EVALUATING THE PERFORMANCE OF A FREQUENCY-DOMAIN GROUND PENETRATING RADAR AND MULTI-RECEIVER ELECTROMAGNETIC INDUCTION SENSOR TO MAP SUBSURFACE DRAINAGE IN AGRICULTURAL AREAS

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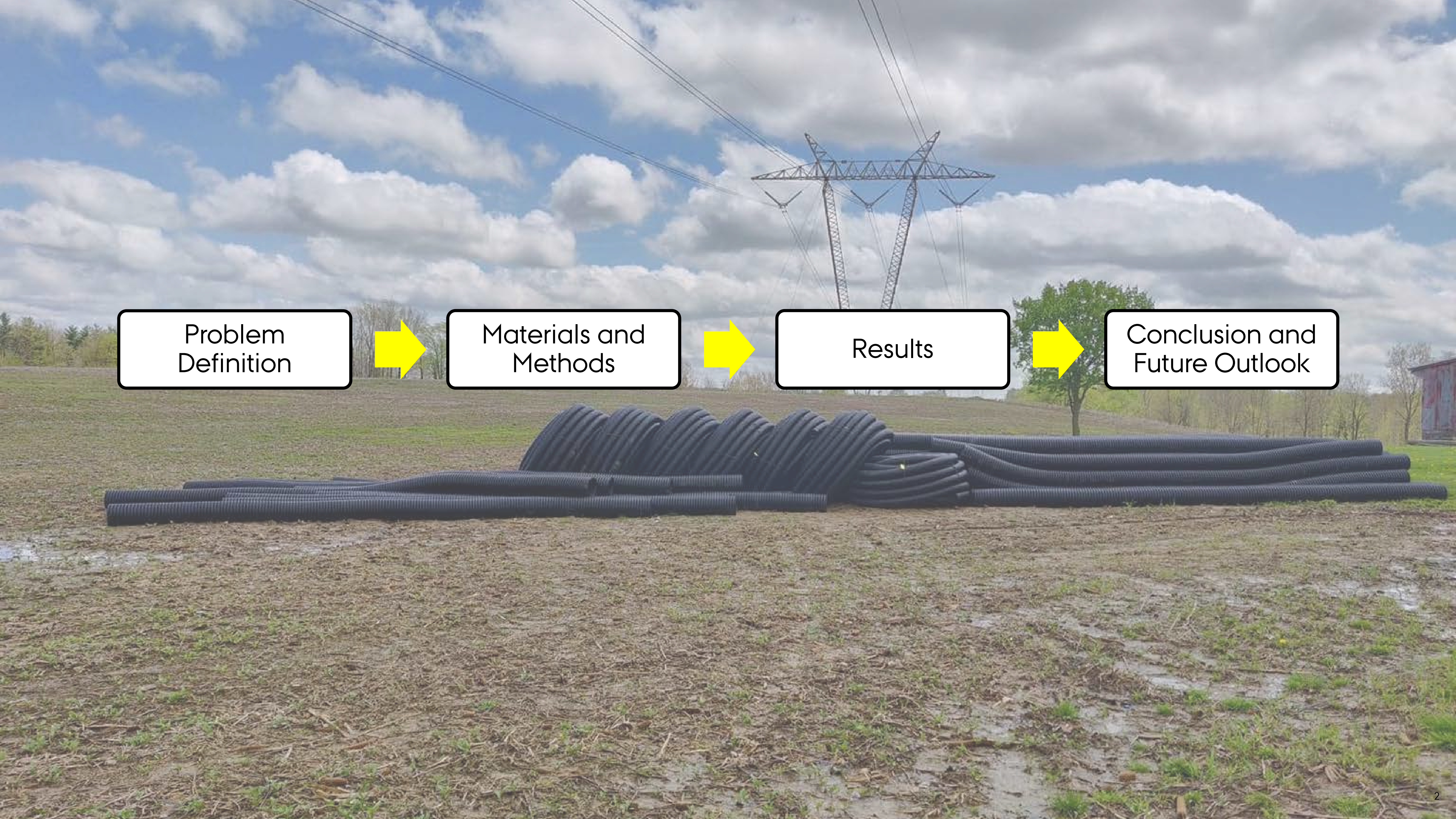

Problem Definition
Materials and Methods
Results
Conclusion and Future Outlook

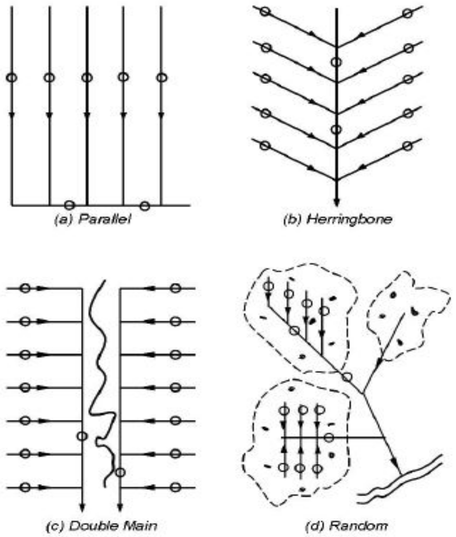
PROBLEM DEFINITION

Subsurface Drainage:

- Artificial drainage systems installed to transform poorly drained soils into productive cropland.
- At present, more than 50% of the agricultural areas in Denmark are artificially drained (Iversen et al., 2019).

