Estimation of Water Resources

Groundwater Recharge

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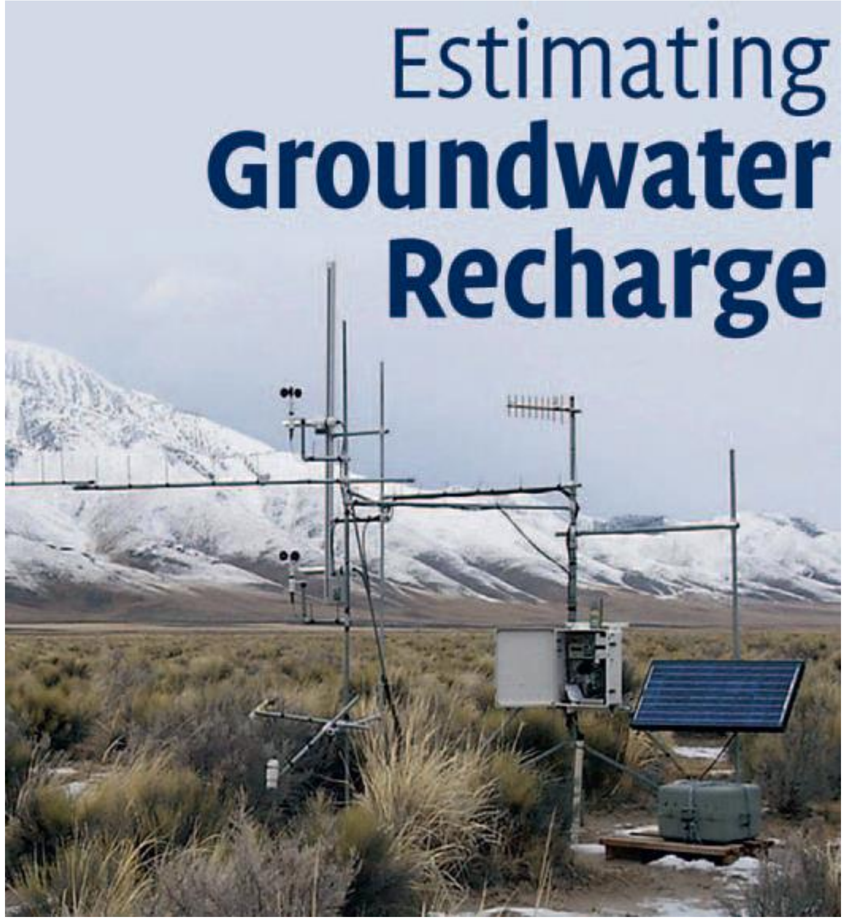
Sustainable Water Resources Management
1. Estimating Groundwater Recharge

Content

- **What is Groundwater Recharge?**
- **How can it be measured?**
- **Techniques**
- **Examples and Exercise**

Sustainable Water Resources Management
1.1 Books and Articles on Groundwater Recharge



Healy E. (2015)

- Books on Recharge and important studies

  - ❑ Allison et al. (Australia)
  - ❑ Verhagen et al. (South Africa)
  - ❑ Scanlon B. in USA
  - ❑ Zagana & Kuells in Eastern Mediterranean and Cyprus

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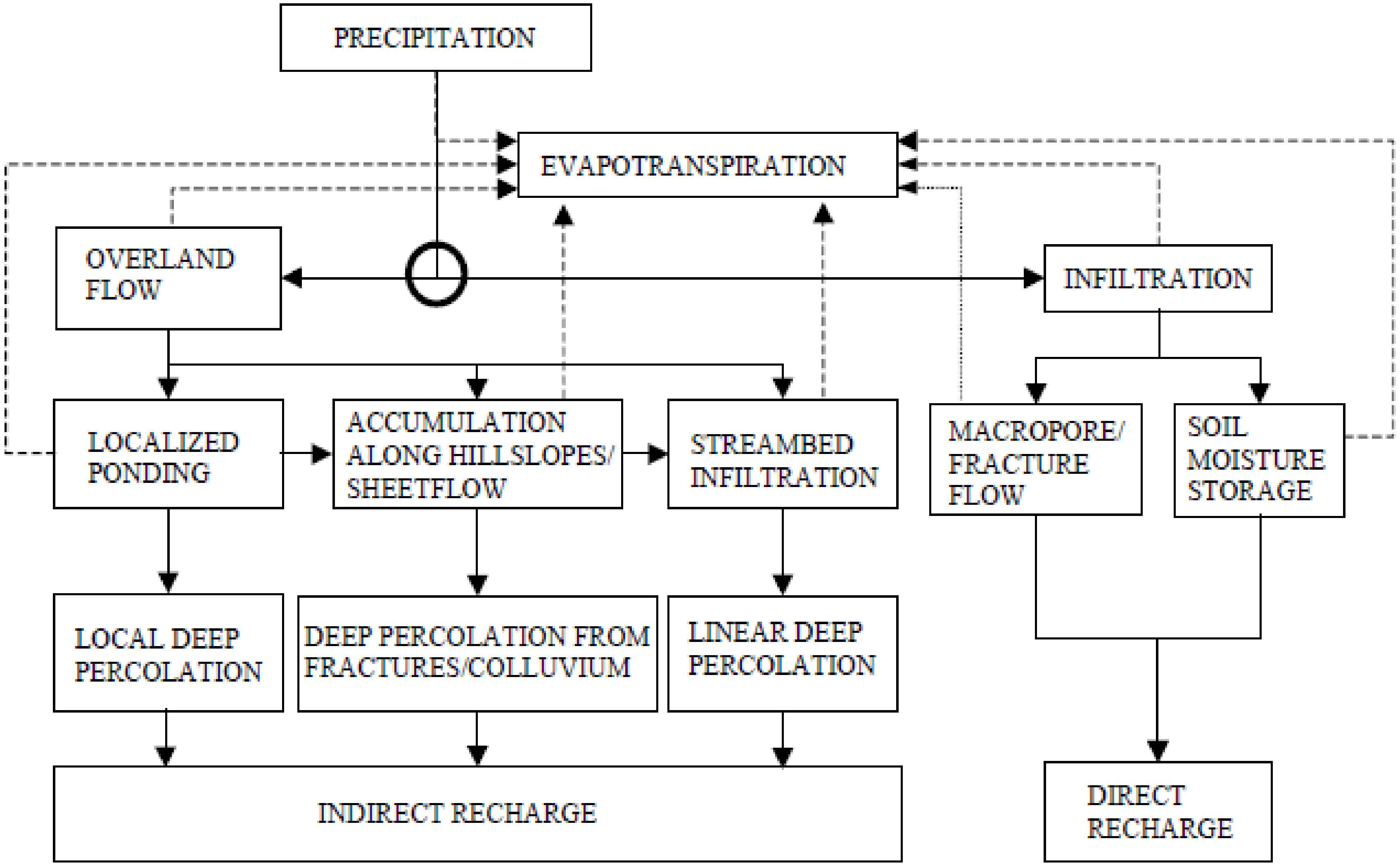
1.2 The Concept of Groundwater Recharge



Külls (2000)

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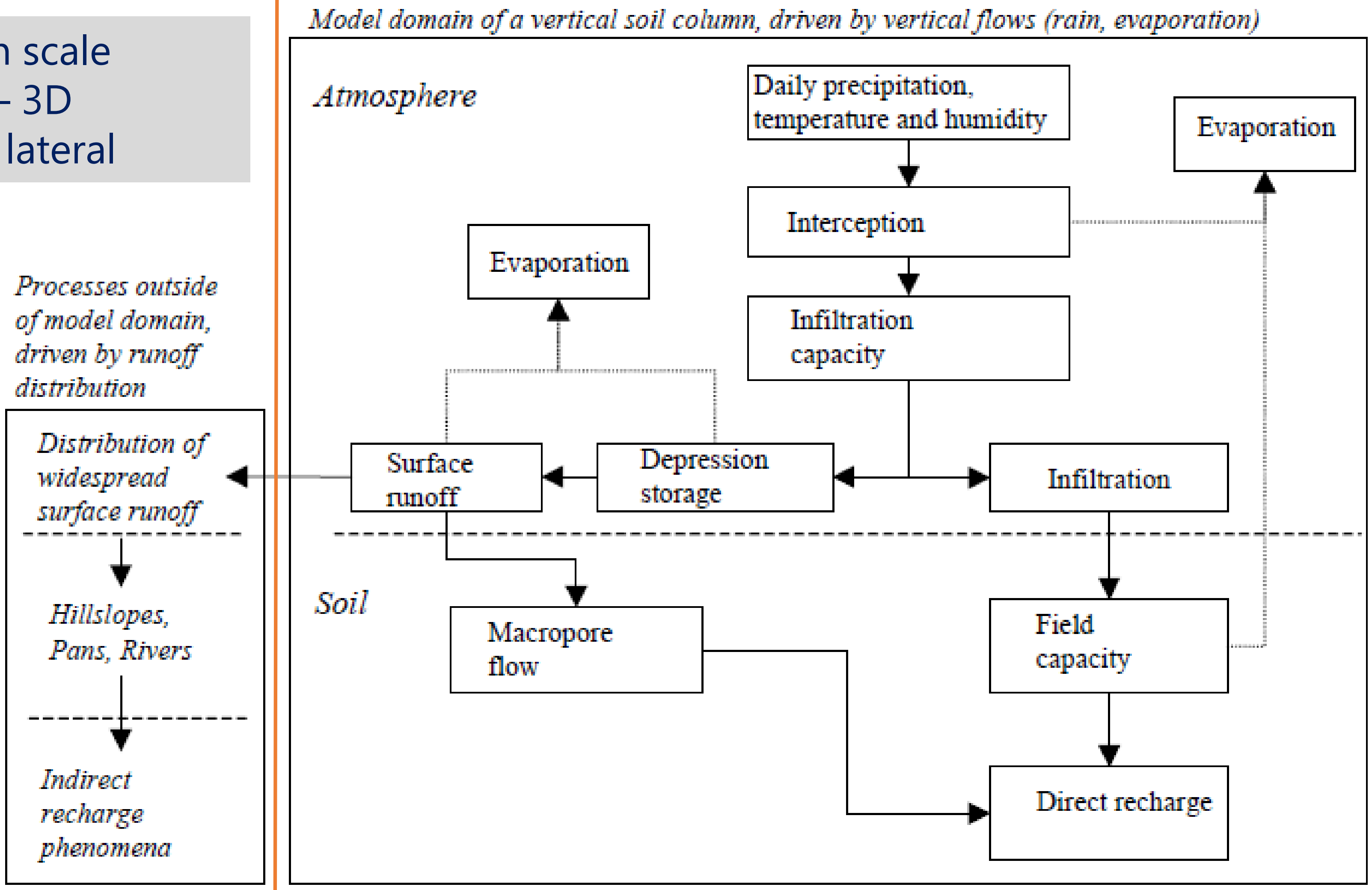
1.3 Groundwater Recharge - Scales

