FACULTY OF
BIOSCIENCE ENGINEERING

DEPARTMENT OF ENVIRONMENT
SOIL-ENVIRONMENT SYSTEMS
EXPLORATION & ENGINEERING GROUP

PROBLEM 1

Wim Cornelis

GHENT UNIVERSITY

SENSE Soil-Environment System Exploration & Engineering

unesco Chair

EUROPEAN SOCIETY for SOIL CONSERVATION

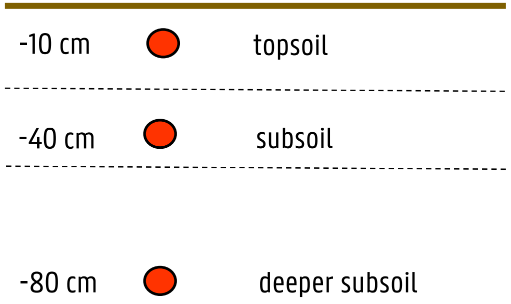
GIVEN

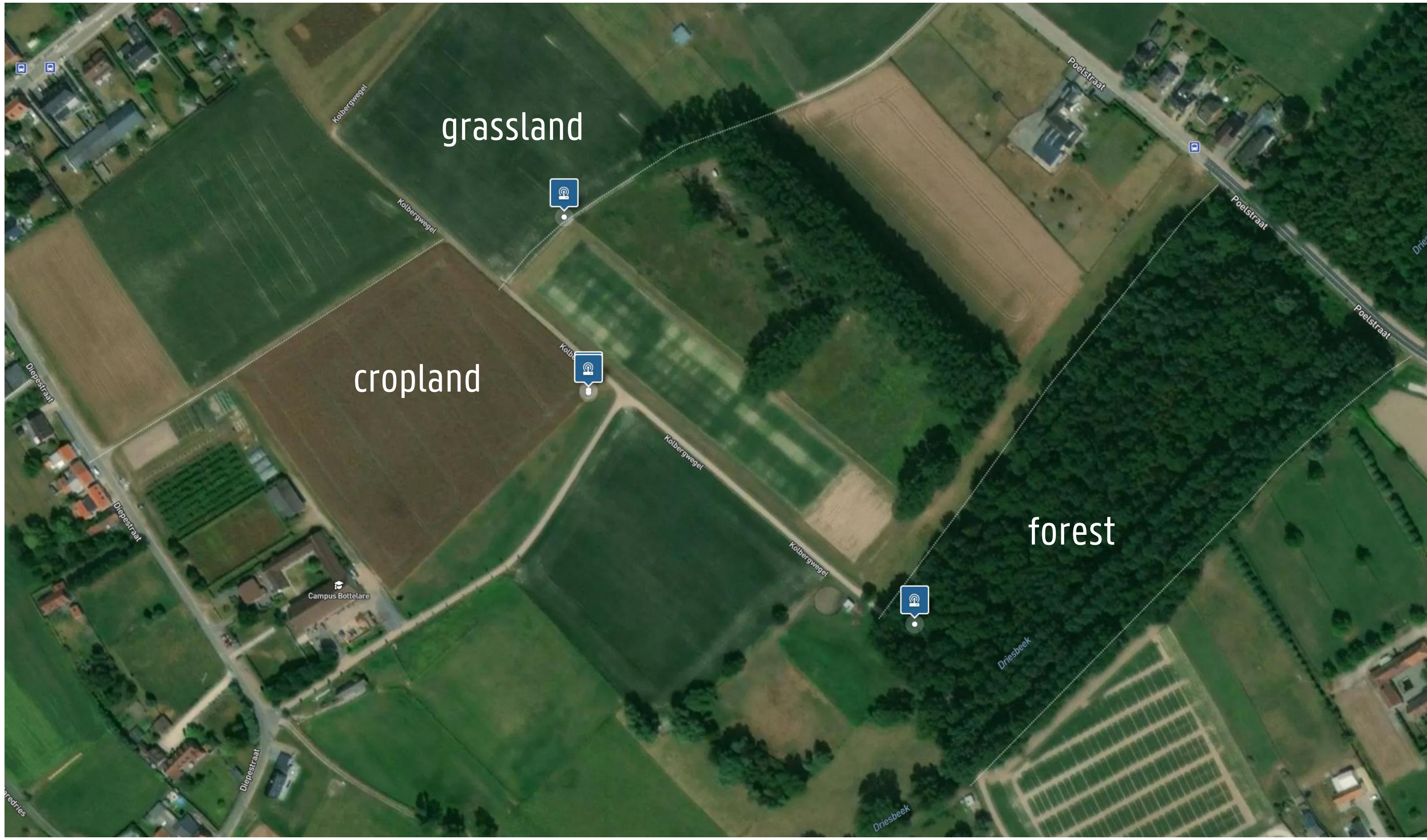
- Bottelare experimental site: 3 land uses → understand their impact on water and air regime

  → monitor soil-water content indirectly → sensor output at 3 depths

`Data_Problem_1.xlxs` or

`Data_Problem_1_*.csv`





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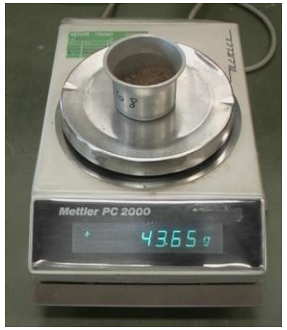
	porosity (m^3 m^{-3})		
depth (cm)	cropland	forest	grassland
-10	0.440	0.678	0.488
-40	0.379	0.486	0.394
-80	0.397	0.432	0.419

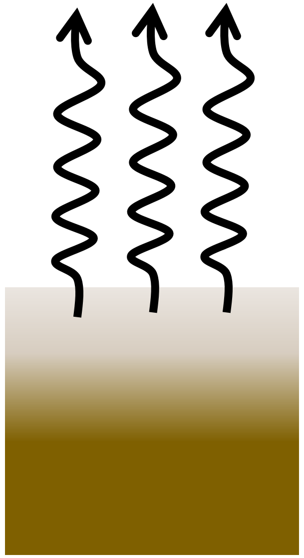
undisturbed soil cores → to lab

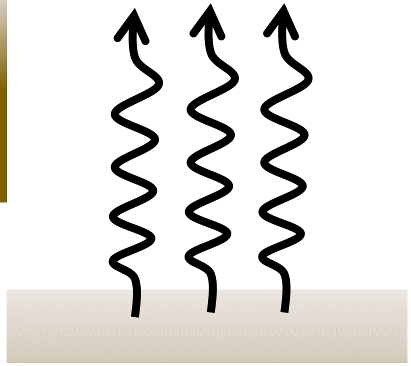
- with pycnometer
- from bulk density ρ_b
  (core, excavation, clod method, or PTFs)



$\boxed{\rho_b \rightarrow \phi}$

$$\rho_s = \frac{1}{\frac{X_{w,m}}{\rho_m} + \frac{X_{w,om}}{\rho_{om}}}$$





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2.2. BULK DENSITY
2.2.1. DEFINITION

$$\boxed{\rho_b = \frac{m_s}{V}}$$

m_s = oven-dry soil (105 °C – 24 h)

2.2. BULK DENSITY
2.2.3. MEASUREMENT OF BULK DENSITY

Core method

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2.2. BULK DENSITY
2.2.3. MEASUREMENT OF BULK DENSITY

Excavation method

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2.2. BULK DENSITY
2.2.3. MEASUREMENT OF BULK DENSITY

Clod method

→ coat cl

Archimede

water equ

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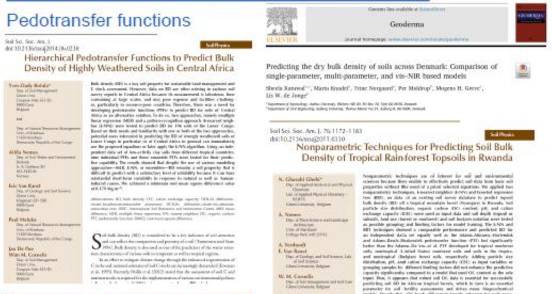
2.2. BULK DENSITY
2.2.3. MEASUREMENT OF BULK DENSITY

Pedotransfer functions


Hierarchical Pedotransfer Functions to Predict Bulk Density of Highly Weathered Soils in Central Africa

Geoderma

Predicting the dry bulk density of soils across Denmark: Comparison of single-parameter, multi-parameter, and vis–NIR based models

Nonparametric Techniques for Predicting Soil Bulk Density of Tropical Rainforest Topsoils in Rwanda

$\boxed{\rho_b = f(\text{texture, OC, depth, DCB-Al, DCB-Fe})}$

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2.3. PARTICLE DENSITY
2.3.1. DEFINITION

$$\boxed{\rho_s = \frac{m_s}{V_s}}$$

2.3. PARTICLE DENSITY
2.3.2. MEASUREMENT OF PARTICLE DENSITY

Pycnometer method/air pycnometer method

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2.3. PARTICLE DENSITY
2.3.2. MEASUREMENT OF PARTICLE DENSITY

Estimated from weighted average of solid components

- volume fractions

$$\boxed{\rho_s = \rho_m\, X_m + \rho_{om}\, X_{om}}$$

with X in m³/m³

- weight fractions

$$\boxed{\rho_s = \frac{1}{\frac{X_{w,m}}{\rho_m} + \frac{X_{w,om}}{\rho_{om}}}}$$

with Xw in kg/kg

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2.3. PARTICLE DENSITY
2.3.2. MEASUREMENT OF PARTICLE DENSITY

Pedotransfer functions


Geoderma

Predicting soil particle density from clay and soil organic matter contents

Corrigendum

Corrigendum to 'Predicting soil particle density from clay and soil organic matter contents' [Geoderma 286 (2017) 83–87]

$\boxed{\rho_s = f(\text{clay, OC})}$

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2.4. POROSITY
2.4.1. DEFINITION

$$\boxed{\phi = \frac{V_g + V_l}{V}}$$

2.4. POROSITY
2.4.2. MEASUREMENT OF POROSITY

Air pycnometer method

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2.4. POROSITY
2.4.2. MEASUREMENT OF POROSITY

Calculated from bulk and particle density

$$\boxed{\phi = 1 - \frac{\rho_b}{\rho_s}}$$

some values for orientation:

	ϕ (m³ m⁻³)
sandy soil	0.28-0.47
loamy soil	0.40-0.55
clayey soil	0.47-0.66

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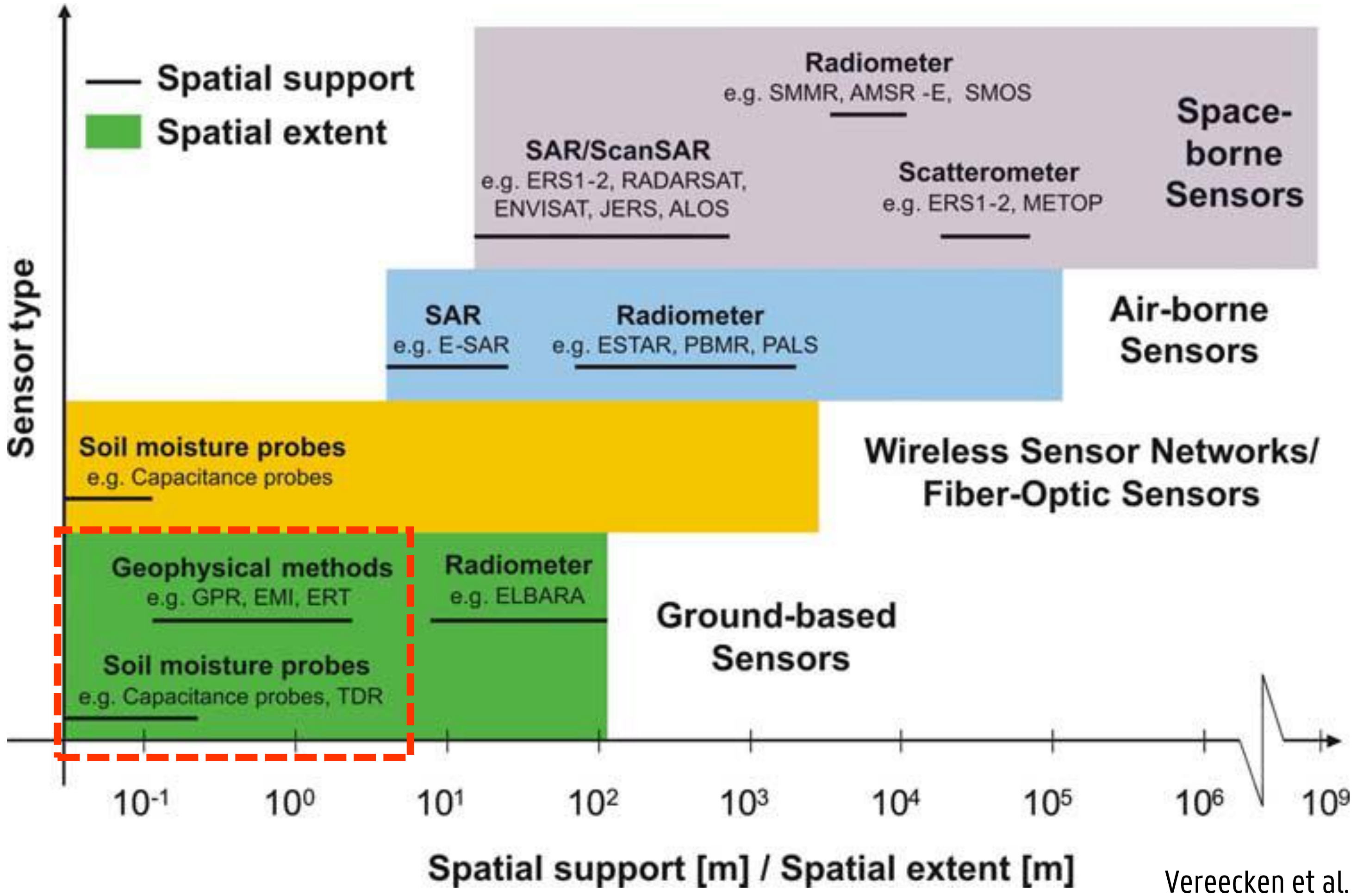
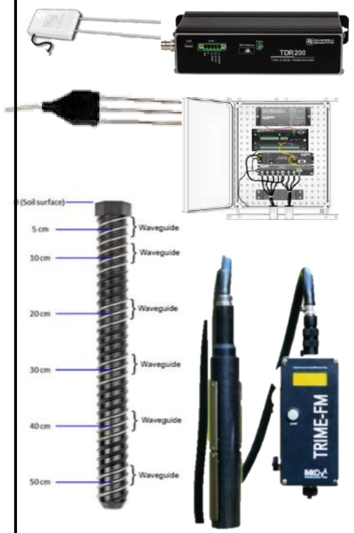
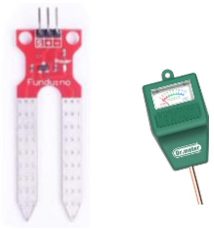
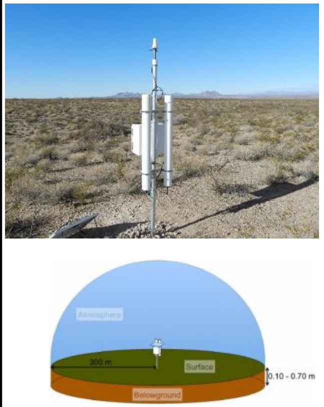
QUESTION 1

Which type of sensor (i.e., based on which method) would you use for accurately monitoring soil-water content on an hourly basis at a given depth at a relatively low cost?



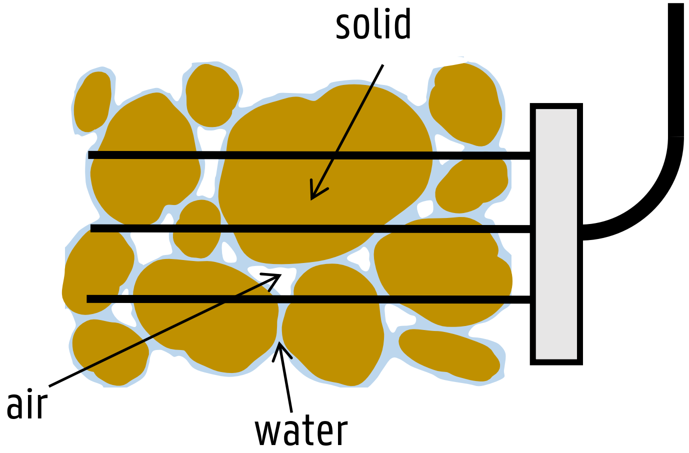
Vereecken et al. (2008)

QUESTION 1

	TDR (+Trime)	Impedance	Capacitance	EC	Geophysical (GPR, ERT, EMI)	Other (cosmic ray, ...)
						
accuracy	++	+	+	-	+/-	++
frequency of reading	++	++	++ → +/-	++ → +/-	+/-	++
cost	--	--	-	++	--	--
depth reading	++	++	++	++	+	--

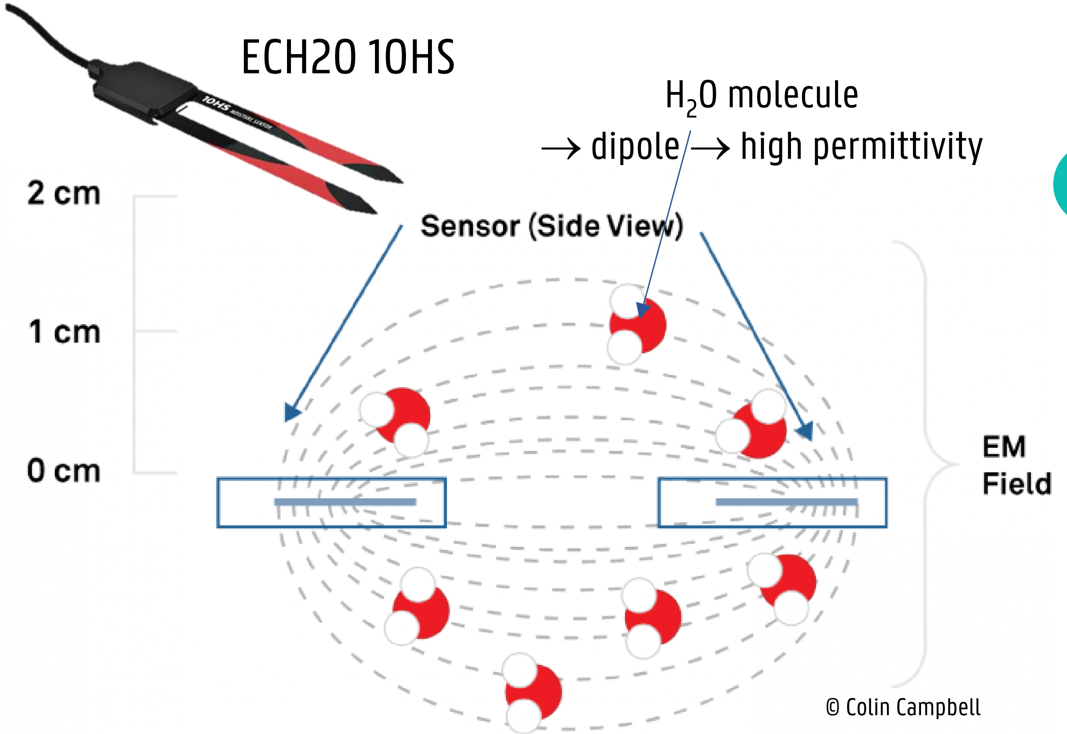
QUESTION 1

→ capacitance, based on dielectric method



e.g. Teros 10-12

via telemetry → data in cloud
https://zentracloud.com/#/dashboard_map



Positively and negatively charged rods form an EM field
→ bulk soil = capacitor → measure charge time
→ charge-storing capacity (capacitance) ~ dielectric properties (permittivity)

QUESTION 1

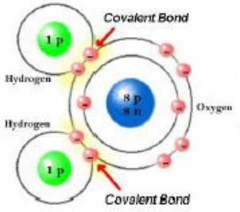
4.1. MOLECULAR PROPERTIES OF WATER

H_2O

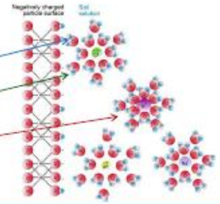
- 10 protons
- 10 electrons

→ electrically neutral

however, centre of + charge
displaced from centre of – charge



→ dipole moment → electric field
→ H_2O molecules interact with
- electric field of solids (minerals and OM) (adhesion)
- each other (cohesion)
- dissolved ions



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4.2. FLUID PROPERTIES OF WATER

4.2.1. THERMAL AND MECHANICAL PROPERTIES

- very high boiling point
- high melting point
- low fluid density
- liquid phase is denser than solid phase
- large quantity of heat to melt unit mass of ice
- large quantity of heat to evaporate unit quantity of water
- large permittivity or dielectrical constant!
- large specific heat → small temperate rise as it adsorbs heat → strong moderating effect on climate
- excellent solvent (→ chemicals dissolve, react, are transported in water)