Why do we map them?

- The leaching of nutrients in artificially drained areas poses a potential eutrophication risk (Strock et al., 2004).
- To install new drain lines, it is essential to know the location of the existing drainage system (Allred et al., 2005).



(Source: www.suburbanplumbingexperts.com; www.trailism.com)

PROBLEM DEFINITION

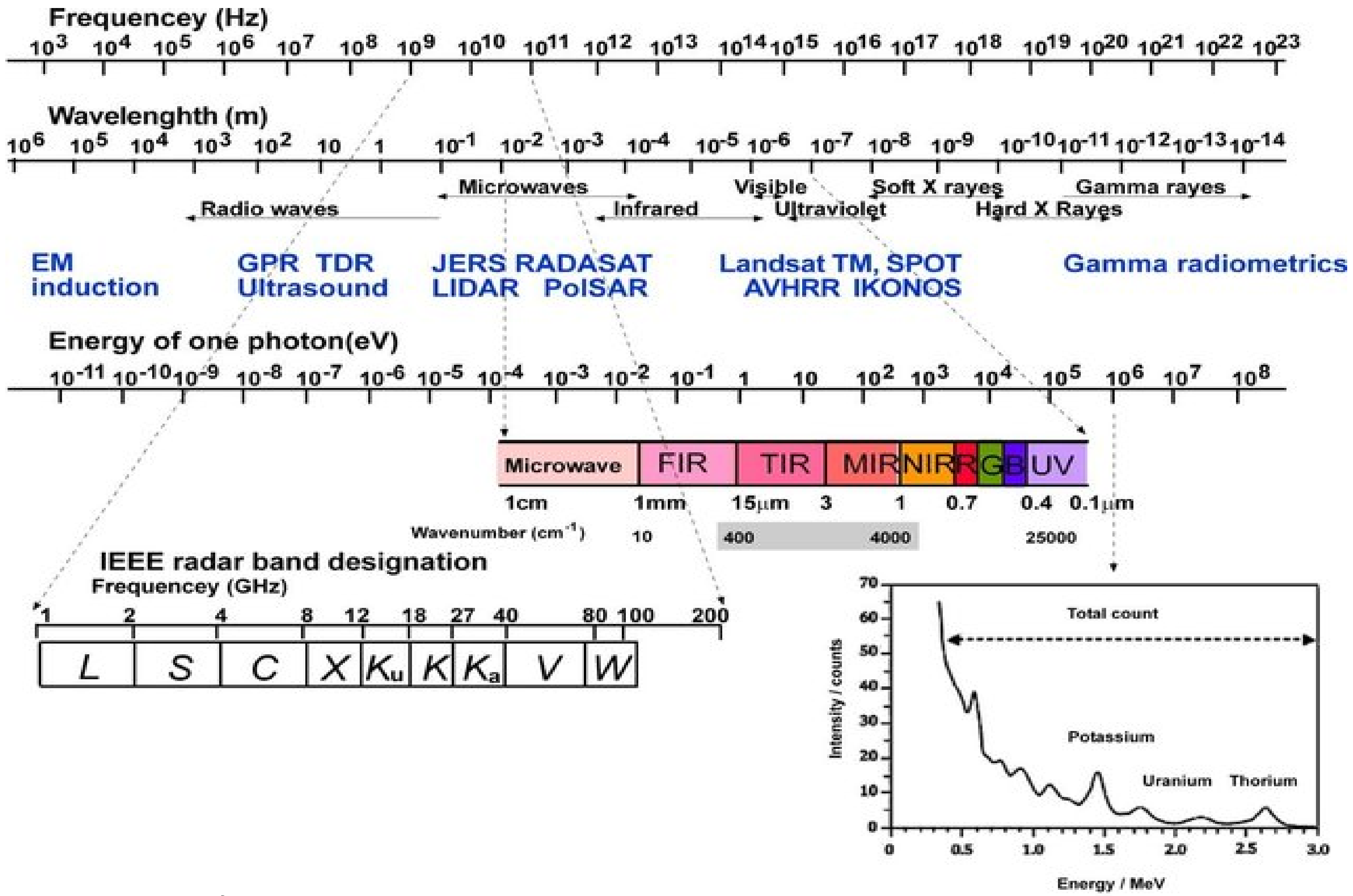
Traditional Methods:

- Tile probing
- Trenching

Limitations:

- Labour intensive and tiresome
- Damage risk

MATERIALS AND METHODS



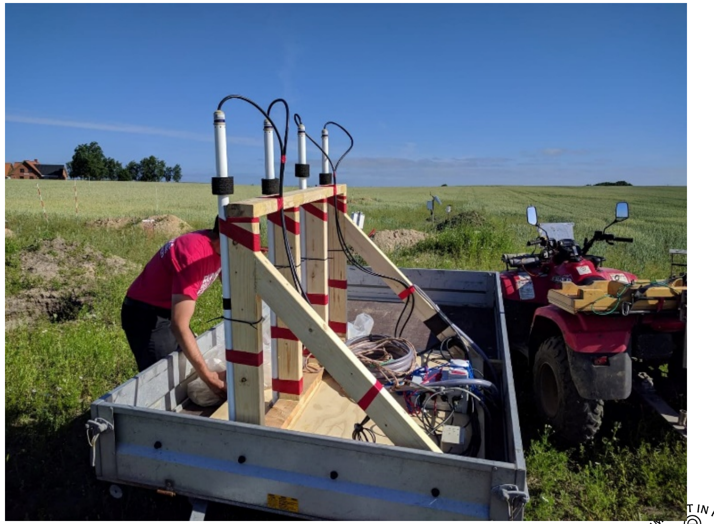
(After McBratney et al., 2003)

SENSORS OF INTEREST

Proximal Sensors:
Geophysical instruments capable of measuring soil-water content and detecting magnetic anomalies.

- **Electromagnetic Induction (EMI)**
- **Ground Penetrating Radar (GPR)**
- Direct current resistivity
- Magnetic gradiometer

(Source: www.veristech.com)



SENSORS OF INTEREST

Remote Sensors:

High resolution imagery from drones.

- Visible
- Near Infrared
- Thermal Infrared

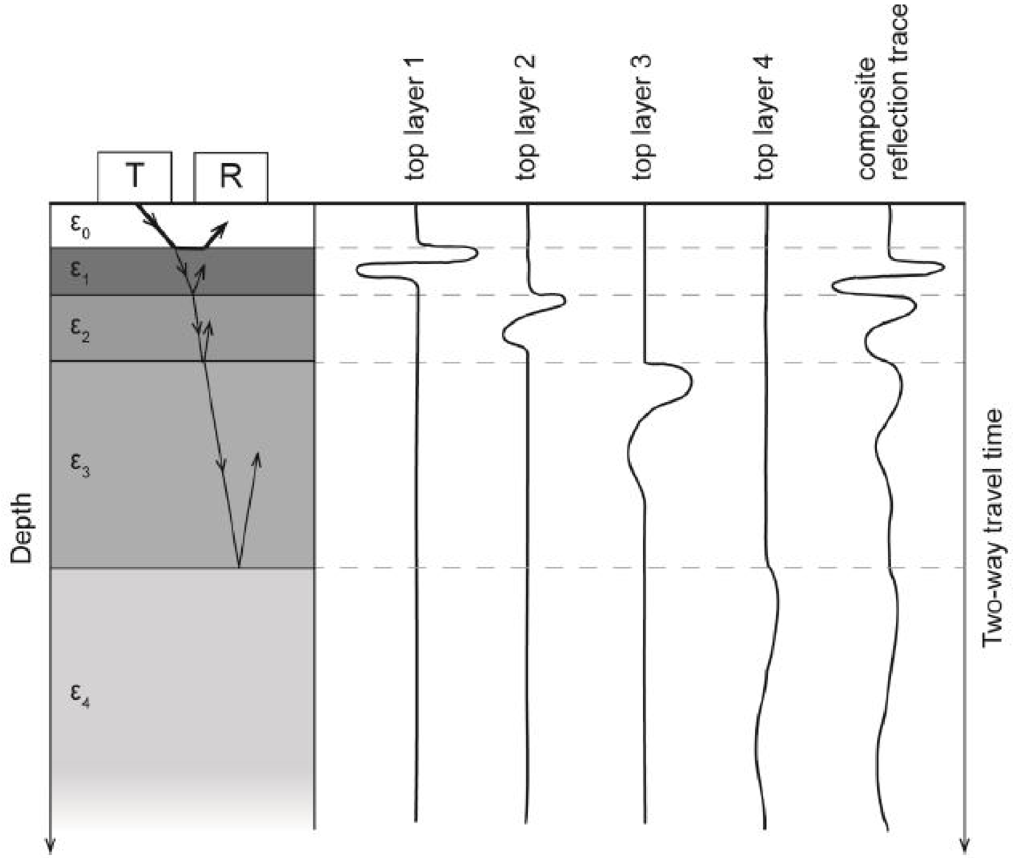
(Source: www.mydronelab.com)

GROUND PENETRATING RADAR (GPR)

Ground Penetrating Radar (GPR):

- Works on frequency bandwidth of 10 MHz - 3 GHz.
- Bound-charge displacement, or **polarization** is the dominant mechanism.
- Waves get reflected at the interface of media with different **relative dielectric permittivity (RDP)**.
- **Electrical conductivity** controls the degree of attenuation and hence, the penetration depth.

$$v = \frac{c}{\sqrt{\varepsilon_r}} \qquad \alpha \sim 1690 \frac{\sigma}{\sqrt{\varepsilon_r}}$$