Basin

- Basin scale
- 2 D – 3D
- Also lateral

Point, site, soil



- Point scale
- 1 D
- Only vertical

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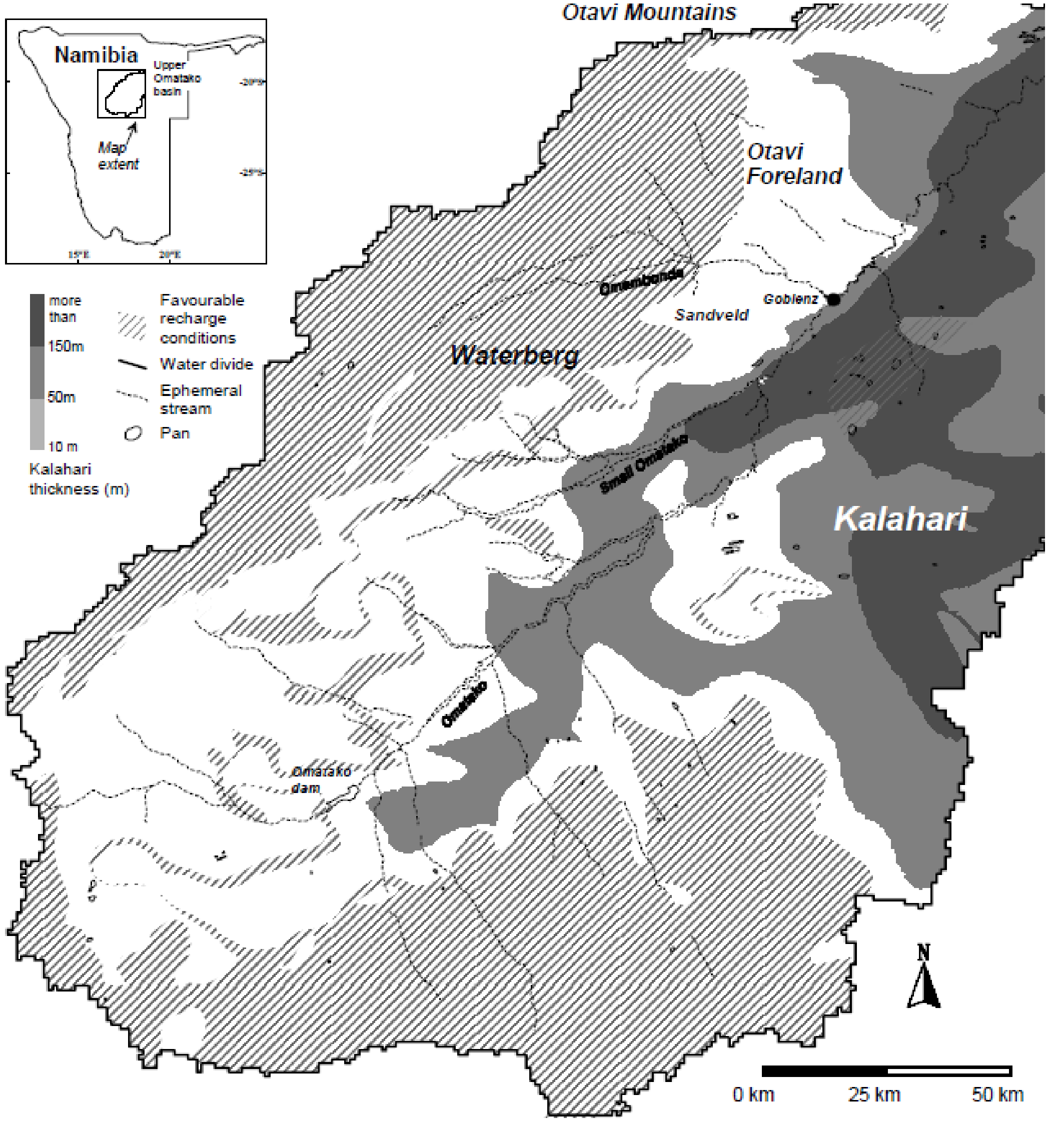
2. Groundwater Recharge Environments - Hydrotopes



- Where does groundwater recharge take place?
- Differentiate the environments and visit them

Külls (2000)

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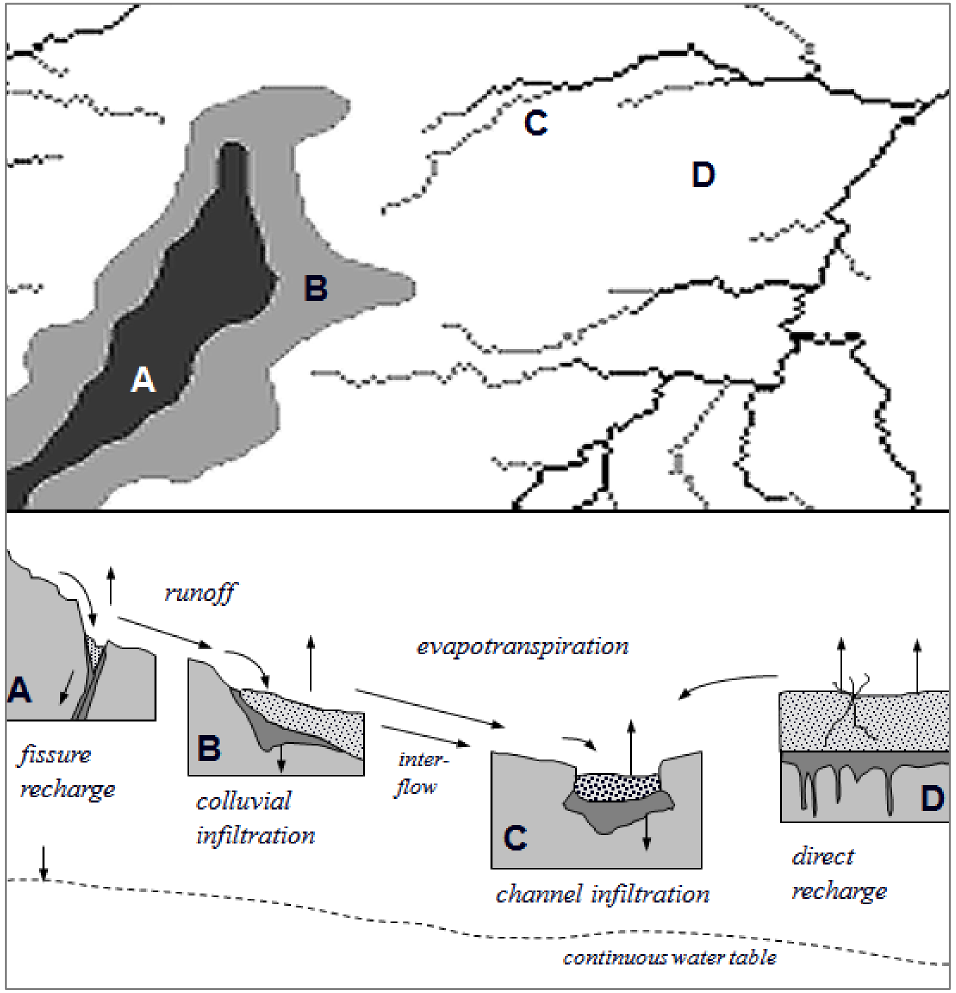
2.1 Groundwater Recharge Environments - Hydrotopes



Külls (2000)

- Different environments different recharge processes
- Direct on flat areas
- Indirect in valleys and lakes
- Sediment and hard-rock environments are different

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2.2 Groundwater Recharge Environments - Research

Authors	Country	Method	Rainfall (mm/y)	Recharge (% of MAR) Min.	Mean	Max.
VOGEL ET AL. (1974)	Botswana	tritium	500		2	
DACHROTH & SONNTAG (1983)	Namibia	groundwater chloride	472	0.8		1.7
DE VRIES & HOYER (1988)	Botswana	chloride	550		9.6	
GEHRELS & VAN DER LEE (1990)	Botswana	chloride	586		2.6	
GIESKE (1992)	Botswana	soil chloride	550		2.1	
VERHAGEN (1992)	Botswana	isotopes	450	0.1	0.7	1.3
SAMI & HUGHES (1996)	S. Africa	chloride	483	0.6		1.7
VERHAGEN (1999)	Botswana	equal volume	350	0.9	-	1.4
		equal volume	350	0.8	-	1.7
		isotopes	350	0.3	-	1.1
WRABEL (1999)	Namibia	soil and groundwater chloride	412	0.3	7.1	10.3

Külls (2000)

- Recharge rates for the Kalahari sand desert – semi-arid
- 2-9 % of rainfall
- Depends on mean annual rainfall

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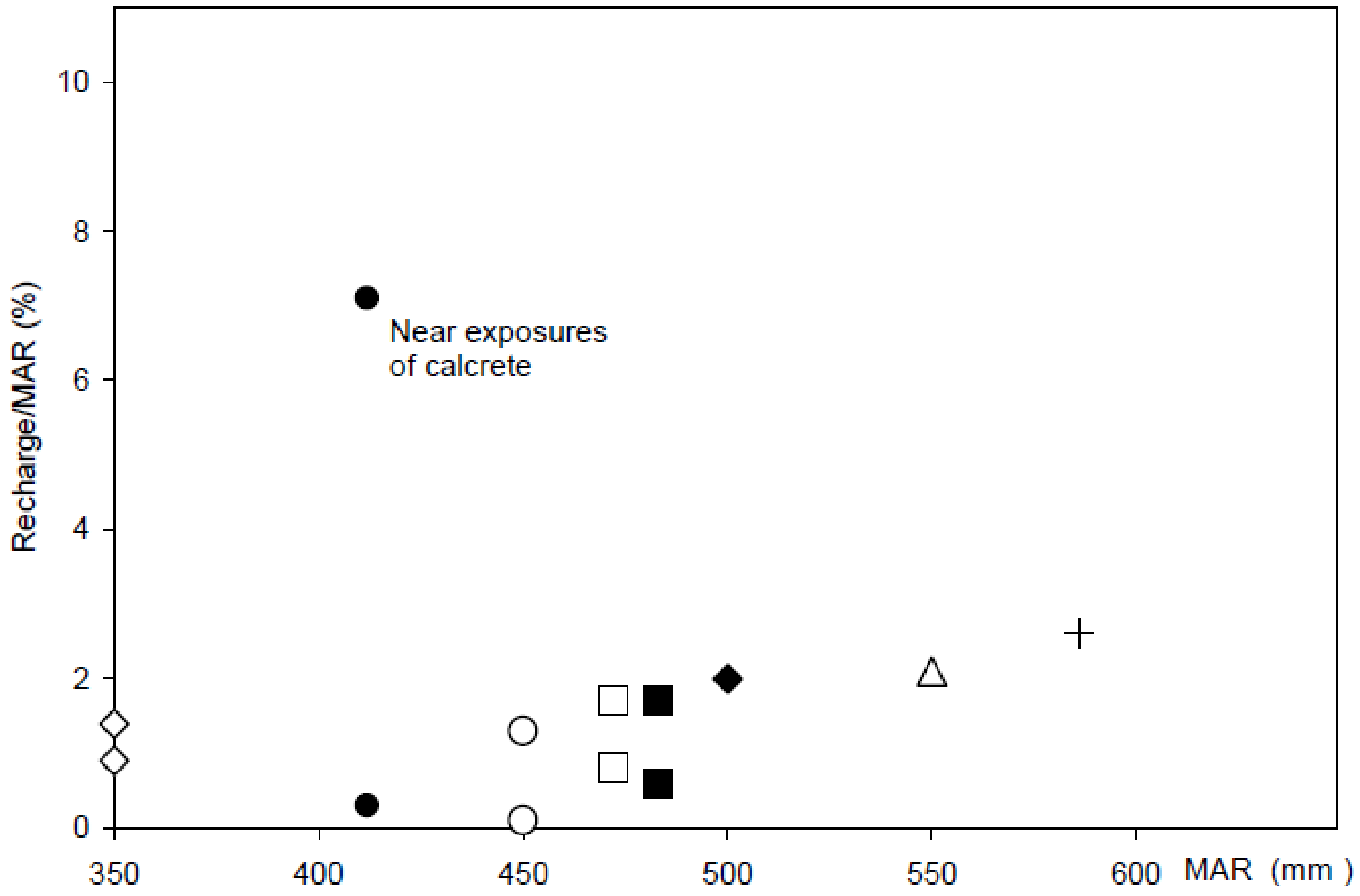
2.3 Groundwater Recharge Environments - Rates