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5.2. DEFINITIONS

5.2.1. GRAVIMETRIC WATER CONTENT

$$\boxed{\theta_g = \frac{m_w}{m_s}}$$

alternative symbol
w

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5.2. DEFINITIONS

5.2.2. VOLUMETRIC WATER CONTENT

$$\theta_v = \frac{V_w}{V}$$

alternative symbol
θ

$$\boxed{\theta_v = \theta_g \frac{\rho_b}{\rho_w}}$$

air content

$$\boxed{a = \phi - \theta_v}$$

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QUESTION 1


5.3. MEASUREMENT OF WATER CONTENT
5.3.1. VARIETY OF METHODS
Spatial support
Spatial extent
Sensor type
Radiometer
SAR/ScanSAR
Scatterometer
Space-borne Sensors
SAR
Radiometer
Air-borne Sensors
Soil moisture probes
Wireless Sensor Networks/ Fiber-Optic Sensors
Geophysical methods
Radiometer
Soil moisture probes
Ground-based Sensors
5.3. MEASUREMENT OF WATER CONTENT
5.3.3. DIELECTRIC METHODS
exploit strong dependence of soil dielectric properties on water content
soil dielectric properties affect
velocity of EM wave along transmission line (TDR)
characteristic impedance of transmission line (ADR)
capacitance of two electrodes (capacitance - FDR)
dielectric methods boosted since 1980's
Gaylon Campbell & Clark Topp
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5.3. MEASUREMENT OF WATER CONTEN
5.3.2. GRAVIMETRY BY OVEN-DRYING
Volumetric soil-water content from oven drying
photos: Eijkelkamp Soil & Water
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5.3. MEASUREMENT OF WATER CO
5.3.2. GRAVIMETRY BY OVEN-DRYING
Convective oven drying
photo: Eijkelkamp Soil & Water
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5.3. MEASUREMENT OF WATER CONTENT
5.3.2. GRAVIMETRY BY OVEN-DRYING
Volumetric soil-water content from oven drying
$\theta_v = \frac{m_{wet} - m_s}{\rho_w V_{core}}$
$\theta_v = \theta_g \frac{\rho_b}{\rho_w}$
wet soil
oven (105 °C – 24 h)
dry soil
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5.3. MEASUREMENT OF WATER CONT
5.3.2. GRAVIMETRY BY OVEN-DRYING
Convective oven drying
$\theta_g = \frac{m_{wet} - m_s}{m_s}$
wet soil
oven (105 °C – 24 h)
photos: UGent
dry soil
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QUESTION 1

5.3. MEASUREMENT OF WATER CONTENT
5.3.3. DIELECTRIC METHODS – E. Capacitance technique

- measures capacitance C between two electrodes)

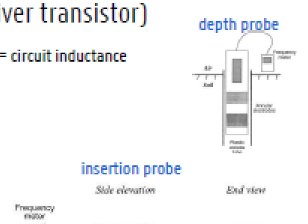
$$C = \epsilon_r \, \epsilon_0 \, G$$

G = geometric constant

- by measuring frequency of oscillation F of an oscillator circuit (which exists of capacitor formed by electrodes, inductor, driver transistor)

$$F = \frac{1}{2 \, \pi \, \sqrt{L_i \, C}}$$

L_i = circuit inductance



- can be calibrated against θ or ε_r
- in soil F determined by C and EC

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5.3. MEASUREMENT OF WATER CONTENT
5.3.3. DIELECTRIC METHODS – E. Capacitance technique

- termed Frequency Domain Reflectometry (FDR) in case oscillator frequency is controlled within a certain range to find resonant frequency (at which amplitude is greatest), which is related to soil's water content
- wide variety of sensors (insertion probes, depth probes)

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5.3. MEASUREMENT OF WATER CONTENT
5.3.3. DIELECTRIC METHODS – E. Capacitance technique

Insertion (pin/rod) probes

HydroSense (Campbell Sci.)

Hydra Probe (Stevens Water Monitoring Systems)

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5.3. MEASUREMENT OF WATER CONTENT
5.3.3. DIELECTRIC METHODS – F. Field installation

horizontal insertion probes → boreholes

newest device on market for Teros 10 sensors

https://www.metergroup.com/environment/?wvideo=bieasfa6sl

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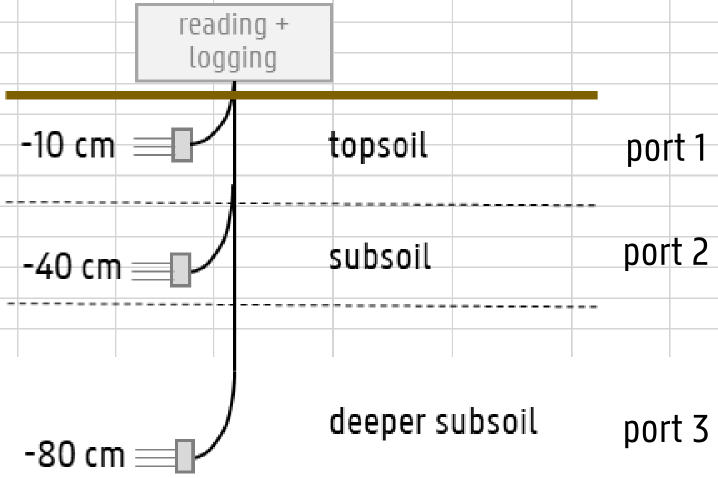
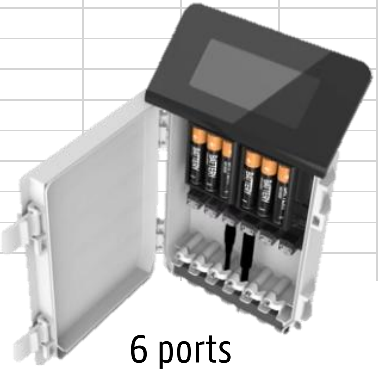
QUESTION 2

Determine the volumetric soil-water content (in m^3 m^{-3}) from the ε_r data (= sensor output) recorded per hour from 1 January 2021 till 29 September 2022, per sensor and land use, and plot it over complete period – work in groups of three, one land use per student

`Data_Problem_1.xlxs` or `Data_Problem_1_*.csv`

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	z6-08476	Port1	Port2	Port3	Port1	Port2	Port3	Port1	Port2	Port3	Sensor1	Sensor2	Sensor3	Sensor1	Sensor2	Sensor3			
2	# Records: 4173	TEROS 12	TEROS 10	TEROS 12							DMM	DMM	DMM	DMM_filte	DMM_filte	DMM_filter			
3	Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta	theta	theta	theta	W mm	P mm	ET mm
4	2021-01-01 00:00:00	20.1	14.6	17.4															
5	2021-01-01 01:00:00	20.1	14.6	17.4															
6	2021-01-01 02:00:00	20.1	14.6	17.4															
7	2021-01-01 03:00:00	20.1	14.6	17.4															
8	2021-01-01 04:00:00	20.1	14.6	17.4															
9	2021-01-01 05:00:00	20.1	14.6	17.4															
10	2021-01-01 06:00:00	20.1	14.6	17.4															
11	2021-01-01 07:00:00	20.1	14.6	17.4															
12	2021-01-01 08:00:00	20.1	14.6	17.4															
13	2021-01-01 09:00:00	20.1	14.6	17.4															
14	2021-01-01 10:00:00	20.1	14.6	17.4															
15	2021-01-01 11:00:00	20.1	14.6	17.4															
16	2021-01-01 12:00:00	20.1	14.6	17.4															
17	2021-01-01 13:00:00	20.1	14.6	17.4															
18	2021-01-01 14:00:00	20.1	14.6	17.4															



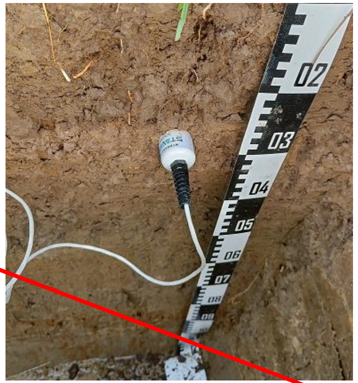


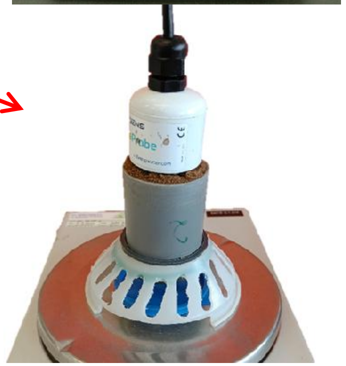
QUESTION 2

$\boxed{\varepsilon_r \rightarrow \theta}$ calibration curve! $\sqrt{\varepsilon_r} \rightarrow \theta = f(\sqrt{\varepsilon_r})$

- Literature: "universal" equations ("Topp's equation", Ledieu's equation", …)
- Empirical : own regression

  $\rightarrow$ based on own dataset of (sensor) measured ε_r and gravimetrically determined θ
  - field calibration
  - laboratory calibration



- Theoretical: dielectric mixing model

$$\boxed{\epsilon_r^{\alpha} = \epsilon_{r\ a}^{\alpha}\ f_a + \epsilon_{r\ s}^{\alpha}\ f_s + \epsilon_{r\ w}^{\alpha}\ f_w + \epsilon_{r\ bw}^{\alpha}\ f_{bw}}$$

$$\sqrt{\epsilon_r} = 1 + \frac{(\sqrt{\epsilon_{r\ s}} - 1)\ \rho_b}{\rho_s} + 8\ \theta$$

$$\theta = \frac{\sqrt{\epsilon_r} - [1 + (\sqrt{\epsilon_{rs}} - 1)(1 - \phi)]}{8}$$