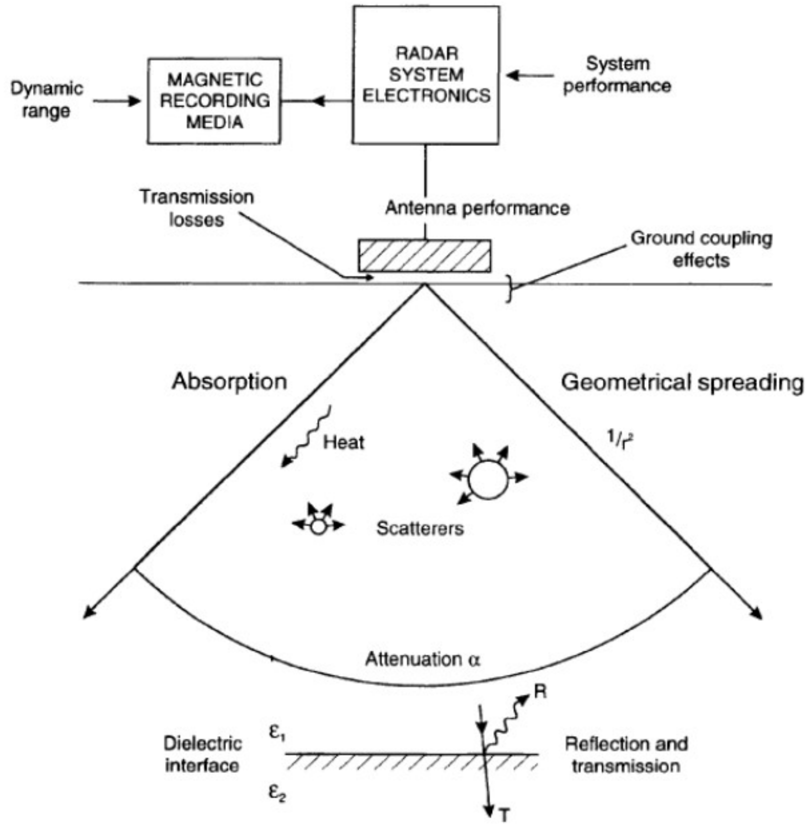


(After Conyers, 2004; Annan, 2009 and Van De Vijver, 2017)

GROUND PENETRATING RADAR (GPR)

Other factors affecting GPR wave propagation:

- Energy loss at the antenna.
- Loss due absorption, scattering and geometric spreading – **soil type** and **RDP.**
- Loss from reflections – contrast in **RDP**.

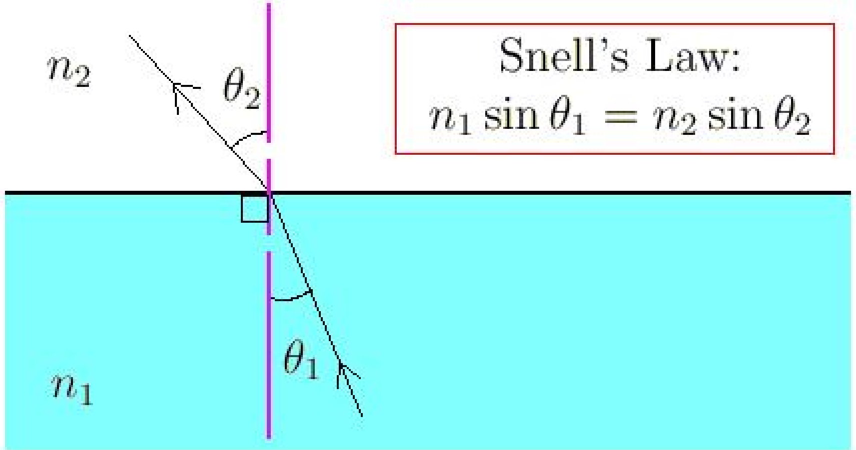


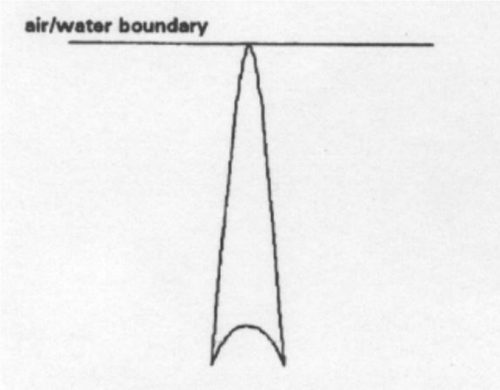
(After Reynolds, 1997)

POPULAR MYTHS - GPR

Popular Myths vs Facts:

- GPR doesn't work on wet soil – Water (**high RDP**) actually is good provided the **electrical conductivity** does not increase.
    - Helps in downward focusing.
    - More energy is coupled into the ground.
    - Better vertical resolution because of slow wave propagation.