- Recharge rates for the Kalahari sand desert – semi-arid
- 2-9 % of rainfall
- Depends on mean annual rainfall
    - ❑ Try to draw a function into the diagram
    - ❑ Explain why this function
    - ❑ Try to write an equation

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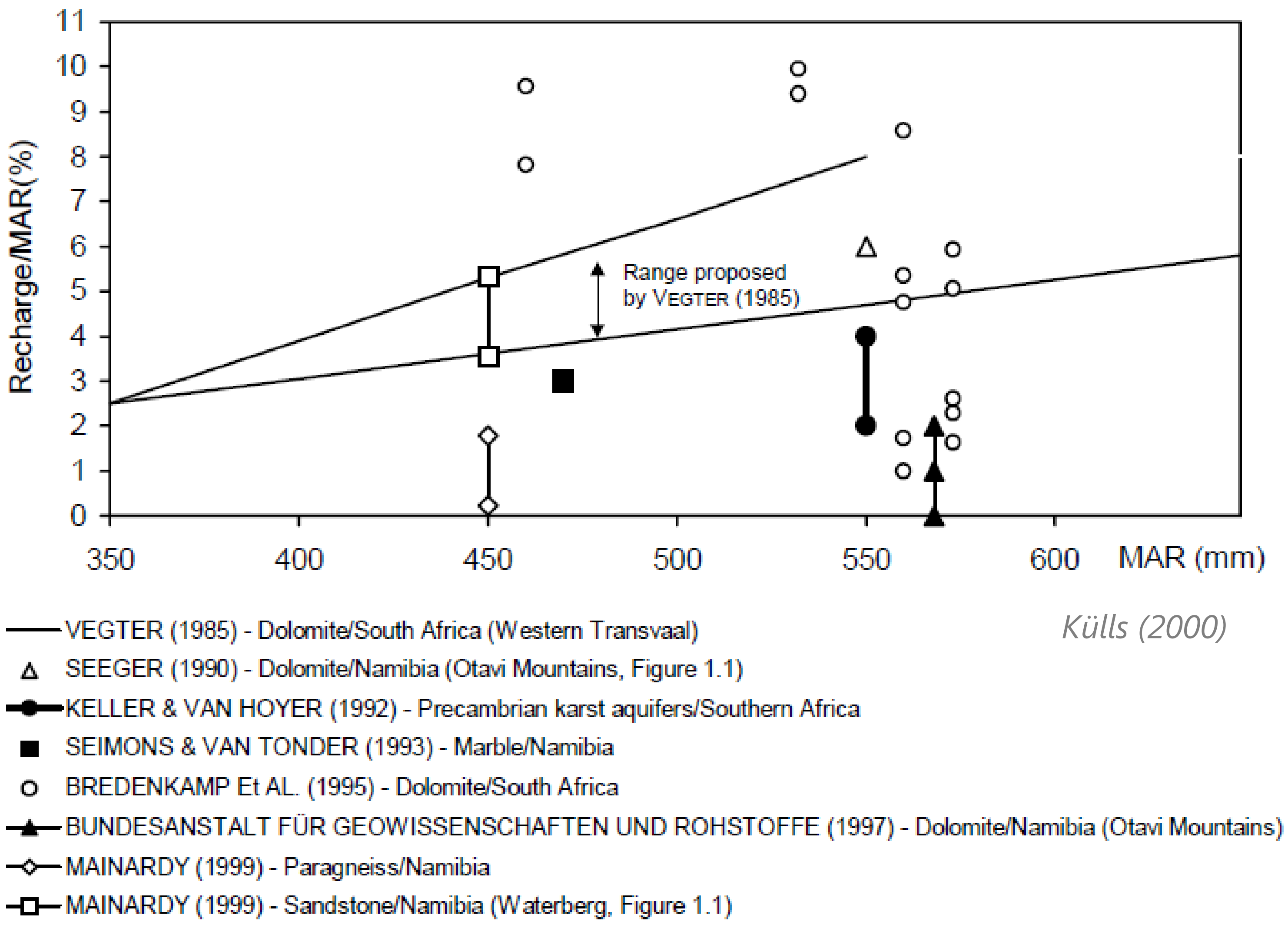
2.3 Groundwater Recharge Environments - Hydrotopes



Külls (2000)

- Recharge rates for the Kalahari sand desert – semi-arid
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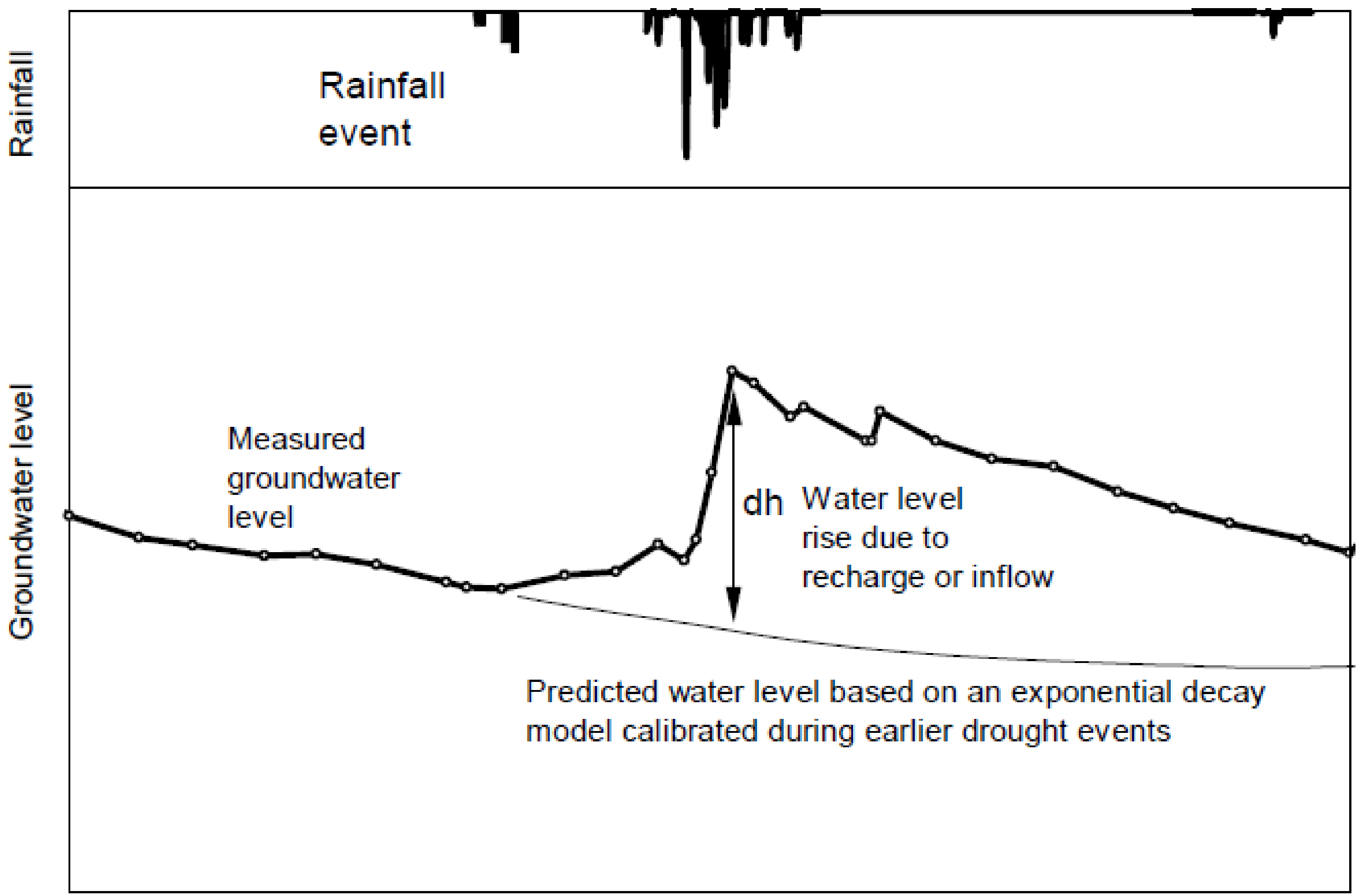
3. Groundwater Recharge Methods



Külls (2000)

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3.1 The chloride method

$$\overline{PC} + \overline{D} = \overline{R\,C_s}$$

where $\overline{P}$ is mean annual rainfall, $\overline{C}$ the mean chloride concentration of rainfall, and $\overline{D}$ is dry deposition. The right hand side of the equation represents the flux of chloride out of the root zone as the product of mean annual recharge $\overline{R}$ and chloride concentration of the soil water $\overline{C_s}$.

$$\overline{P\,C} = \overline{P}\,\overline{C} + \overline{\Delta P\,\Delta C} \approx \overline{P}\,\overline{C}$$

$$\overline{R\,C_s} = \overline{R}\,\overline{C_S} + \overline{\Delta R\,\Delta C_S} \approx \overline{R}\,\overline{C_S}$$

Külls (2000)

Sustainable Water Resources Management
3.1 The chloride method

In general, it is assumed that the covariances between annual rainfall and annual chloride deposition $\overline{\Delta P \Delta C}$, and between recharge and soil-water chloride concentrations $\overline{\Delta R \Delta C_S}$, are close to zero which simplifies the equations. Mean annual recharge can then be expressed as a function of mean annual rainfall, mean concentration of chloride in the rainfall, dry deposition, and measured chloride concentrations in the soil water:

$$\overline{R} = \frac{(\overline{P}\,\overline{C} + \overline{D})}{\overline{C_S}}$$

Külls (2000)