$$\phi = 1 - \frac{\rho_b}{\rho_s}$$

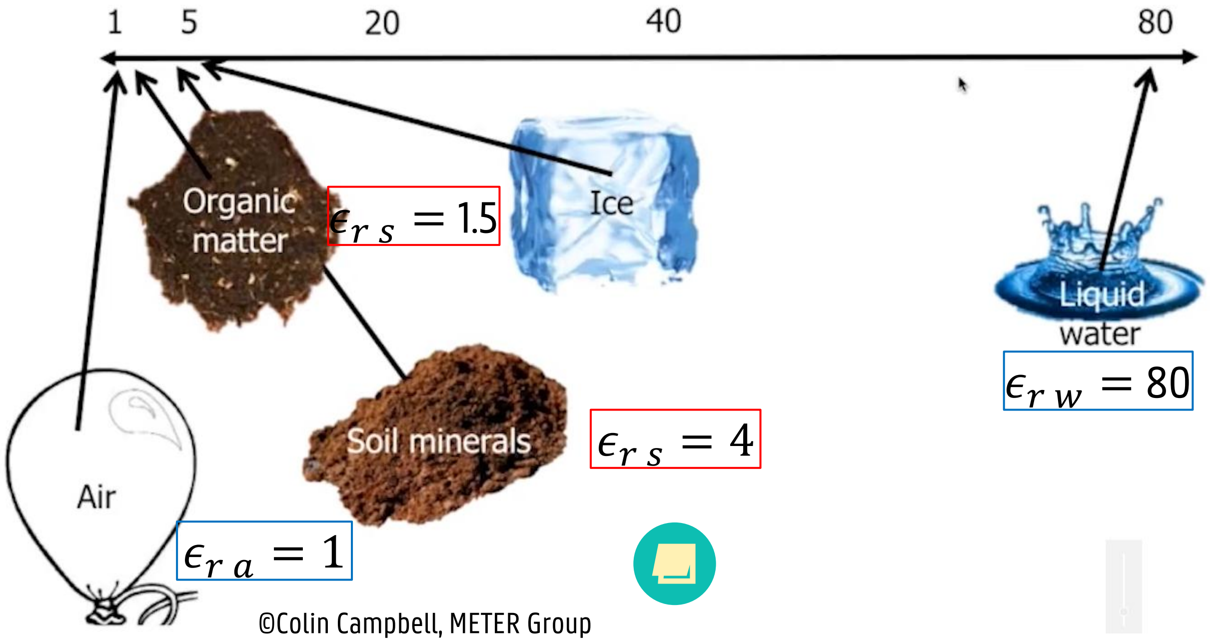
$$\frac{\rho_b}{\rho_s} = 1 - \phi$$

QUESTION 2

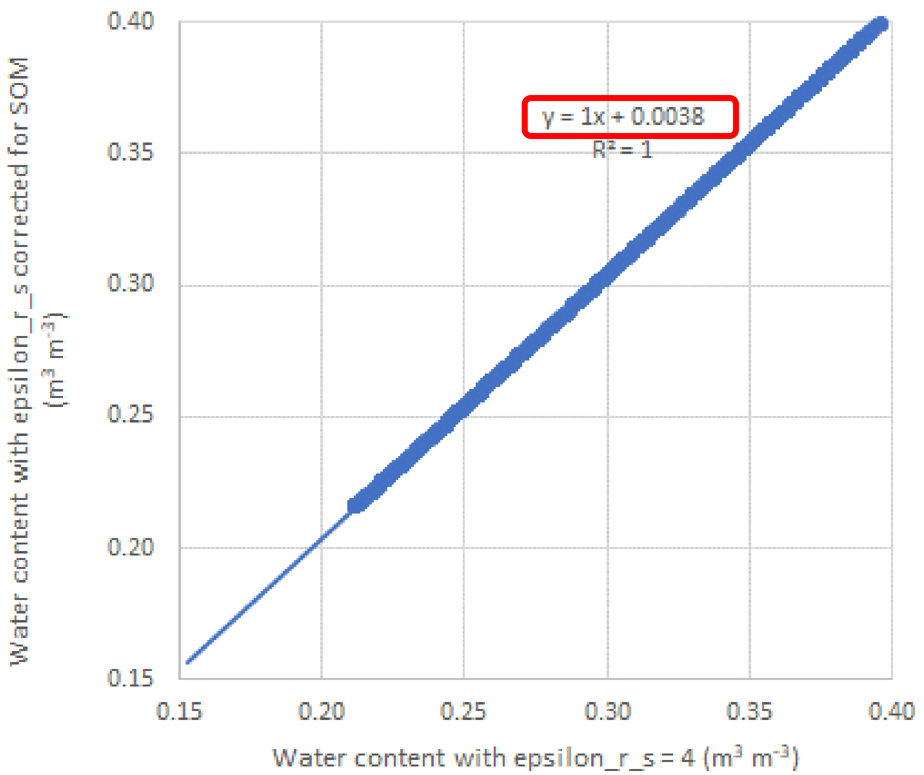
$$\theta = \frac{\sqrt{\epsilon_r} - [1 + (\sqrt{\epsilon_{rs}} - 1)(1 - \phi)]}{8}$$

for OM = 7.8% (0.078 kg kg^{-1}) (topsoil forest) : $\boxed{\epsilon_{r\,s} = 3.7}$

relative permittivity ε_r



©Colin Campbell, METER Group



→ underestimation of θ with 0.0038 m^3 m^{-3} or 0.4 vol% if SOM is not accounted for

$$\epsilon_{rs} = X_{w,m}\frac{\rho_s}{\rho_{s,m}}\epsilon_{rs,m} + X_{w,om}\frac{\rho_s}{\rho_{s,om}}\epsilon_{rs,om}$$

QUESTION 2

5.3. MEASUREMENT OF WATER CONTENT

5.3.3. DIELECTRIC METHODS – B. Dielectric properties of water and soil

medium	ε_r
free (pure) water	~81
frozen water	~4
bound water	4-40
air	1
soil minerals	2-5
organic matter	1.5
epoxy resin	3.32
poly ethylene	2.30

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5.3. MEASUREMENT OF WATER CONTENT

5.3.3. DIELECTRIC METHODS – B. Dielectric properties of water and soil

- bulk soil (relative) permittivity ε_r

$$\boxed{\epsilon_r^\alpha = \epsilon_{r\ a}^\alpha\ f_a + \epsilon_{r\ s}^\alpha\ f_s + \epsilon_{r\ w}^\alpha\ f_w + \epsilon_{r\ bw}^\alpha\ f_{bw}}$$

$$\theta = f_w + f_{bw} \approx f_w$$

$$f_a + f_s + \theta = 1$$

$$f_s = \frac{\rho_b}{\rho_s} = 1 - \phi$$

$$f_a = \phi - \theta$$

$\varepsilon_{rw} = 81$
$\varepsilon_{ra} = 1$

$$\rightarrow \quad \sqrt{\epsilon_r} = 1 + \frac{(\sqrt{\epsilon_{r\ s}} - 1)\ \rho_b}{\rho_s} + 8\ \theta$$

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5.3. MEASUREMENT OF WATER CONTENT

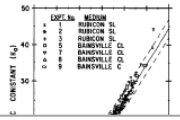
5.3.3. DIELECTRIC METHODS – G. Calibration

- Literature: "universal" equations
  - Topp et al. (1980) (4 mineral soils; other eq. for organic soil)

$$\boxed{\theta = -5.3\times10^{-2} + 2.92\times10^{-2}\ \varepsilon_r - 5.5\times10^{-4}\ \varepsilon_r^2 + 4.3\times10^{-6}\ \varepsilon_r^3}$$

  - Ledieu et al. (1986) (loam)

$$\boxed{\theta = 0.1138\sqrt{\varepsilon_r} - 0.1758}$$



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5.3. MEASUREMENT OF WATER CONTENT

5.3.3. DIELECTRIC METHODS – G. Calibration

- Theoretical: dielectric mixing model

$$\epsilon_r^\alpha = \epsilon_{r\ a}^\alpha\ f_a + \epsilon_{r\ s}^\alpha\ f_s + \epsilon_{r\ w}^\alpha\ f_w + \epsilon_{r\ bw}^\alpha\ f_{bw}$$

$\varepsilon_{rw} = 81$
$\varepsilon_{rs} = 4$
$\varepsilon_{ra} = 1$

$$\rightarrow \quad \sqrt{\epsilon_r} = 1 + \frac{(\sqrt{\epsilon_{r\ s}} - 1)\ \rho_b}{\rho_s} + 8\ \theta$$

$$\downarrow$$

$$\boxed{\theta = \frac{\sqrt{\epsilon_r} - (2 - \phi)}{8}}$$

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5.3. MEASUREMENT OF WATER CONTENT

5.3.3. DIELECTRIC METHODS – G. Calibration

- Empirical : own regression

$$\epsilon_r^\alpha = \epsilon_{r\ a}^\alpha\ f_a + \epsilon_{r\ s}^\alpha\ f_s + \epsilon_{r\ w}^\alpha\ f_w + \epsilon_{r\ bw}^\alpha\ f_{bw}$$

$$\downarrow$$

$$\boxed{\theta = a\sqrt{\epsilon_r} + b}$$

5.3. MEASUREMENT OF WATER CONTENT

5.3.3. DIELECTRIC METHODS – G. Calibration

- field calibration
- laboratory calibration

$\rightarrow \varepsilon_r$ (or F, or V) vs. θ by oven-drying on soil cores (field) or
w by oven-drying for known (repacked) densities (lab)

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QUESTION 2

`=(SQRT(B4)-1-(SQRT(H4)-1)*(1-E4))/8`

cropland

Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta
2021-01-01 00:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 01:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 02:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 03:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 04:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 05:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 06:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 07:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 08:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 09:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320
2021-01-01 10:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320

forest

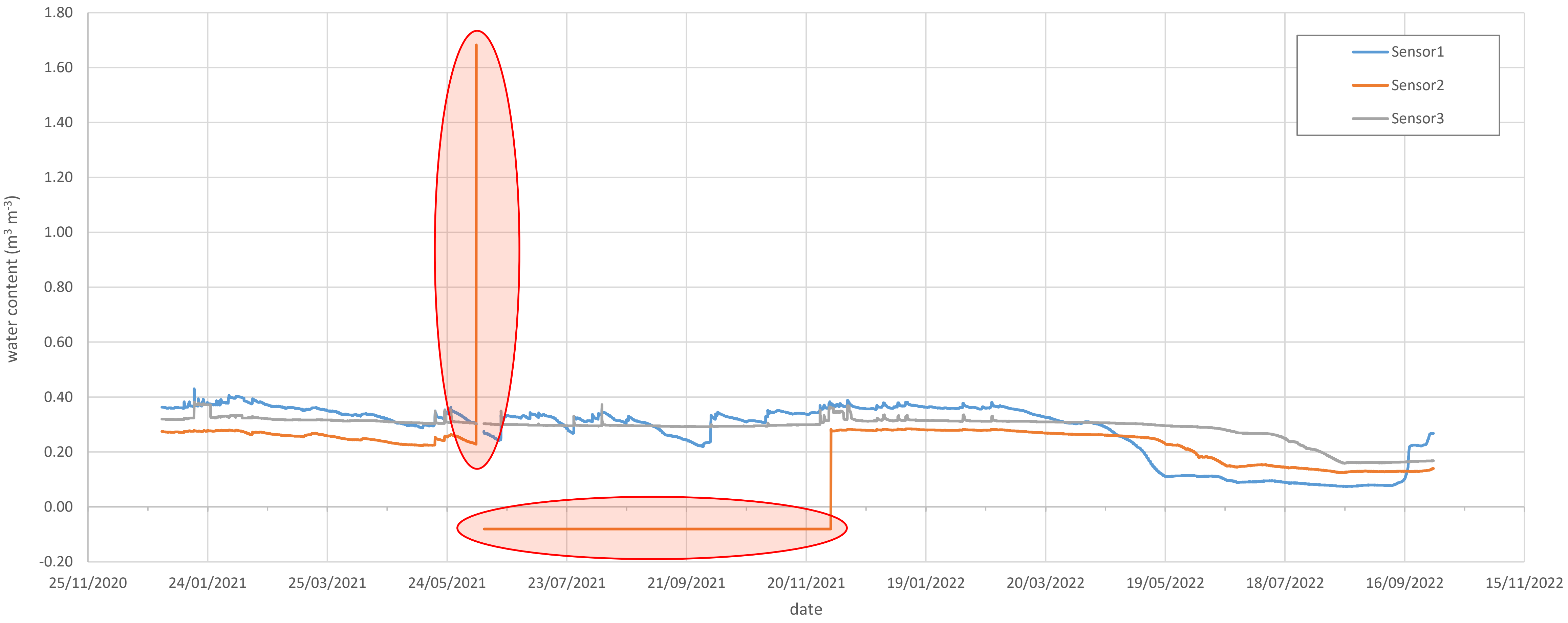
Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta
2021-01-01 00:00:00	17.1	13.1	15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.351	0.264	0.300
2021-01-01 01:00:00	17.1	13.1	15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.351	0.264	0.300
2021-01-01 02:00:00	17.1	13.1	15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.351	0.264	0.300