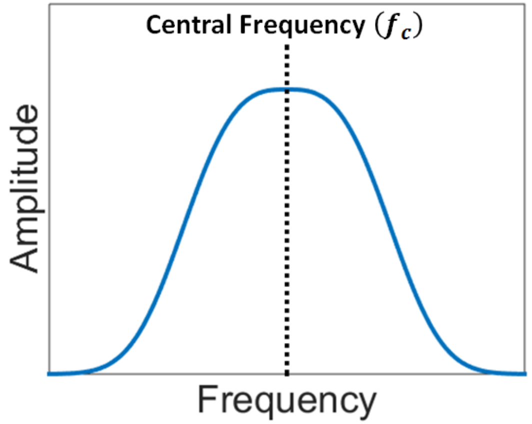


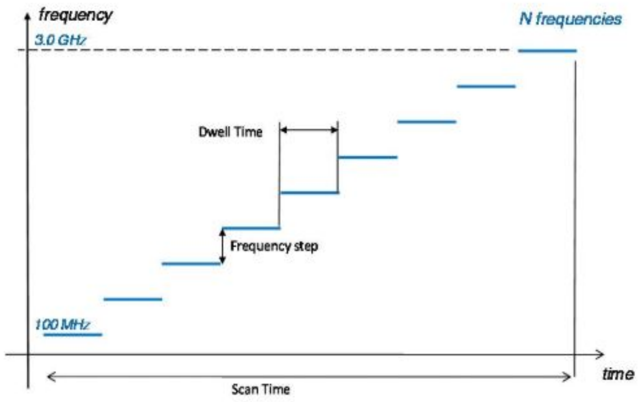
(Source: www.math.ubc.ca; www.sensoft.ca)

TIME-DOMAIN VS FREQUENCY-DOMAIN GPR

Differences:

- Limited bandwidth (E.g., 250 MHz).
- Wide band coverage (E.g., 60 MHz - 3 GHz).



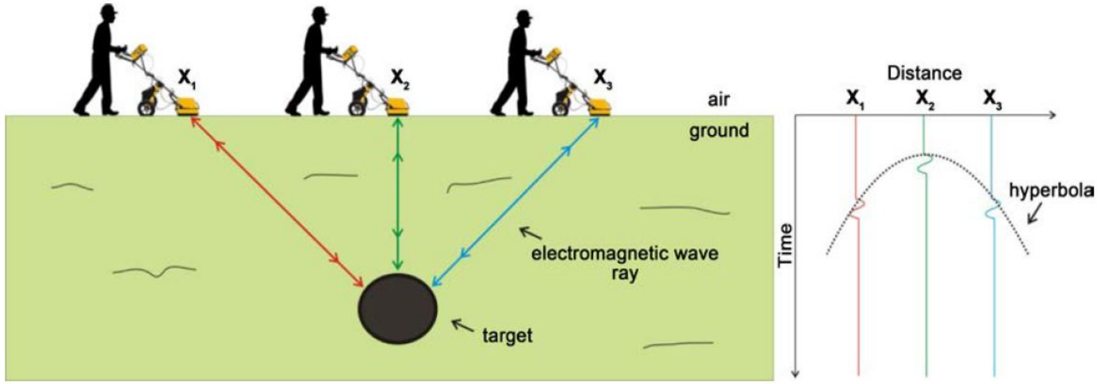


(Source: www.em.geosci.xyz; www.3d-radar.com)