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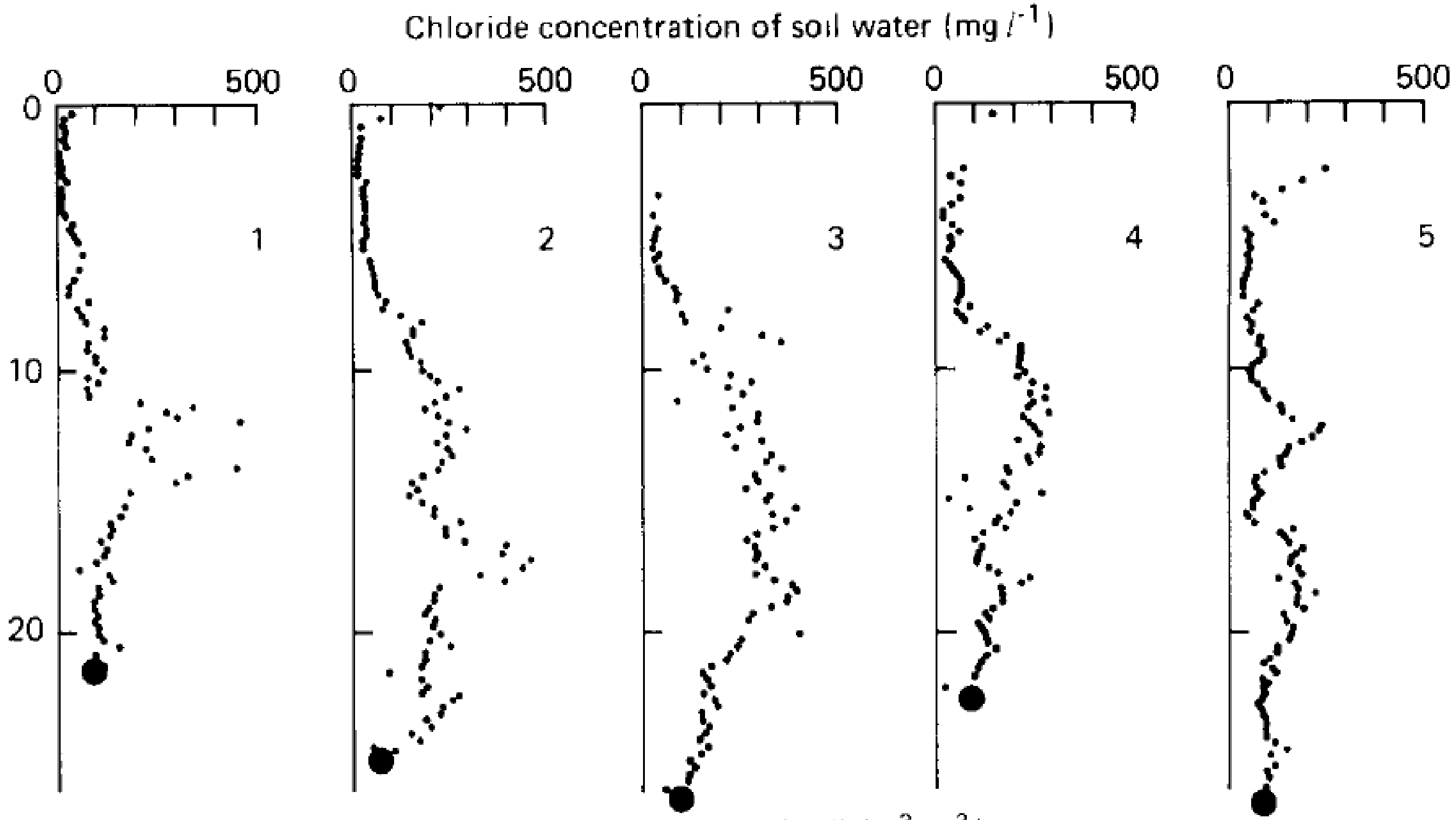
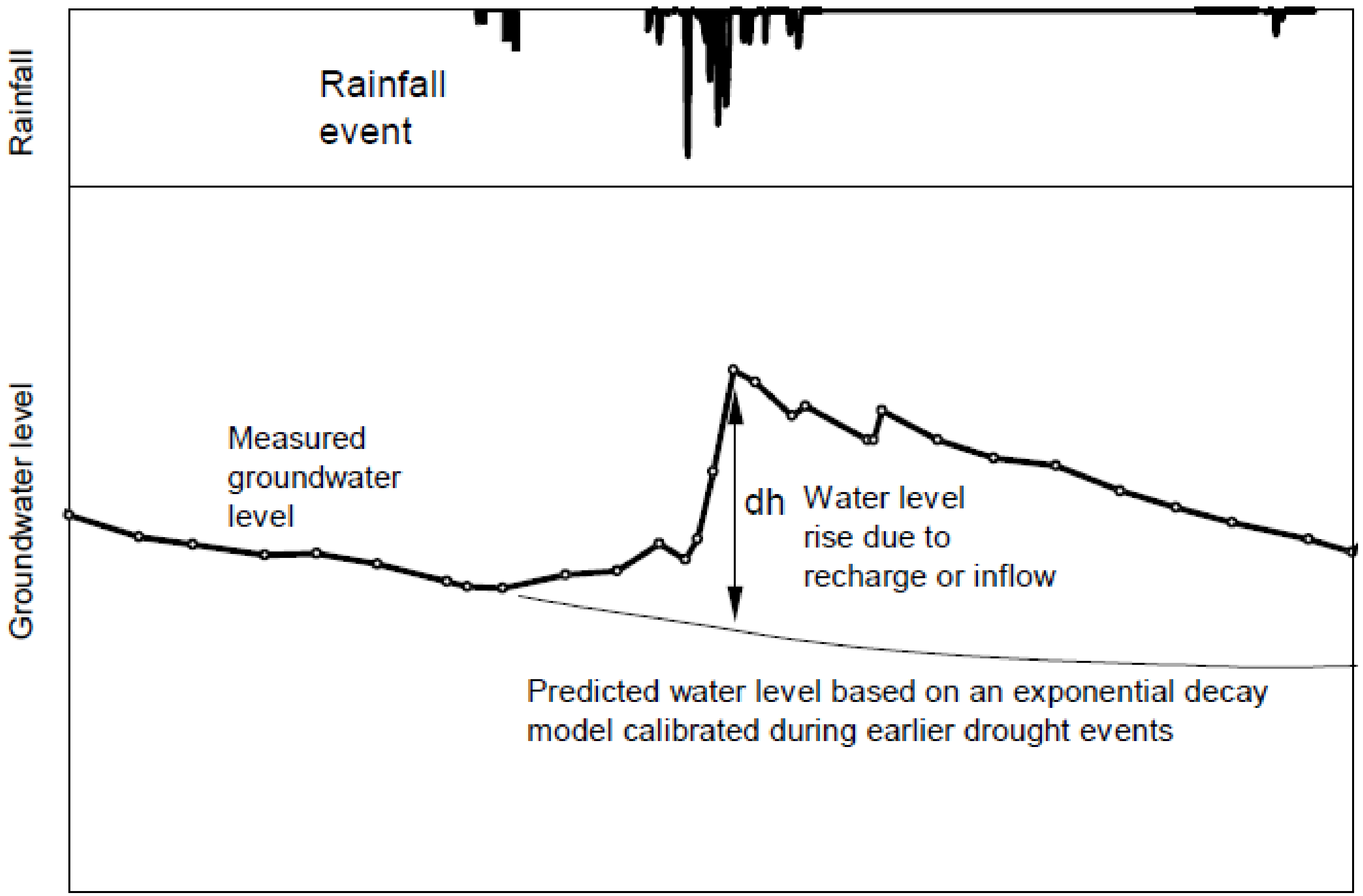
3.1 The chloride method



Allison et al. 1982

Sustainable Water Resources Management
3.2 Water level fluctuations



Allison et al. 1982

Sustainable Water Resources Management
3.2 Water level fluctuations

groundwater levels have to be rescaled to an elevation above a base-level h'. The drop in water level during no-recharge conditions depends on a decline constant y and on the time step Δt (UDLUFT & BLASY, 1975):

$$y = -\frac{1}{\Delta t} \ln\left(\frac{h'}{h_0'}\right)$$ *prolonged dry periods*

Allison et al. 1982

Sustainable Water Resources Management
3.2 Water level fluctuations

The difference between predicted and actual groundwater levels can then be transformed into groundwater recharge, if the effective porosity is known and is constant for the full range of water level changes:

$$R = p^*(h' - h_0' \exp^{-\gamma t})$$

Allison et al. 1982

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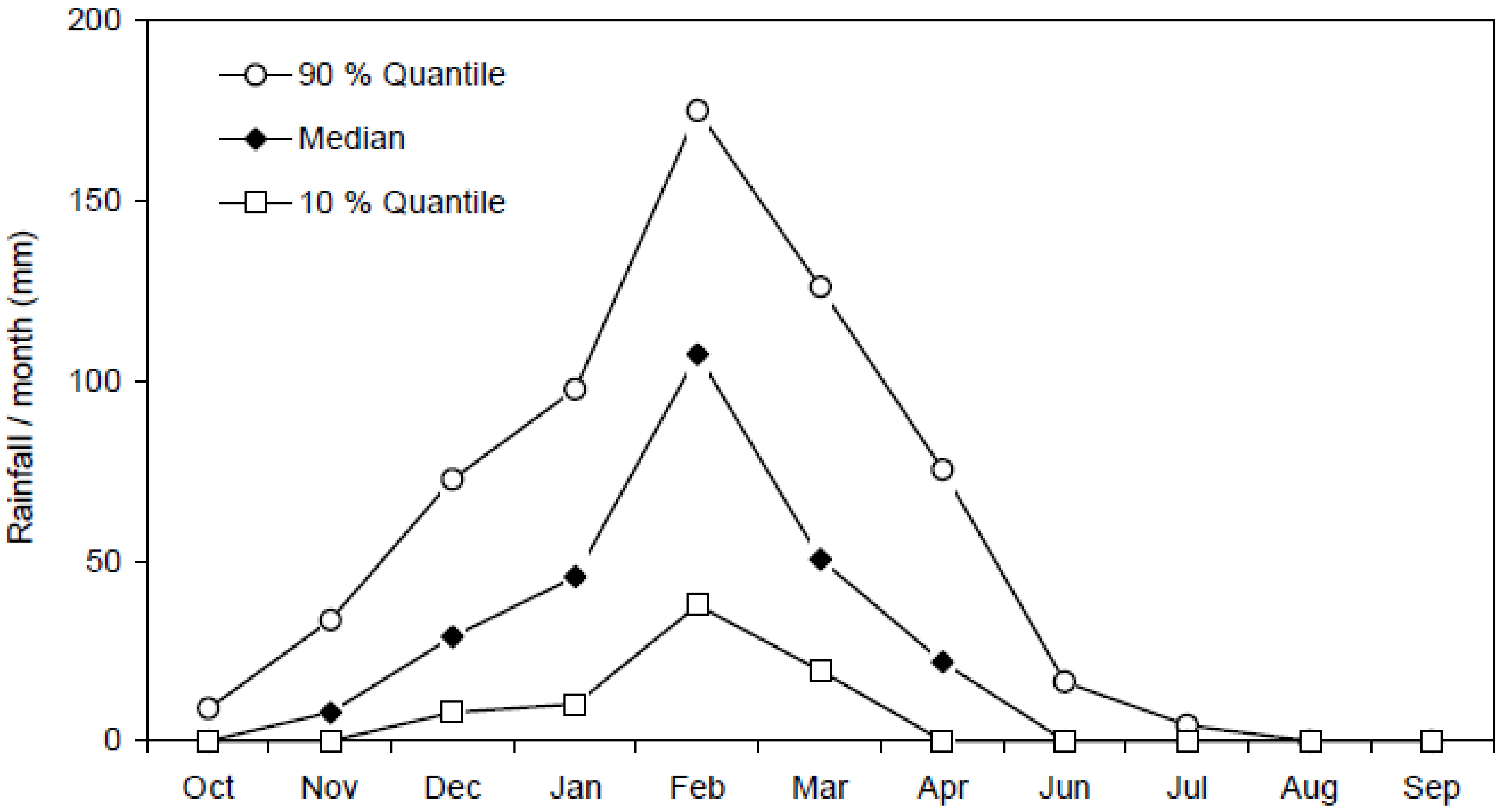
3.3 The water balance method