grassland

Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta
2021-01-01 00:00:00	18.3	15.4	18.0	0.488	0.394	0.419	4.0	4.0	4.0	0.345	0.290	0.333
2021-01-01 01:00:00	18.3	15.4	18.0	0.488	0.394	0.419	4.0	4.0	4.0	0.345	0.290	0.333
2021-01-01 02:00:00	18.3	15.4	18.0	0.488	0.394	0.419	4.0	4.0	4.0	0.345	0.290	0.333

QUESTION 2

cropland



→ **filter**: remove $\theta > \phi$

$\theta < 0$

QUESTION 2

`=(SQRT(B4)-1-(SQRT(H4)-1)*(1-E4))/8`

`=IF(K4>E4,NA(),IF(K4<0,NA(),K4))`

cropland

Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta	theta	theta	theta
2021-01-01 00:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 01:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 02:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 03:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 04:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 05:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 06:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 07:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 08:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 09:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320
2021-01-01 10:00:00	20.1	14.6	17.4	0.440	0.379	0.397	4.0	4.0	4.0	0.365	0.275	0.320	0.365	0.275	0.320

forest

Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta	theta	theta	theta
2021-01-01 00:00:00	17.1	13.1	15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.351	0.264	0.300	0.351	0.264	0.300
2021-01-01 01:00:00	17.1	13.1	15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.351	0.264	0.300	0.351	0.264	0.300
2021-01-01 02:00:00	17.1	13.1	15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.351	0.264	0.300	0.351	0.264	0.300

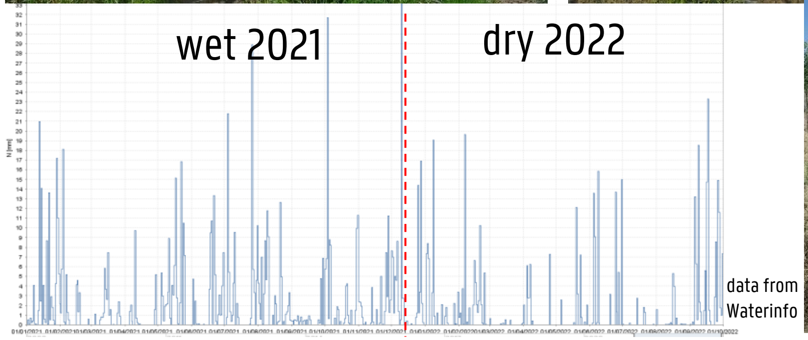
grassland

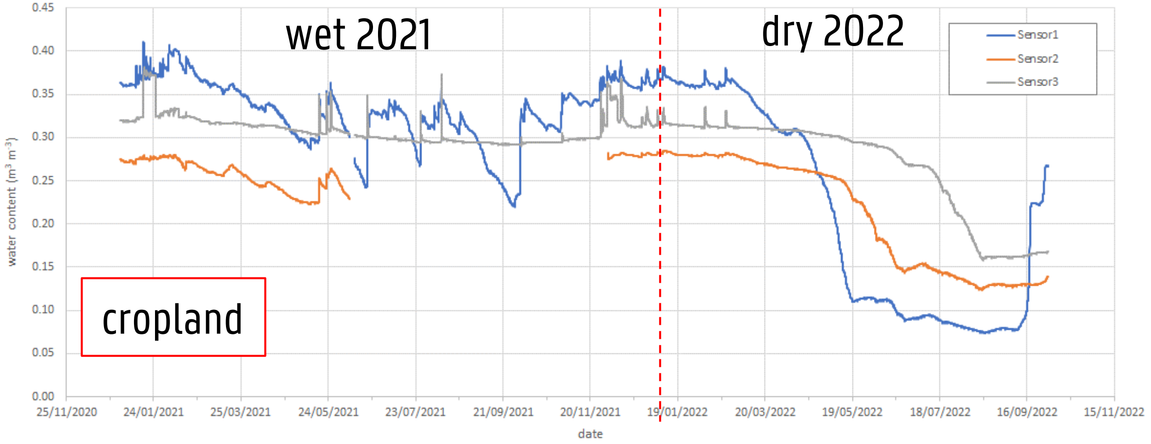
Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta	theta	theta	theta
2021-01-01 00:00:00	18.3	15.4	18.0	0.488	0.394	0.419	4.0	4.0	4.0	0.345	0.290	0.333	0.345	0.290	0.333
2021-01-01 01:00:00	18.3	15.4	18.0	0.488	0.394	0.419	4.0	4.0	4.0	0.345	0.290	0.333	0.345	0.290	0.333
2021-01-01 02:00:00	18.3	15.4	18.0	0.488	0.394	0.419	4.0	4.0	4.0	0.345	0.290	0.333	0.345	0.290	0.333