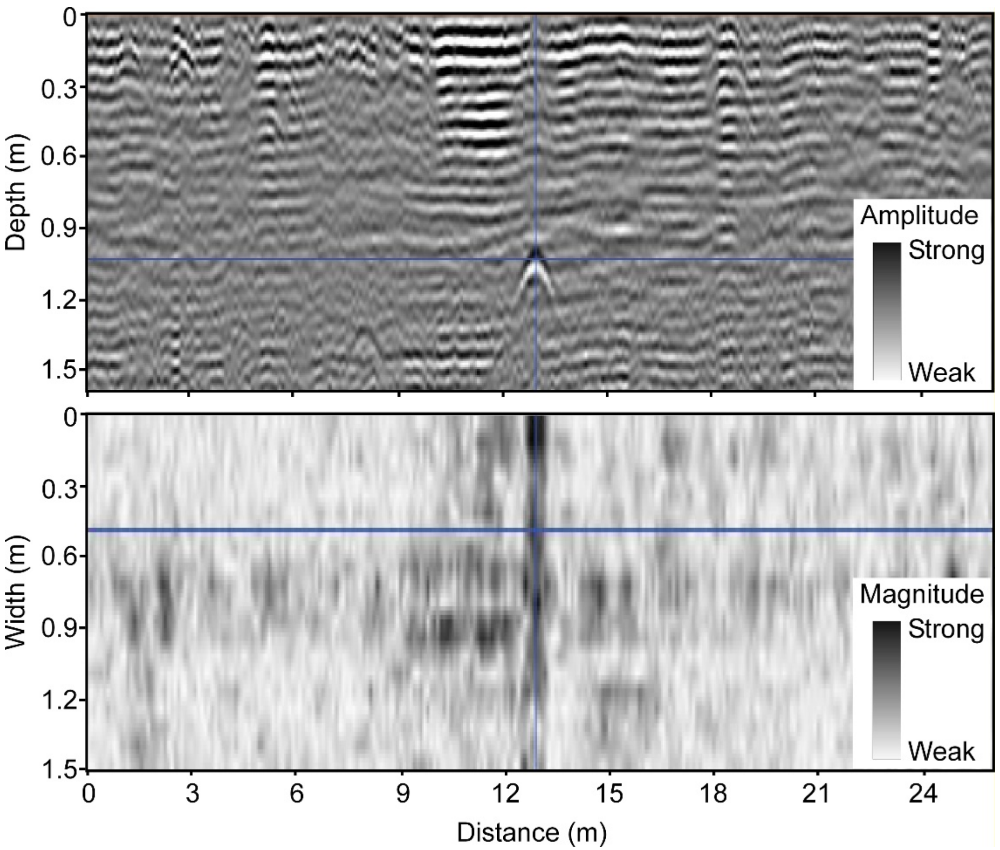
TYPICAL DRAIN PIPE SIGNATURE

<u>Perpendicular to drain line orientation:</u>

- Hyperbolic pattern in the vertical profile.
- Linear pattern in the depth slice.



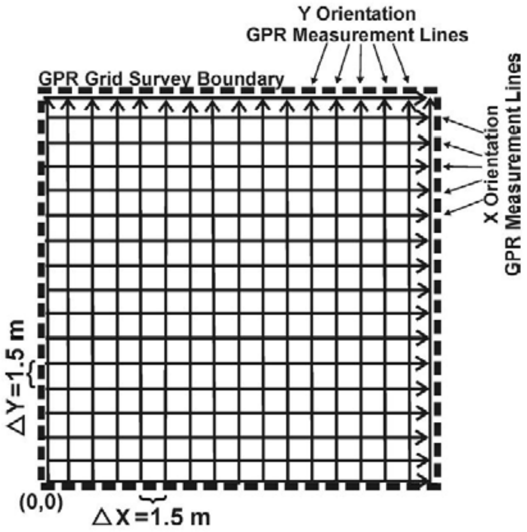
(After Poluha et al., 2017)

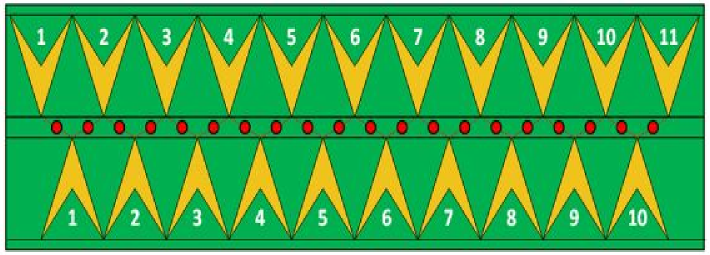


ANTENNA ARRAY

Differences:

- Double grid and spiral/serpentine transects
- 20 Channels – 1.5 m





(After Allred et al., 2005; source: www.3d-radar.com)

ELECTROMAGNETIC INDUCTION (EMI)

Electromagnetic Induction (EMI):

- Works on few kHz frequency (E.g., DUALEM-21S = 9 kHz).
- Quasi-free charge migration, or **conduction** is the dominant mechanism.
- Measures the **apparent electrical conductivity (ECa)** of the subsurface.

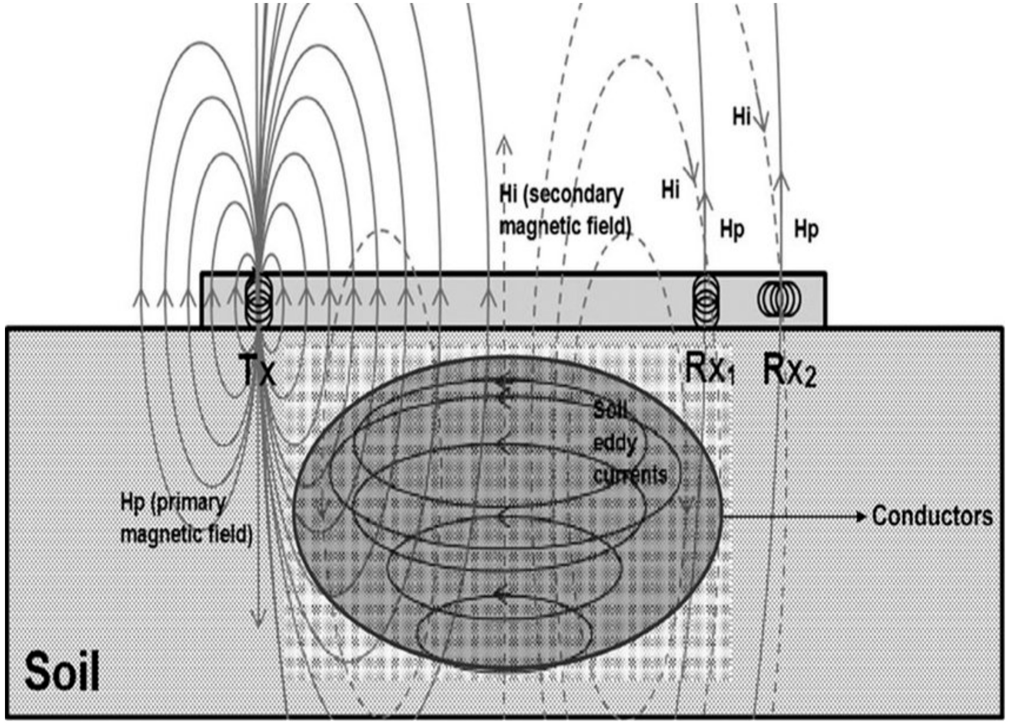
- DUALEM-21S:

  1 m PRP = 0 - 0.5 m

  2 m PRP = 0 - 1 m

  1 m HCP = 0 - 1.6 m

  2 m HCP = 0 - 3.2 m



(After Visconti and dePaz ,2016)

HYPOTHESIS

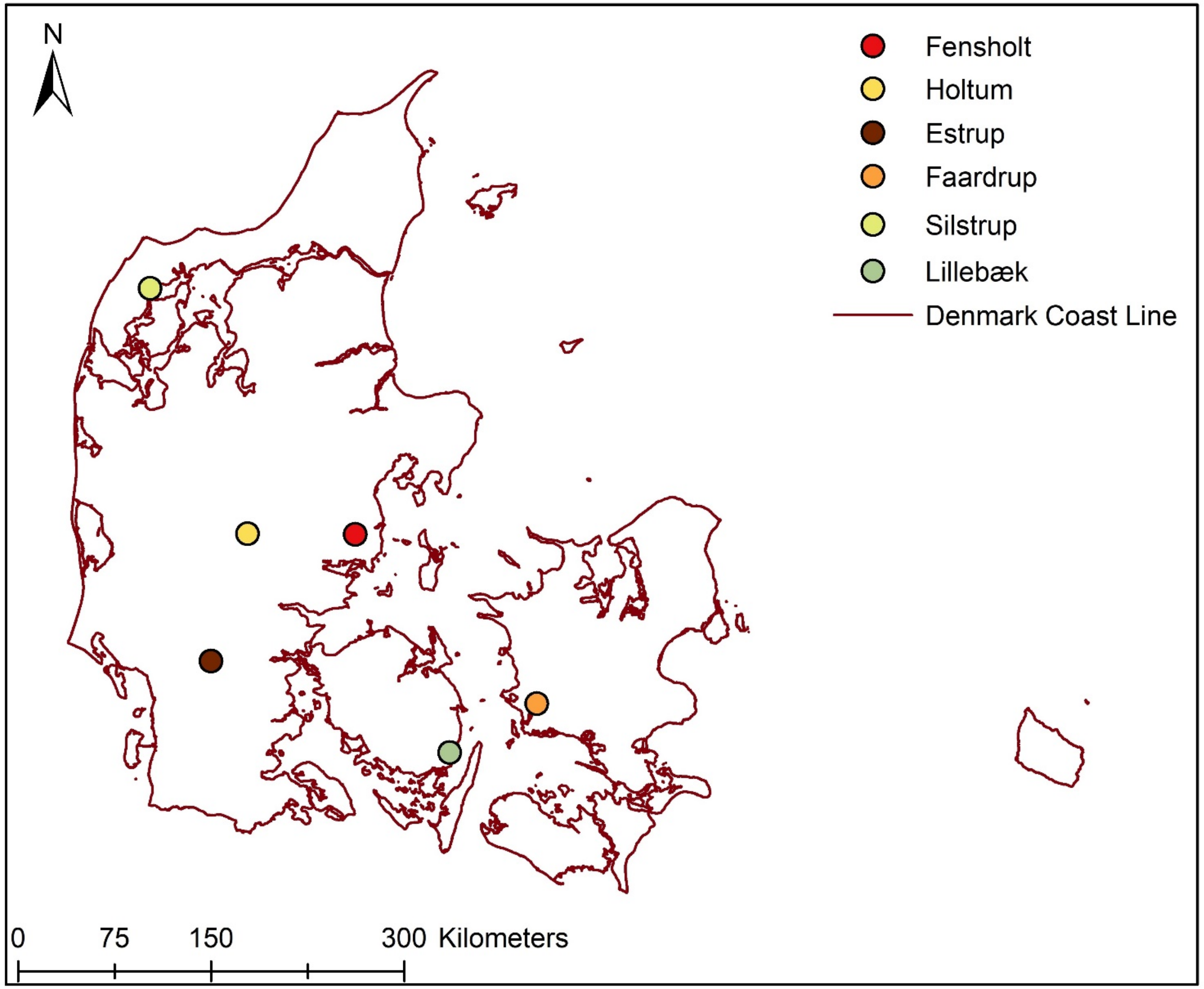
Hypothesis:

- The **electrical conductivity** measured by the EMI instrument determines the attenuation of the electromangetic waves. Hence, it can be a useful proxy to explain the success achieved by GPR in finding the drain lines.

