given as an example for possibilities in Mediterranean developing regions:

Pumping only period

- -1940s, exploitation
- 1940s-1960s, over exploitation,

Pumping and MAR period

- 1960s- 1990s, MAR through wells from other potable water resources using the large scale water supply system
- 1960s- present, MAR of winter floodwater through infiltration basins in the sand dunes
- 1980s – present, use of part of the aquifer for MAR-SAT of secondary effluents of a large wastewater treatment plant for producing large volumes of water for “unlimited irrigation”.
- 2014 – present, Incorporating excess water of high quality (e.g. desalinated seawater) in the floodwater MAR systems

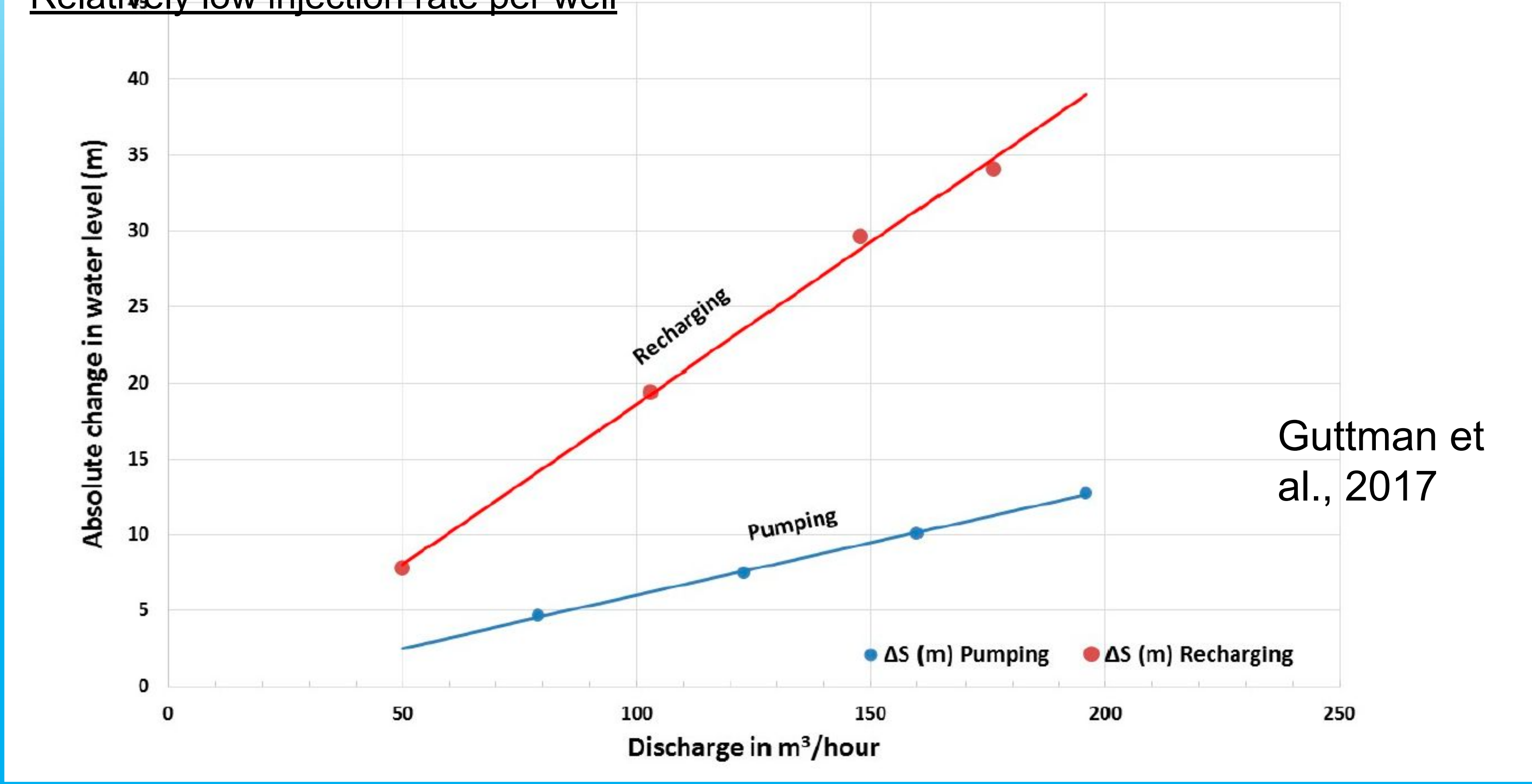
Considerations MAR through wells

Advantages over infiltration basins

- Possible to recharge confined aquifers, clayey vadose-zones, populated areas etc.,
- Usage of the water-supply network (pipes, wells, reservoirs)

Disadvantages

- High sensitivity to water quality, there is no soil aquifer treatment
- Clogging problems: development of physical, biofouling and trapped air bubbles
- <u>Relatively low injection rate per well</u>



Guttman et al., 2017

Managed Aquifer Recharge of Tel Aviv Metropolis secondary effluents - "Shafdan" in sand dunes overlaying the coastal aquifer and using them for unlimited irrigation in the Negev Desert

What do we gain?

1) A very good and cheep advanced treatment-SAT- you can drink Shafdan water
2) Save surface storage area of effluents
3) We irrigate with groundwater – the SAT product can be used for irrigation of all crops as fresh-water "unlimited irrigation"
4) The Shafdan system moved the center of Israel's fruit and vegetable production from expensive land overlying a good aquifer (nitrate contamination etc.) to desert land overlying a naturally-saline poor aquifer.
5) $130*10^6$ m^3/yr water for unlimited irrigation (~15% irrigation water nationally)
6) $130*10^6$ m^3/yr of secondary effluent that did not flow in streams to the Mediterranean Sea

What do we lose?

1) Good parts of the aquifer (under the sand dunes) are not used for drinking water.
2) Significant area of expensive land used for infiltration basins.

Bottom line – most agriculture and water-supply stakeholders are in favor of it