Külls 2000

Sustainable Water Resources Management
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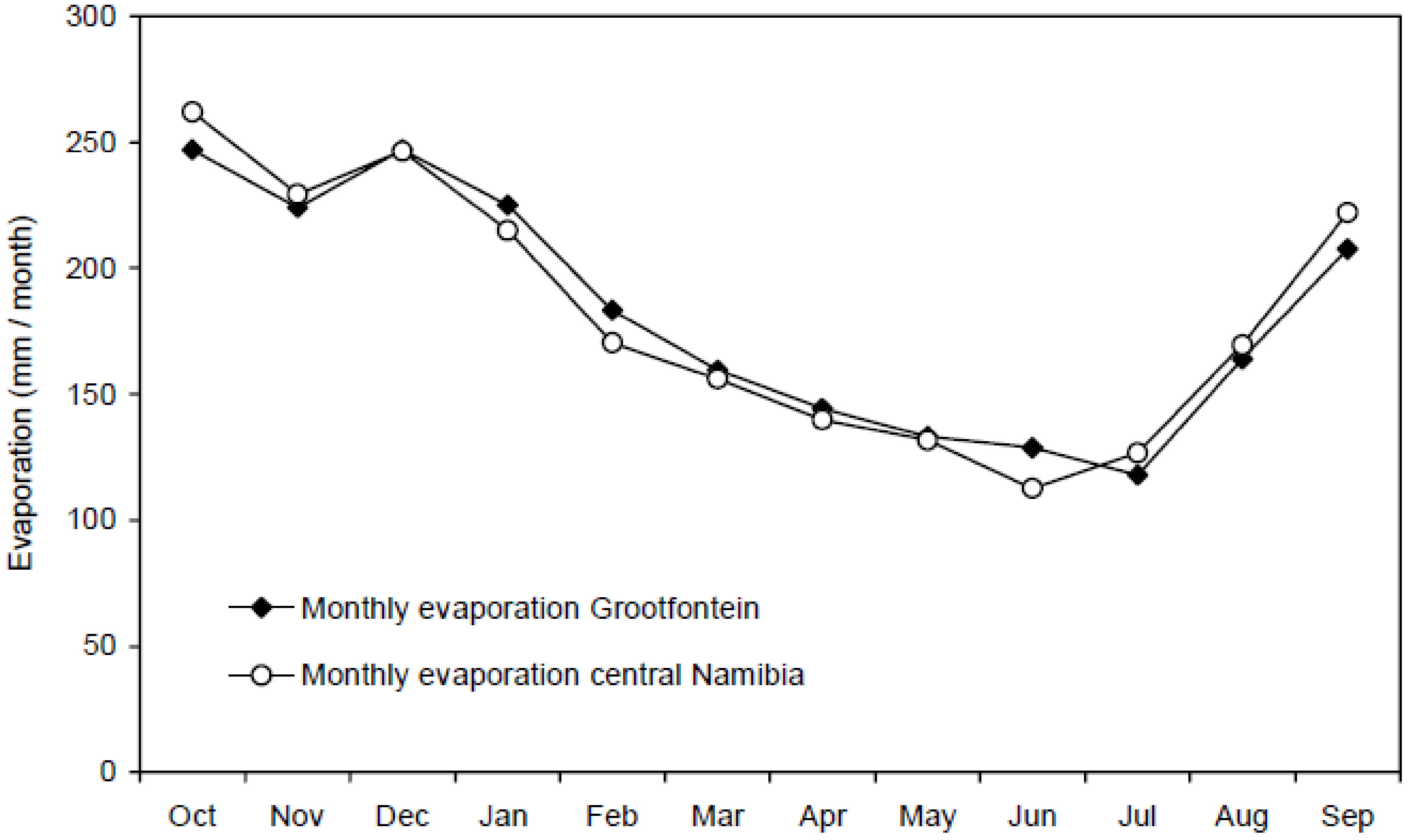

Külls 2000

Sustainable Water Resources Management
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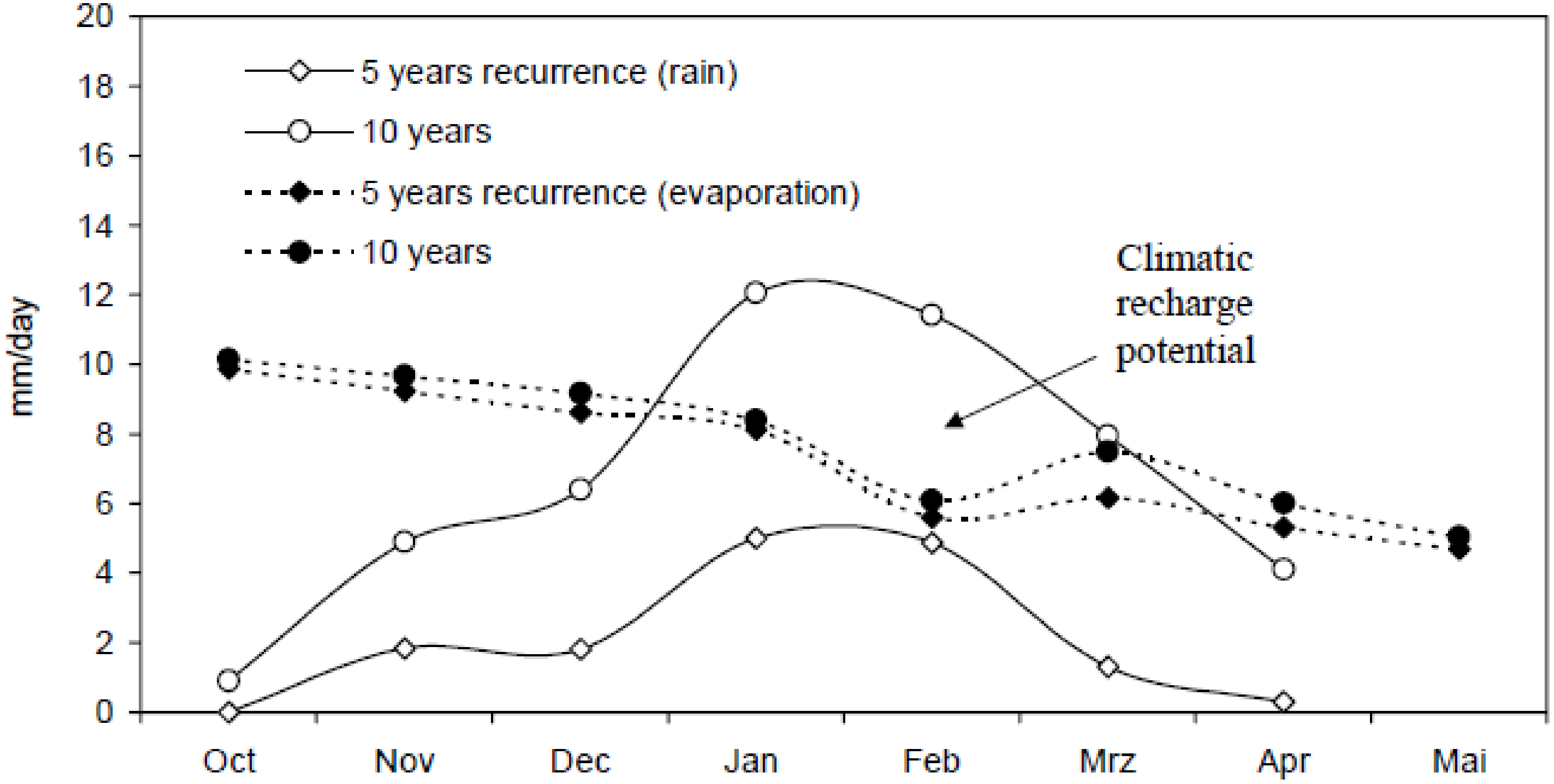

Külls 2000

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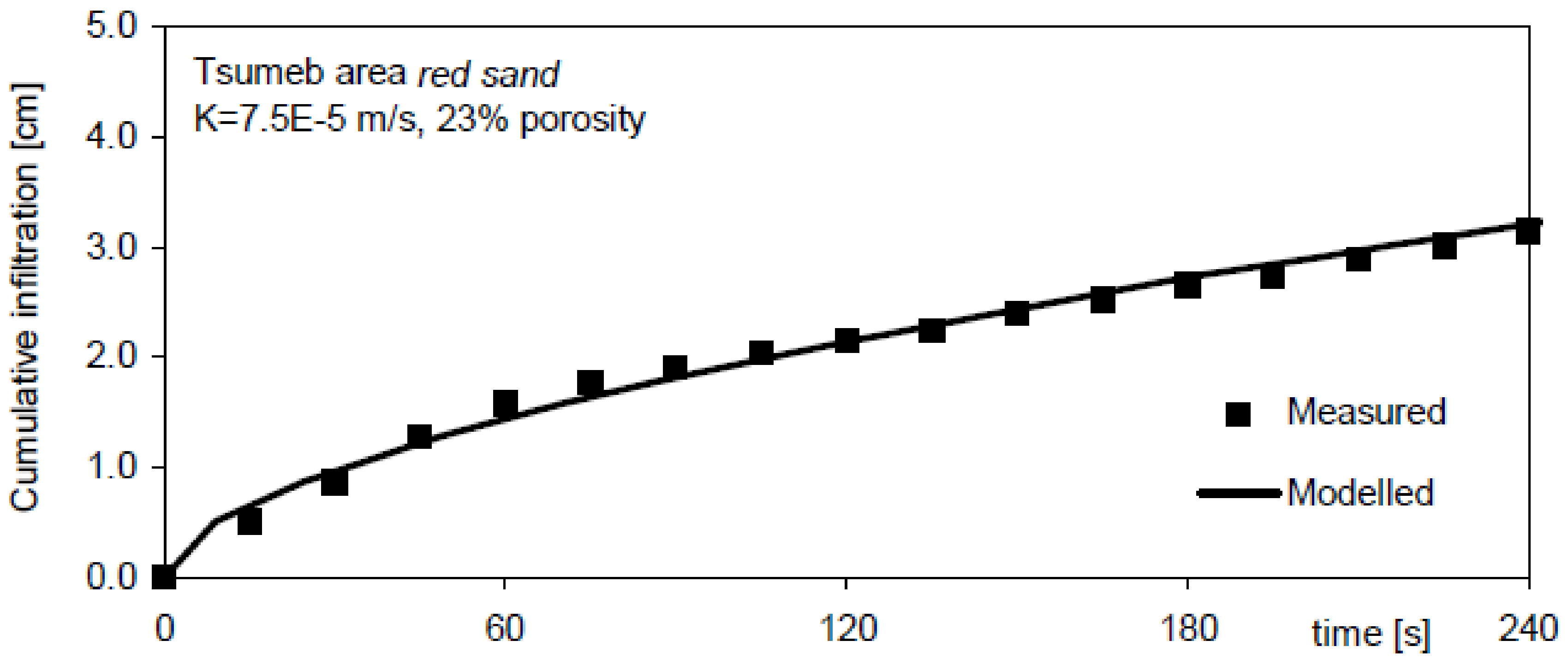