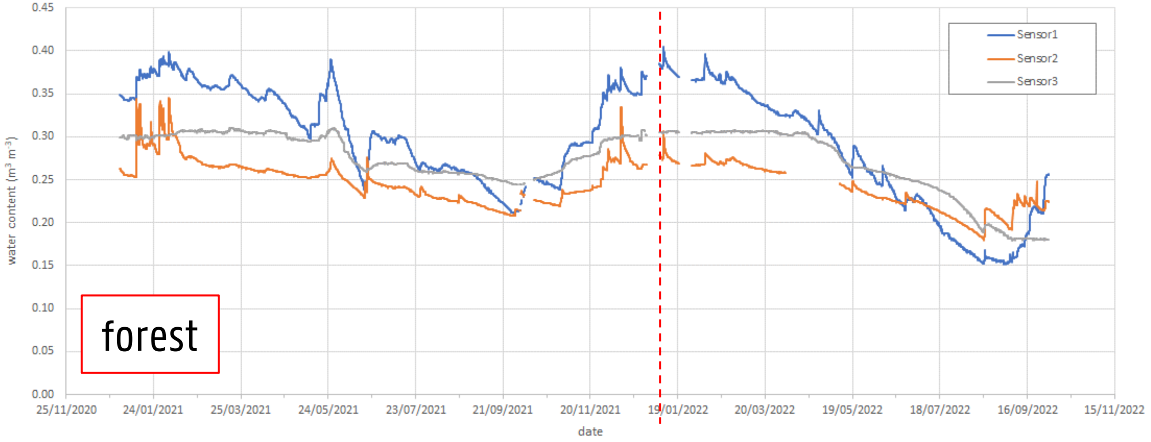
QUESTION 2

wet summer 2021

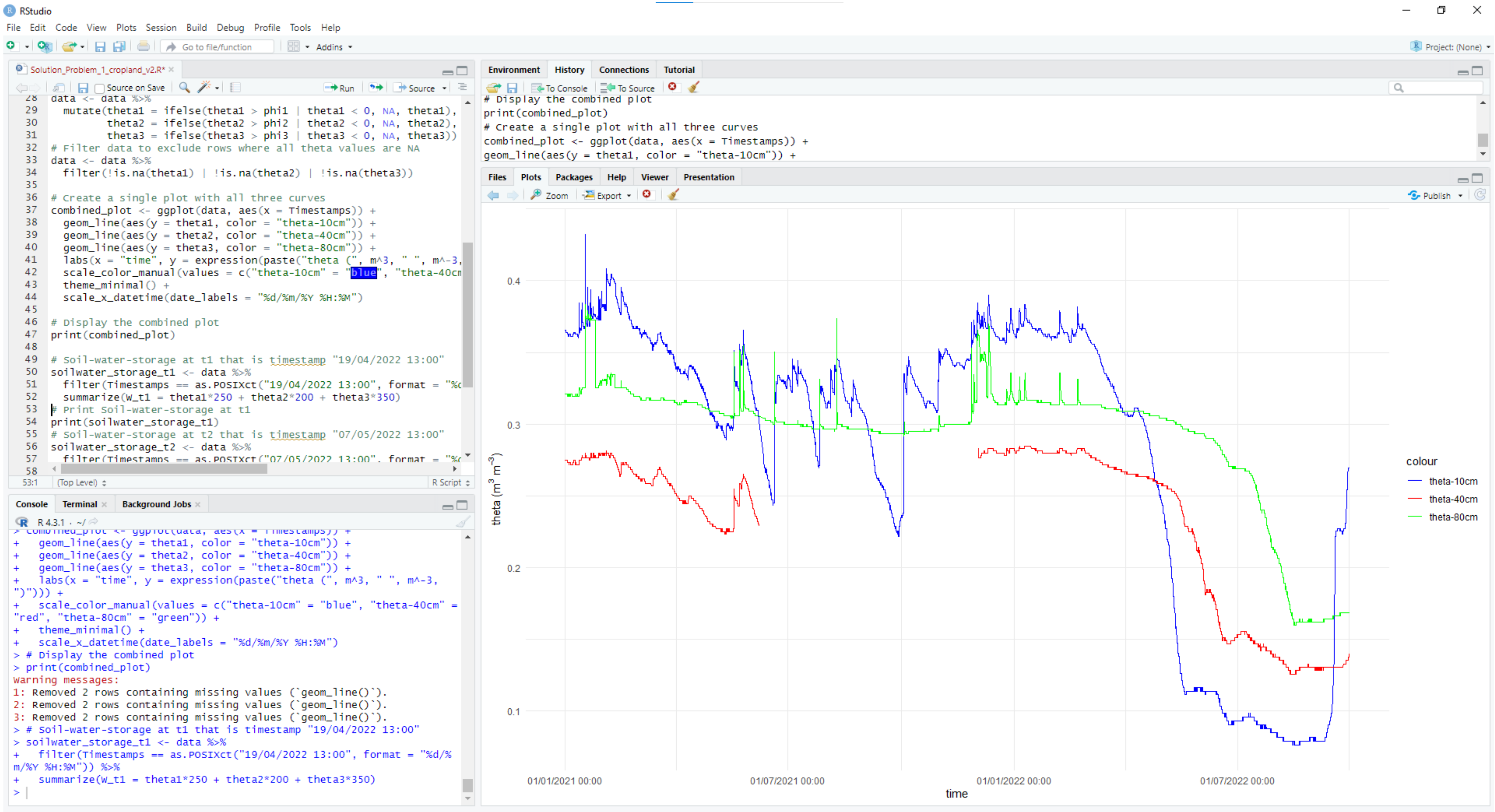
dry summer 2022







QUESTION 2



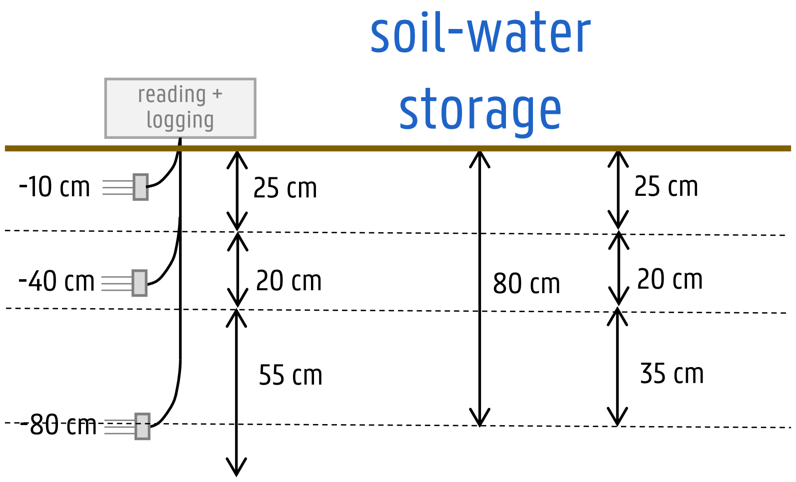
RStudio
File Edit Code View Plots Session Build Debug Profile Tools Help
Go to file/function
Addins
Project: (None)
Solution_Problem_1_cropland_v2.R*
Source on Save
Run
Source
data <- data %>%
mutate(theta1 = ifelse(theta1 > phi1 | theta1 < 0, NA, theta1),
theta2 = ifelse(theta2 > phi2 | theta2 < 0, NA, theta2),
theta3 = ifelse(theta3 > phi3 | theta3 < 0, NA, theta3))
# Filter data to exclude rows where all theta values are NA
data <- data %>%
filter(!is.na(theta1) | !is.na(theta2) | !is.na(theta3))
# Create a single plot with all three curves
combined_plot <- ggplot(data, aes(x = Timestamps)) +
geom_line(aes(y = theta1, color = "theta-10cm")) +
geom_line(aes(y = theta2, color = "theta-40cm")) +
geom_line(aes(y = theta3, color = "theta-80cm")) +
labs(x = "time", y = expression(paste("theta (", m^3, " ", m^-3,
scale_color_manual(values = c("theta-10cm" = "blue", "theta-40cm
theme_minimal() +
scale_x_datetime(date_labels = "%d/%m/%Y %H:%M")
# Display the combined plot
print(combined_plot)
# Soil-water-storage at t1 that is timestamp "19/04/2022 13:00"
soilwater_storage_t1 <- data %>%
filter(Timestamps == as.POSIXct("19/04/2022 13:00", format = "%
summarize(W_t1 = theta1*250 + theta2*200 + theta3*350)
# Print Soil-water-storage at t1
print(soilwater_storage_t1)
# Soil-water-storage at t2 that is timestamp "07/05/2022 13:00"
soilwater_storage_t2 <- data %>%
filter(Timestamps == as.POSIXct("07/05/2022 13:00", format = "%
53:1 (Top Level) R Script
Console Terminal Background Jobs
R 4.3.1 · ~/
+ geom_line(aes(y = theta1, color = "theta-10cm")) +
+ geom_line(aes(y = theta2, color = "theta-40cm")) +
+ geom_line(aes(y = theta3, color = "theta-80cm")) +
+ labs(x = "time", y = expression(paste("theta (", m^3, " ", m^-3,
")"))) +
+ scale_color_manual(values = c("theta-10cm" = "blue", "theta-40cm" =
"red", "theta-80cm" = "green")) +
+ theme_minimal() +
+ scale_x_datetime(date_labels = "%d/%m/%Y %H:%M")
> # Display the combined plot
> print(combined_plot)
Warning messages:
1: Removed 2 rows containing missing values (`geom_line()`).
2: Removed 2 rows containing missing values (`geom_line()`).
3: Removed 2 rows containing missing values (`geom_line()`).
> # Soil-water-storage at t1 that is timestamp "19/04/2022 13:00"
> soilwater_storage_t1 <- data %>%
+ filter(Timestamps == as.POSIXct("19/04/2022 13:00", format = "%d/%
m/%Y %H:%M")) %>%
+ summarize(W_t1 = theta1*250 + theta2*200 + theta3*350)
Environment History Connections Tutorial
To Console To Source
# Display the combined plot
print(combined_plot)
# Create a single plot with all three curves
combined_plot <- ggplot(data, aes(x = Timestamps)) +
geom_line(aes(y = theta1, color = "theta-10cm")) +
Files Plots Packages Help Viewer Presentation
Zoom Export Publish
0.4
0.3
0.2
0.1
theta (m³ m⁻³)
01/01/2021 00:00
01/07/2021 00:00
01/01/2022 00:00
01/07/2022 00:00
time
colour
theta-10cm
theta-40cm
theta-80cm

QUESTION 3

If we assume that

- sensor 1 represents θ between the soil surface and -25 cm depth,
- sensor 2 between -25 and -45 cm depth,
- sensor 3 between -45 and -100 cm depth,

calculate the soil-water storage (in mm) at 19 April 2022 13:00 and at 7 May 2022 13:00 from the soil surface till -80 cm depth per land use.



QUESTION 3

5.2. DEFINITIONS

5.2.3. SOIL-WATER STORAGE

$$\boxed{W = \sum_{i=1}^{n} \theta_i \, \Delta z_i}$$

alternative symbol
S, D_e

also called soil-water content (in mm)

QUESTION 3

=N11368*250+O11368*200+P11368*350

cropland

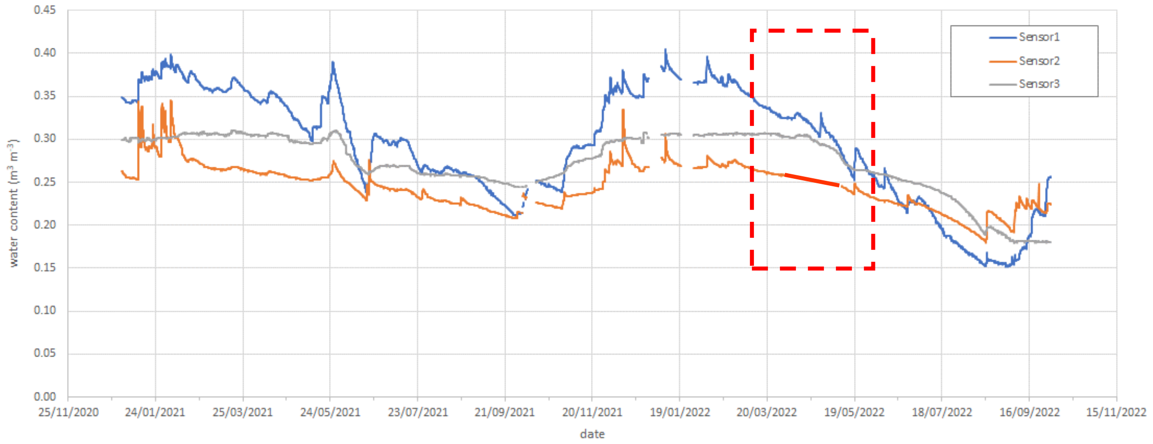
	Timestamps	epsilon_r	epsilon_r	epsilon_r	phi	phi	phi	epsilon_r_s	epsilon_r_s	epsilon_r_s	theta	theta	theta	theta	theta	theta	W mm
11367	2022-04-19 12:00:00	15.1	13.8	16.5	0.440	0.379	0.397	4.0	4.0	4.0	0.291	0.262	0.307	0.291	0.262	0.307	
11368	2022-04-19 13:00:00	15.1	13.8	16.5	0.440	0.379	0.397	4.0	4.0	4.0	0.291	0.262	0.307	0.291	0.262	0.307	232.7
11369	2022-04-19 14:00:00	15.1	13.8	16.5	0.440	0.379	0.397	4.0	4.0	4.0	0.291	0.262	0.307	0.291	0.262	0.307	
																	208.5

forest

11367	2022-04-19 12:00:00	15.1		15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.320	-0.189	0.300	0.320	#N/A	0.300	
11368	2022-04-19 13:00:00	15.1		15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.320	-0.189	0.300	0.320	0.254	0.300	235.8
11369	2022-04-19 14:00:00	15.0		15.8	0.678	0.486	0.432	4.0	4.0	4.0	0.319	-0.189	0.300	0.319	#N/A	0.300	
																	224.1

grassland

11368	2022-04-19 12:00:00	16.1	13.8	17.2	0.488	0.394	0.419	4.0	4.0	4.0	0.312	0.264	0.321	0.312	0.264	0.321	
11369	2022-04-19 13:00:00	16.0	13.8	17.2	0.488	0.394	0.419	4.0	4.0	4.0	0.311	0.264	0.321	0.311	0.264	0.321	242.9
11370	2022-04-19 14:00:00	16.0	13.8	17.2	0.488	0.394	0.419	4.0	4.0	4.0	0.311	0.264	0.321	0.311	0.264	0.321	
																	208.8