Külls 2000

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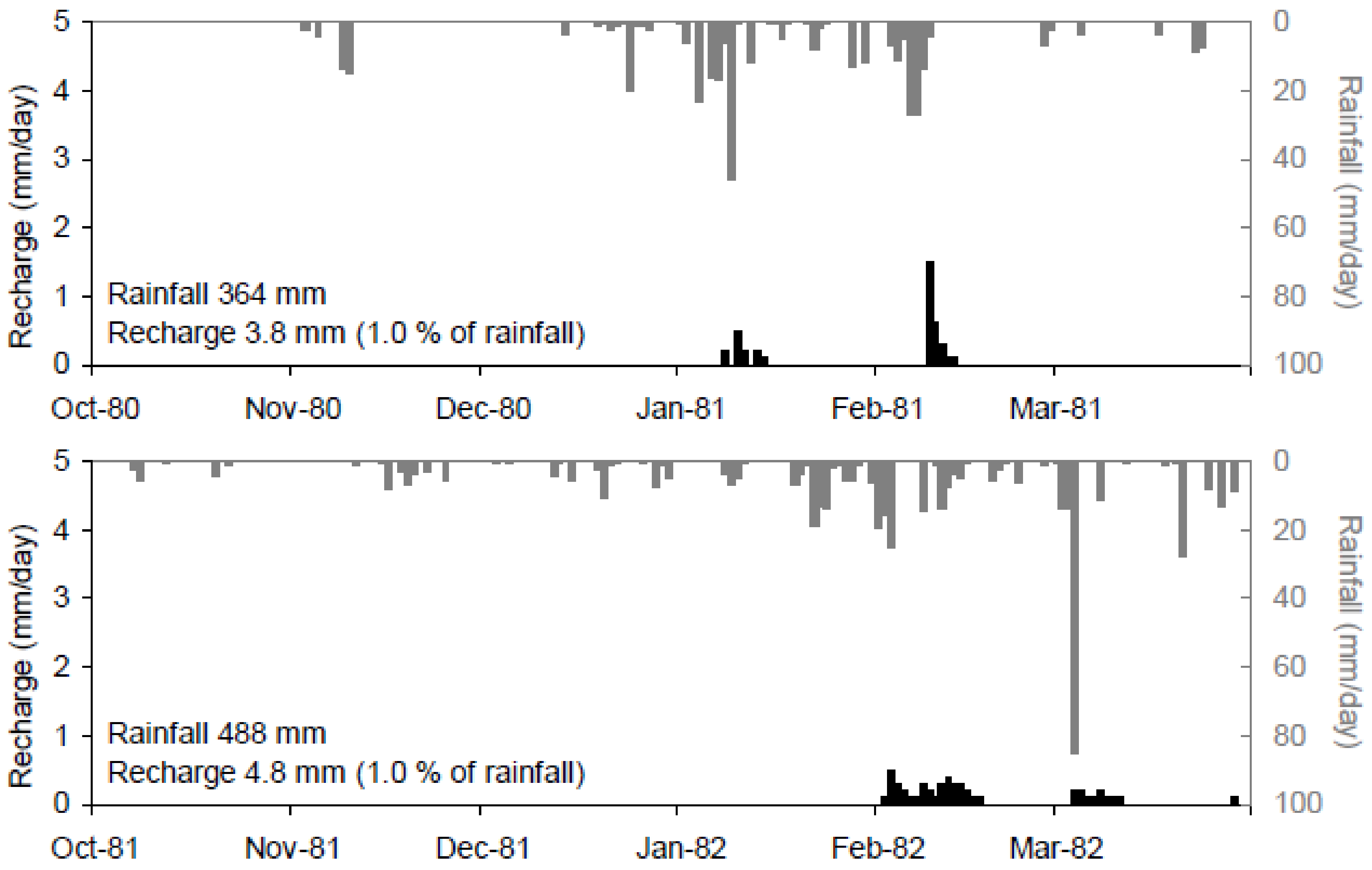

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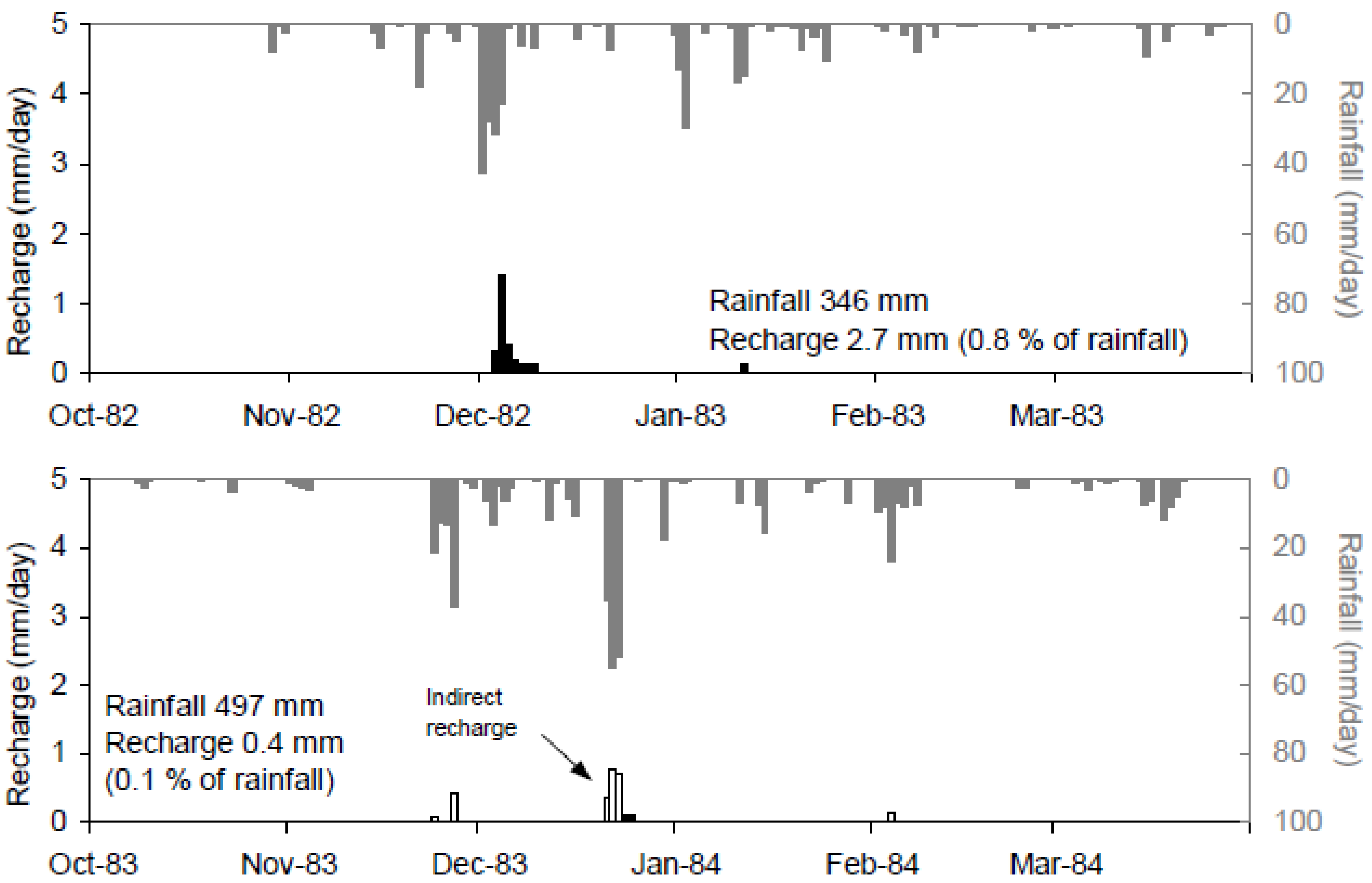
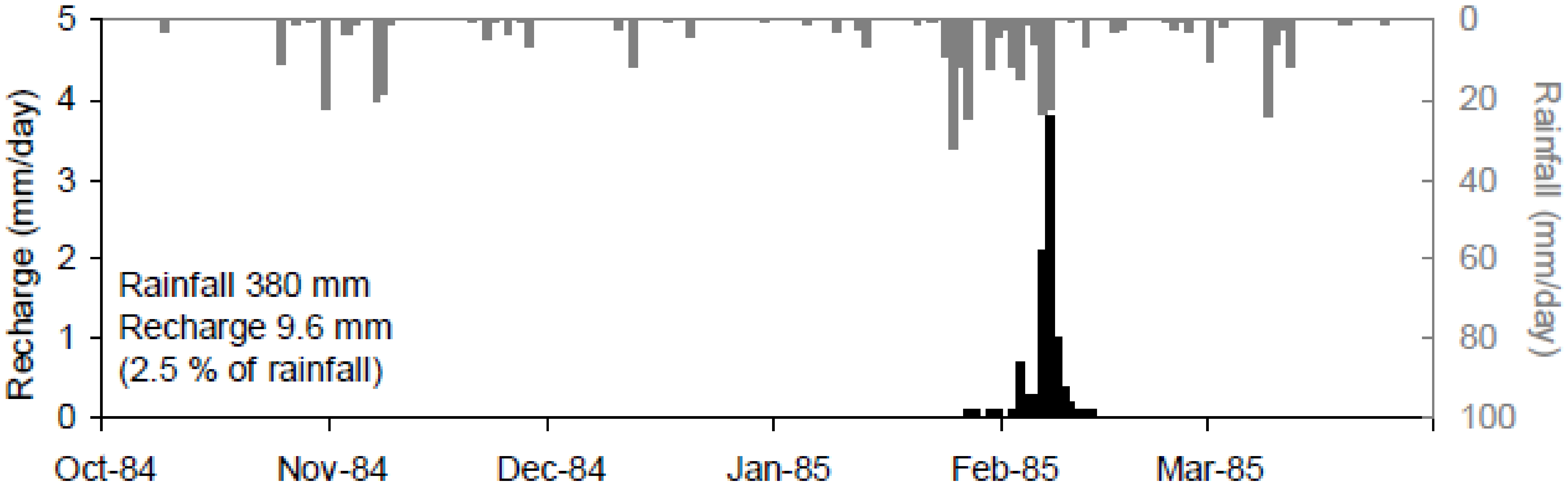


Sustainable Water Resources Management
3.3 The water balance method



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3.3 The water balance method

Season	Precipitation (mm)	Direct recharge (mm)	%
80/81	364	3.8	1.0
81/82	488	4.8	1.0
82/83	346	2.7	0.8
83/84	497	0.4	0.1
84/85	380	9.6	2.5
85/86	477	5.9	1.2
Average	**425**	**4.5**	**1.1***

* Weighted with rainfall amounts

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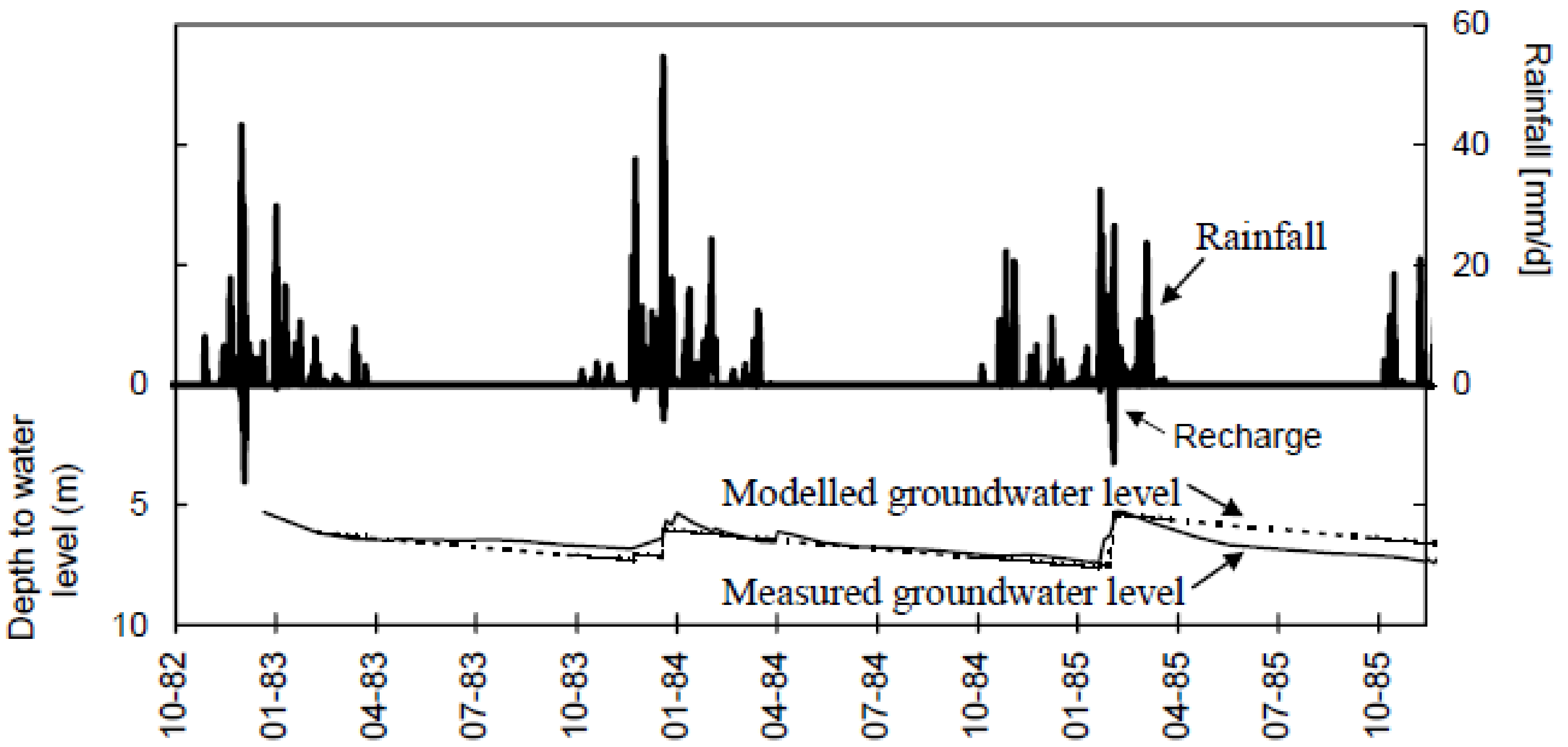
3.3 The water balance method



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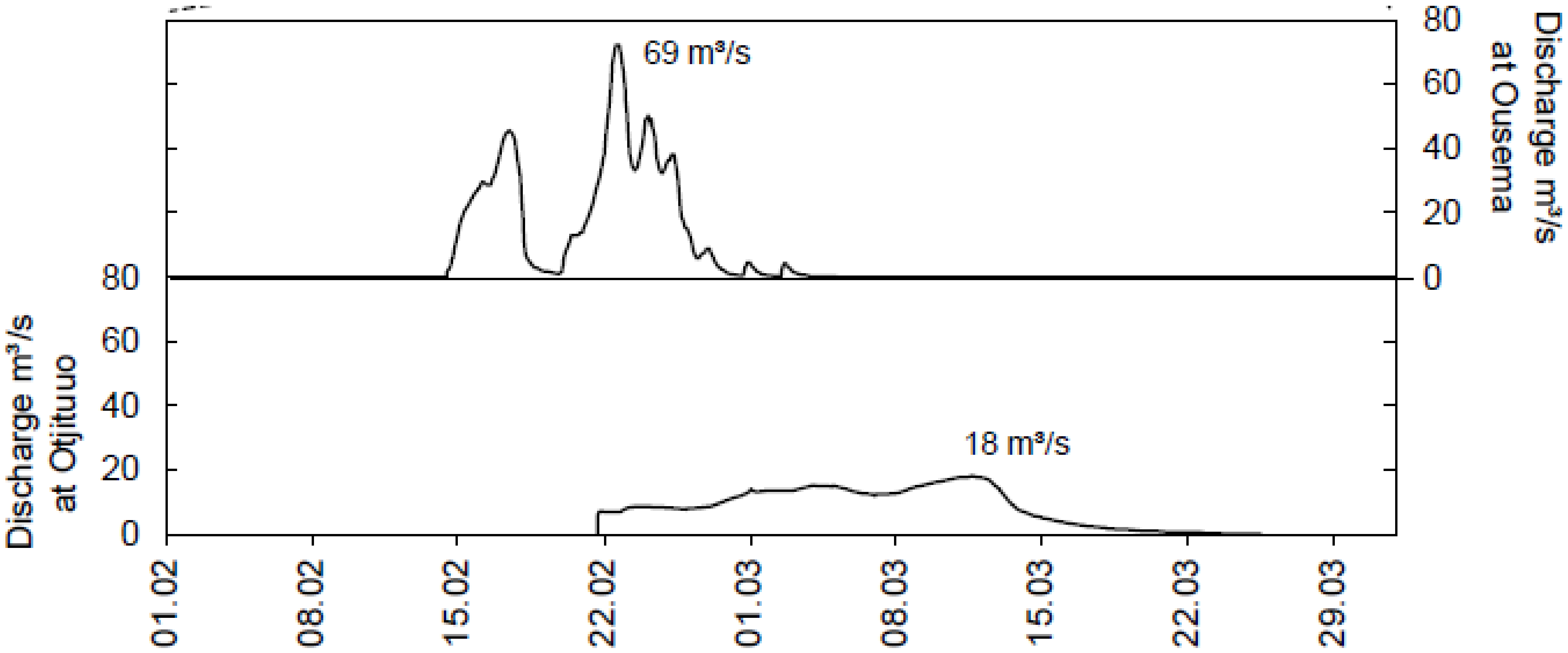
4 The water balance method



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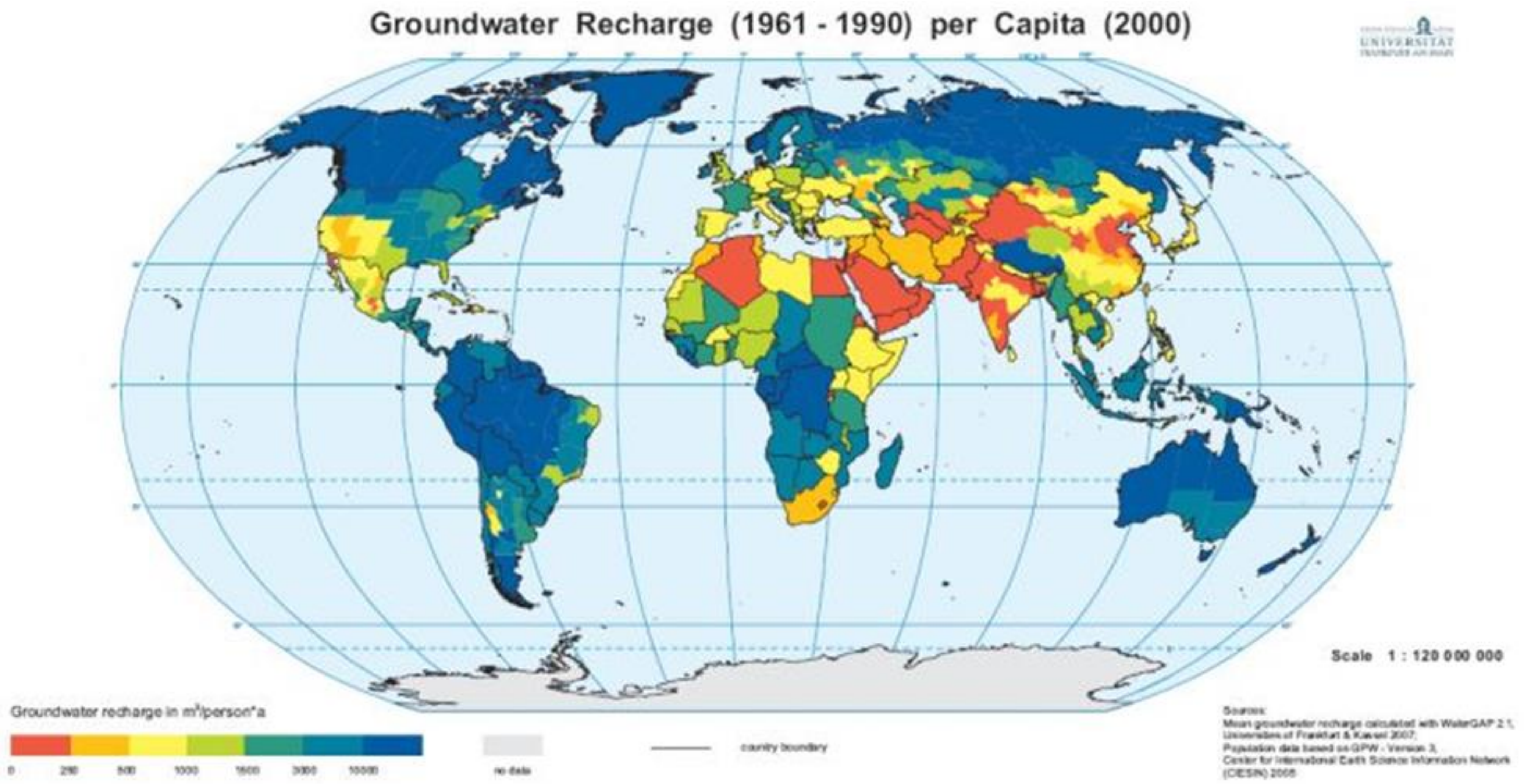
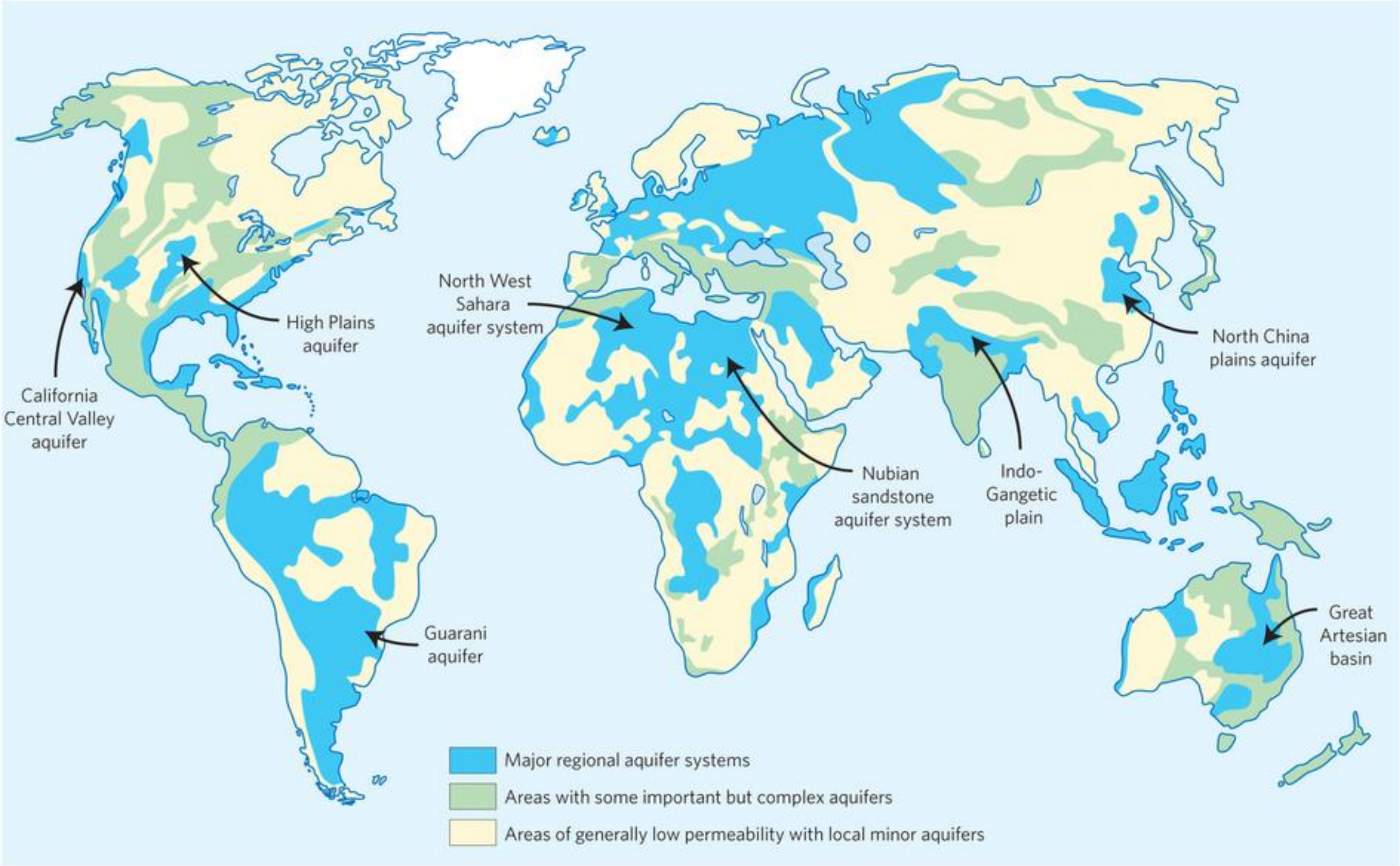
5. *What this is all for …. Access to water*