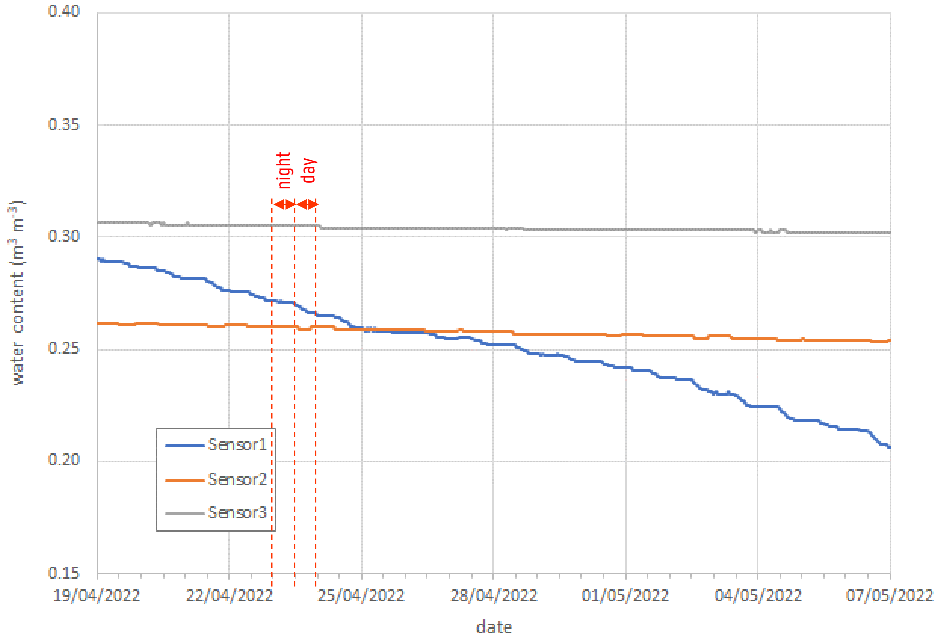


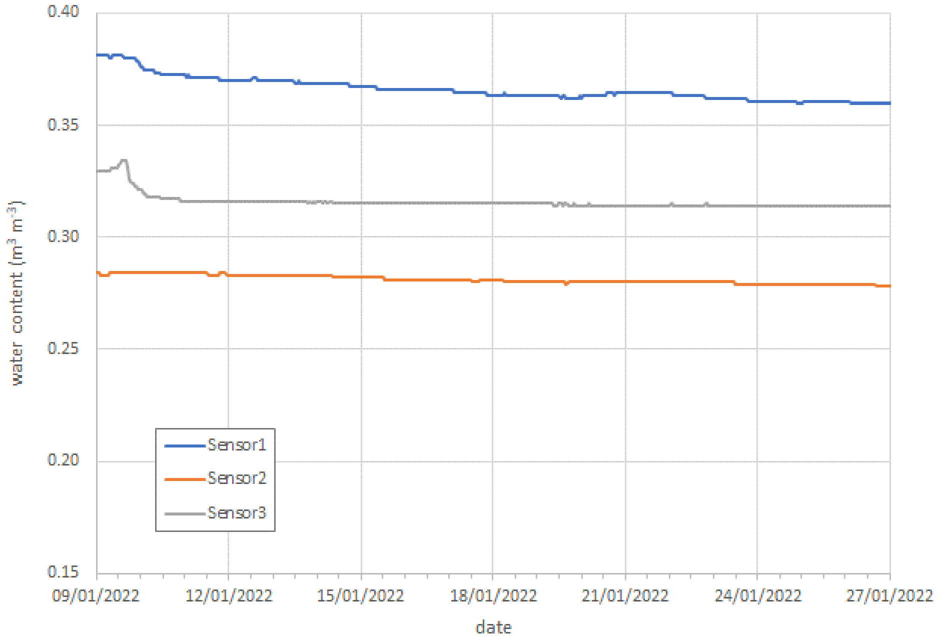
linear interpolation

=O10971+(A11368-A10971)*(O11860-O10971)/(A11860-A10971)

QUESTION 4

Did the roots of the plants per land use have reached a depth of -15 cm between 19 April 2022 and 7 May 2022? And do you see any root activity between 9 and 27 January 2022?



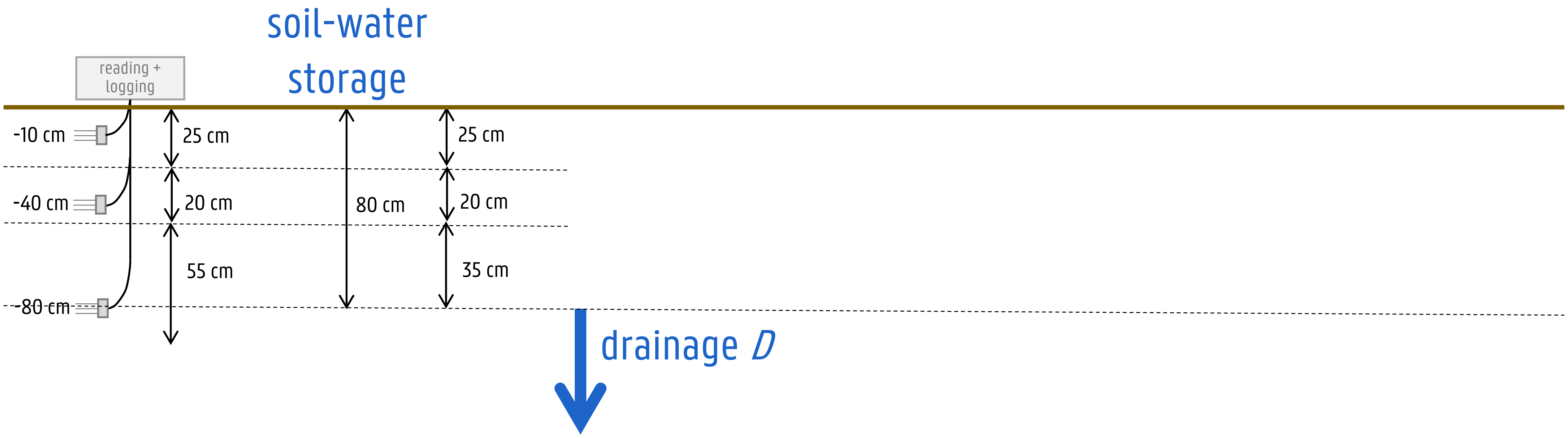


diurnal changes: stepwise change in θ at -15 cm
$\rightarrow$ no change during nighttime, decrease during daytime (stomata close during night, are open during day $\rightarrow$ roots take up water only during daytime)

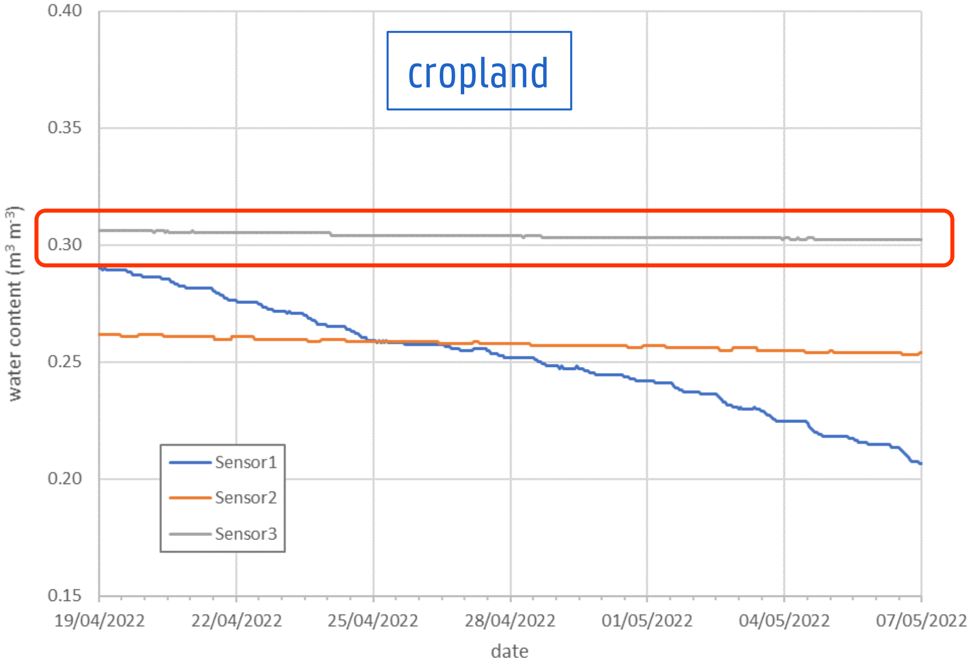
some fluctuations in θ at -15 cm but no real stepwise pattern

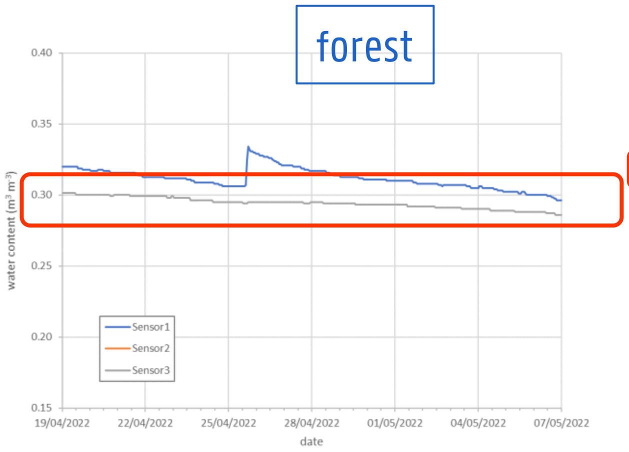
QUESTION 5

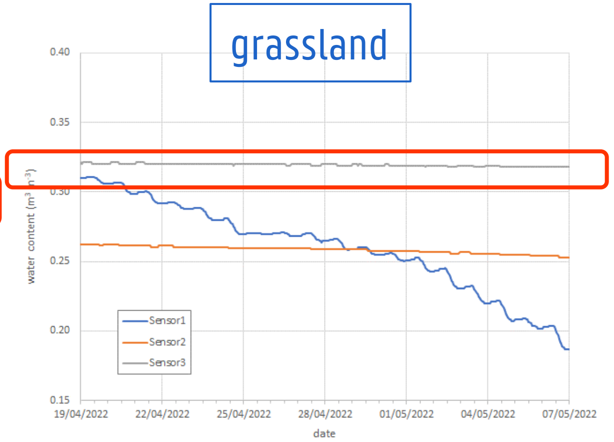
Would there be significant drainage at a depth of -80 cm per land use during this period?