Sustainable Water Resources Management
5.1 Main Aquifer Systems of the World



Taylor, R. G. (2013) Ground water and climate change.
Nature Climate Change, 3, 322–329. doi:10.1038/nclimate1744

- Main aquifer systems sedimentary basins
- Hard-rock aquifers much less storage
- White areas are water scarce
  - ❑ check Europe
  - ❑ check your country
  - ❑ check China
  - ❑ check the Sahara

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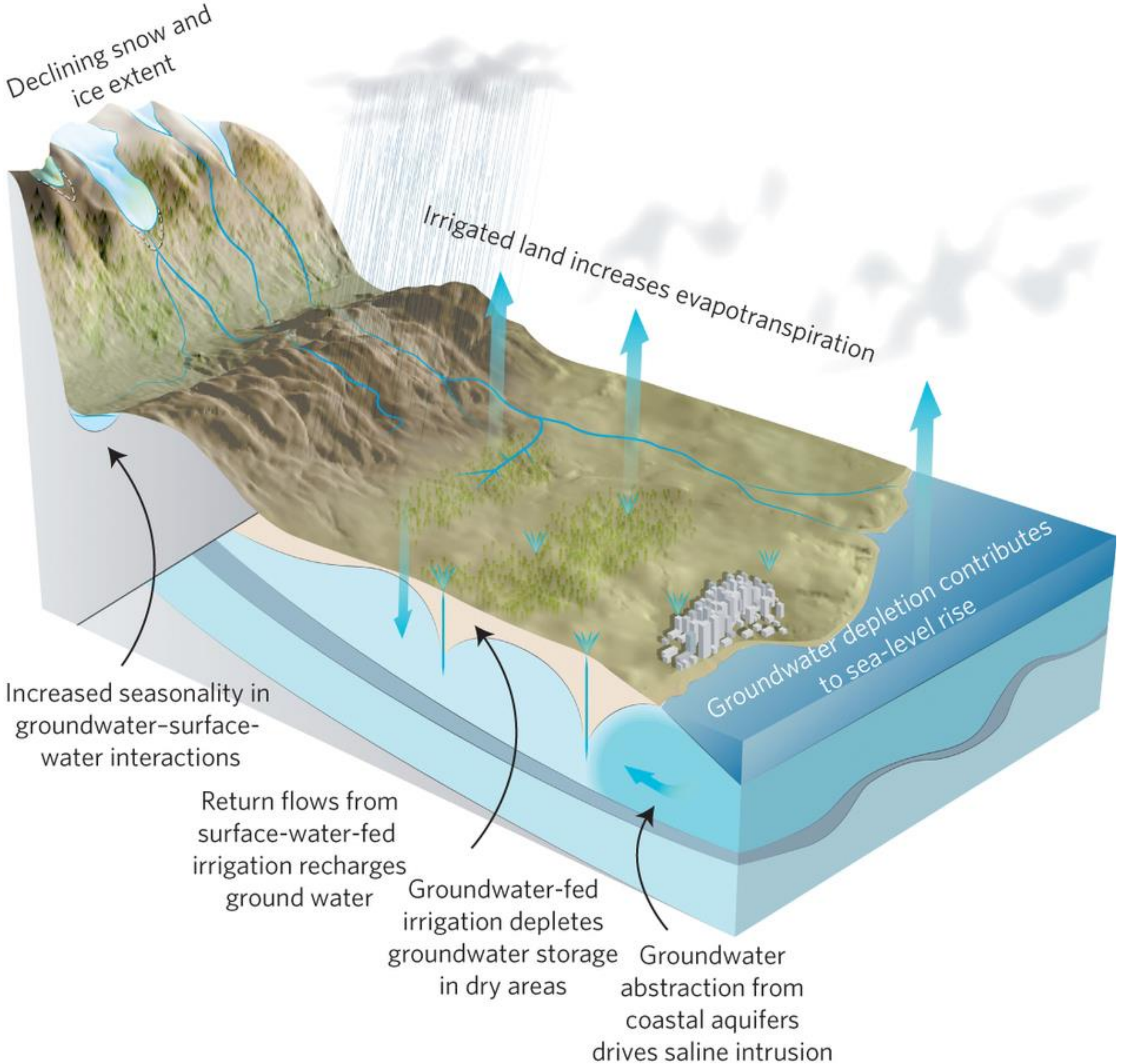
5.2 Anthropogenic Groundwater Recharge from irrigation



What happens to groundwater when climate changes ?

__Direct hydrological changes__

- Rainfall, evaporation and runoff change
- Groundwater levels change

__Indirect socio-hydrological changes__

- ❑ more irrigation

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Sustainable Water Resources Management
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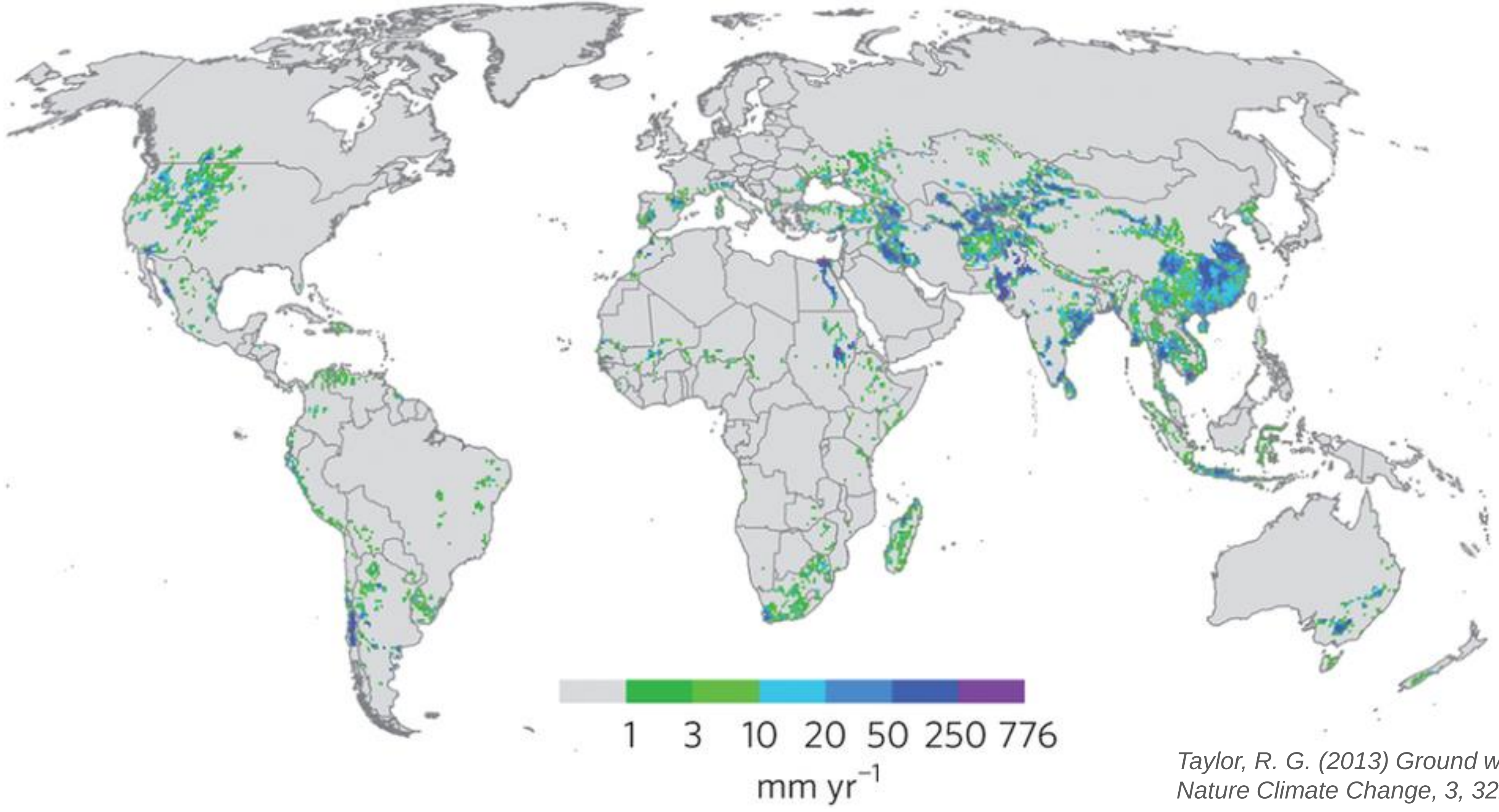

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What happens to groundwater when climate changes ?

Direct hydrological changes

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Indirect socio-hydrological

Prof. Dr. Christoph Külls

Sprechstunde: Mittwoch 11-13:00

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