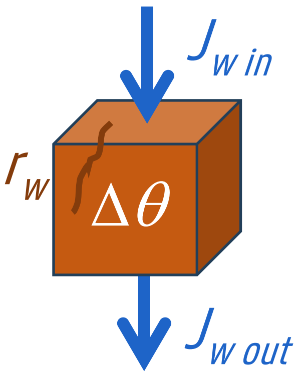


QUESTION 5









θ remains more or less constant at -80 cm depth

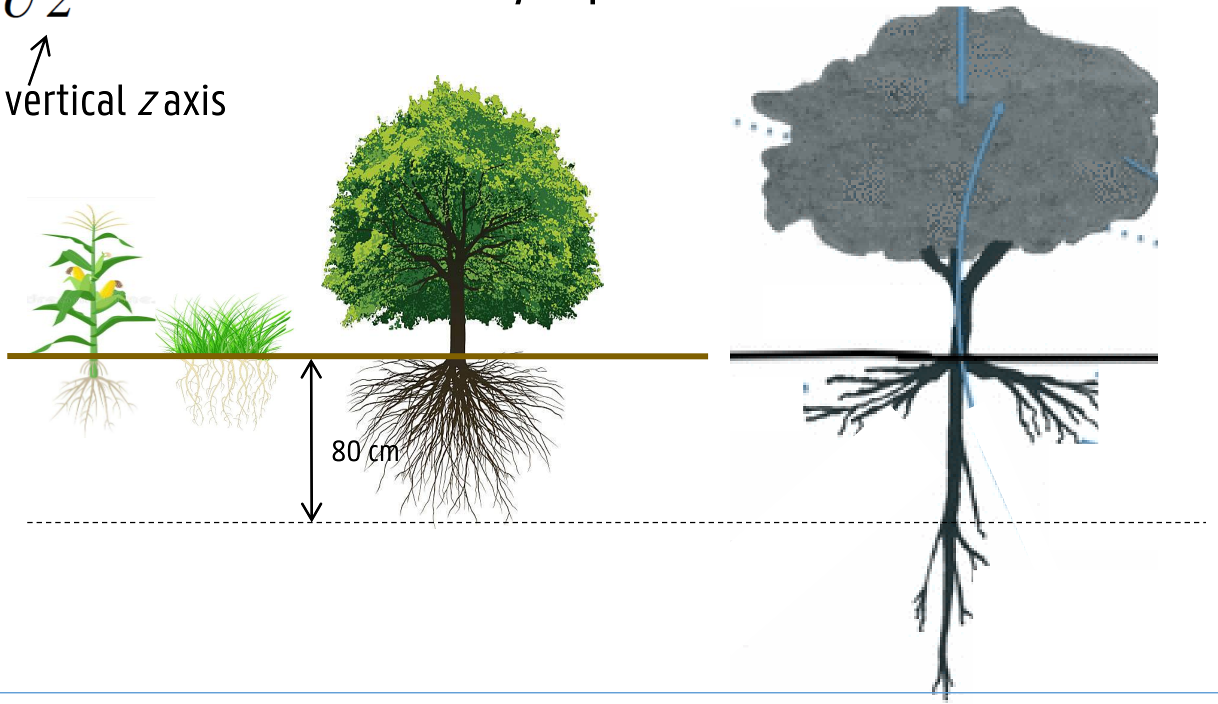
$\rightarrow$ drainage is not significant or $D = 0$

water flux

$$\frac{\partial \theta}{\partial t} = -\frac{\partial J_w}{\partial z} - r_w$$

depth along vertical z axis

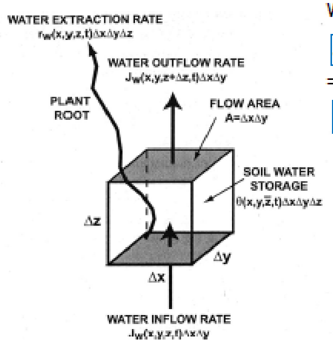
water conservation, mass balance, continuity equation CHA10



QUESTION 5

10.4. WATER CONSERVATION EQUATION

also called mass balance equation or continuity equation



volume of water entering soil volume during Δt

$$\boxed{J_w(x,y,z,t+\Delta t/2)\Delta x\Delta y\Delta t}$$

= volume of water leaving soil volume during Δt

$$\boxed{J_w(x,y,z+\Delta z,t+\Delta t/2)\Delta x\Delta y\Delta t}$$

+ increase of water volume stored in soil volume during Δt

$$\boxed{\begin{aligned}&\theta(x,y,z+\Delta z/2,t+\Delta t)\Delta x\Delta y\Delta z\\ &-\theta(x,y,z+\Delta z/2,t)\Delta x\Delta y\Delta z\end{aligned}}$$

+ volume of water extracted from soil volume by plant roots during Δt

$$\boxed{r_w(x,y,z+\Delta z/2,t+\Delta t/2)\Delta x\Delta y\Delta z}$$

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10.4. WATER CONSERVATION EQUATION

one-dimensional (vertical)

$$\frac{\partial \theta}{\partial t}=-\frac{\partial J_w}{\partial z}-r_w$$

$$\frac{\partial J_w}{\partial z}+\frac{\partial \theta}{\partial t}+r_w=0$$

three-dimensional

$$\frac{\partial J_{wx}}{\partial x}+\frac{\partial J_{wy}}{\partial y}+\frac{\partial J_{wz}}{\partial z}+\frac{\partial \theta}{\partial t}+r_w=0$$

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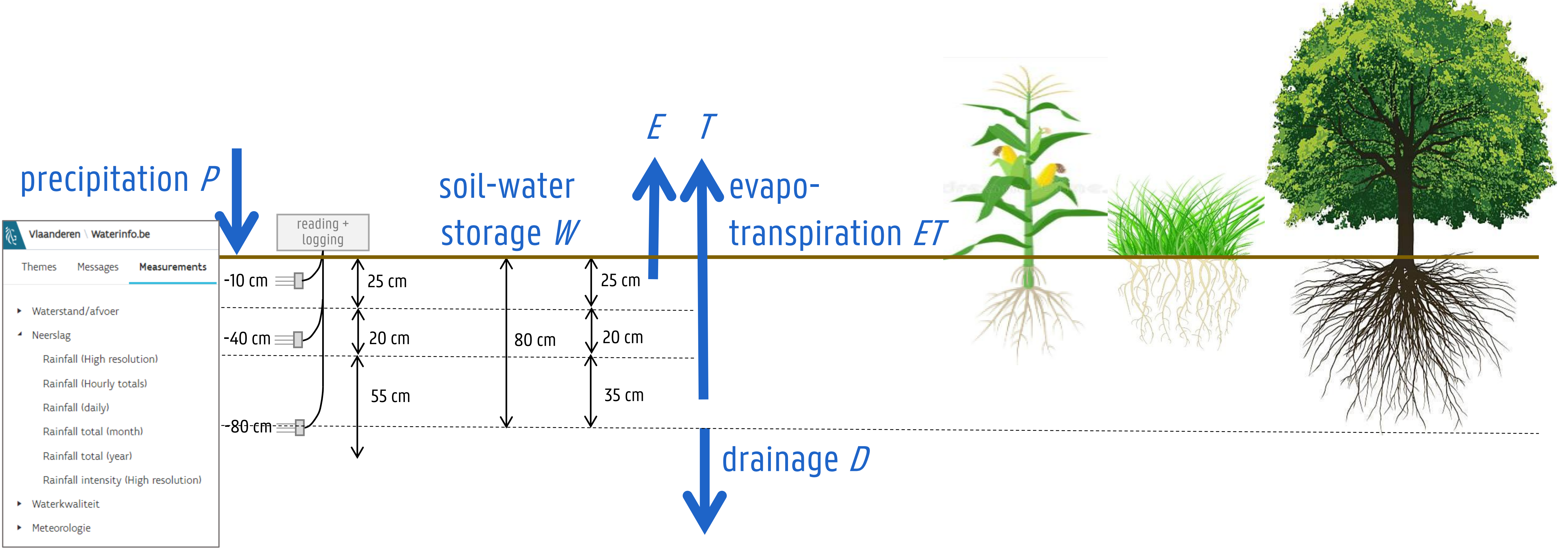
QUESTION 6

Calculate evapotranspiration (in mm) <u>in the top 80 cm</u> of the soil during this period per land use

No runoff, no lateral subsurface water flow, no irrigation

<u>Precipitation</u> was <u>9.9 mm</u> (at all three land uses → weather station Zingem – waterinfo.be)



QUESTION 6

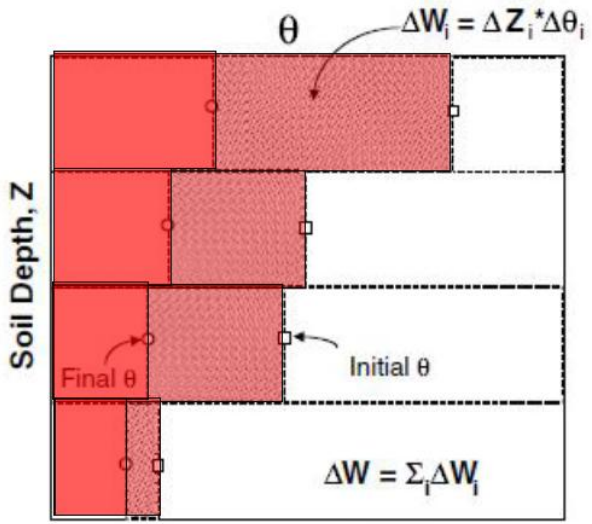
$$\Delta W = P + \cancel{I} - ET - D - \cancel{R}$$

$$\Delta W = W_{end} - W_{initial}$$ see Q3

$$D = 0$$ see Q5

$$ET = P - \Delta W$$

	W_{t2} (mm)	W_{t1} (mm)	ET (mm)
cropland	232.7	208.5	34.1
forest	235.8	224.1	21.6
grassland	242.9	208.8	44.0



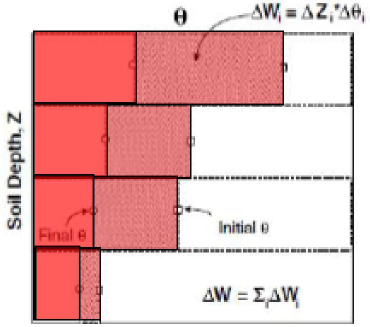
cfr. waterinfo.be: *potential* ET (of clipped grass) in given period = 57.4 mm (3 mm/d)

QUESTION 6

5.2. DEFINITIONS

5.2.3. SOIL-WATER STORAGE

Schematic of soil water depletion calculations for a soil profile divided into four depth increments.
Total changes in soil-water storage is the sum of the depletion in each layer



$$\Delta W = P + I - ET - D - R$$

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Questions?

FACULTY OF
BIOSCIENCE ENGINEERING

Wim Cornelis

SOIL PHYSICS GROUP

E Wim.Cornelis@UGent.be
T +32 9 324 60 40

https://www.ugent.be/bw/environment/en/research/sophy

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UNESCO Chair on Eremology, Ghent University, Belgium