STUDY SITES

Study sites:

- Fensholt upland – Clay till
- Fensholt lowland – Organic
- Holtum – Sand
- Estrup – Clay till
- Faardrup – Sandy clay till
- Silstrup – Clay till
- Lillebæk – Clay till



RESULTS

GPR Results:

Study Site	Time of the Survey	Proportion of target area (%)	Penetration Depth (m)	Success Rate (%)
Fensholt upland	September 2016	30	0.5 - 1	10
Fensholt lowland	August 2015, January 2016, September 2016	100 in total	1.5	75
Silstrup	November 2015	50	1 - 1.5	0
Estrup	November 2015, September 2017, August 2018	95, 25, 25	1 - 1.5	5
Faardrup	September 2015	100	1.6	99
Holtum	January 2016	5	2	High*
Lillebæk-1	August 2015	100	0.5 - 0.8	25
Lillebæk-2	August 2015	50	0.6 - 1.2	15
Lillebæk-3	August 2015	50	0.6 - 1.2	25

*Presumed to be high due to lack of pre-existing drain maps.

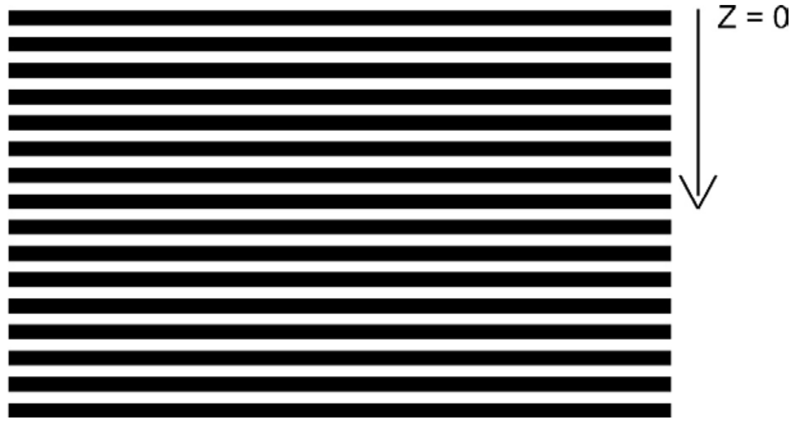
RESULTS

EMI Results:

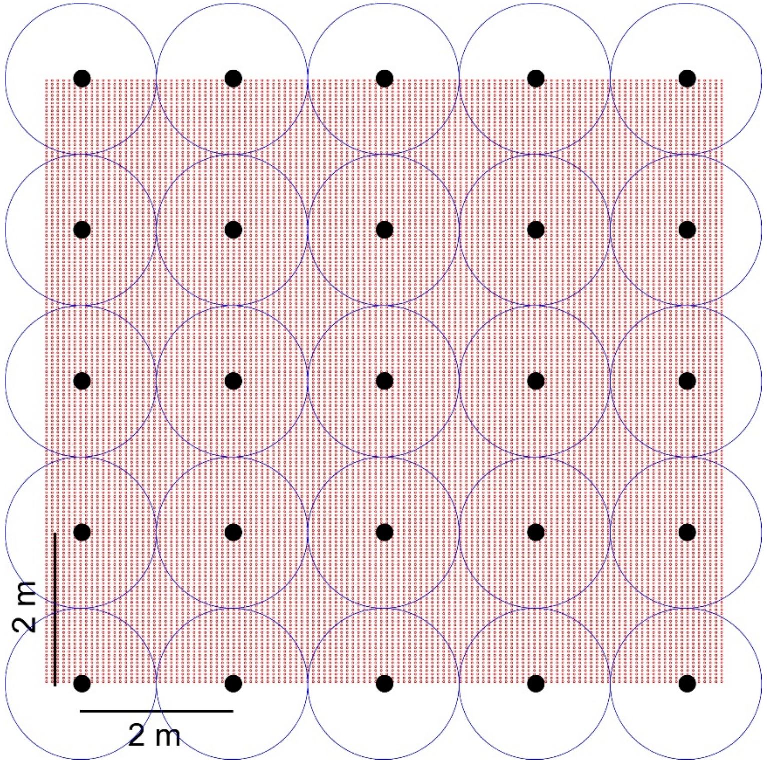
Study Site	1 m PRP	1 m HCP	2 m PRP	2 m HCP
Fensholt upland	10.4	17.7	16.5	23.7
Fensholt lowland	14.2	22.3	20.6	26.7
Silstrup	7.6	18.2	15.3	22.7
Estrup	12.9	28.6	23.3	35.2
Faardrup	7.7	14.8	14.3	19.0
Holtum	4.9	5.9	6.0	8.3
Lillebæk-1	12.1	21.1	19.2	27.5
Lillebæk-2	10.6	20.0	18.1	27.4
Lillebæk-3	10.4	20.8	18.4	29.0

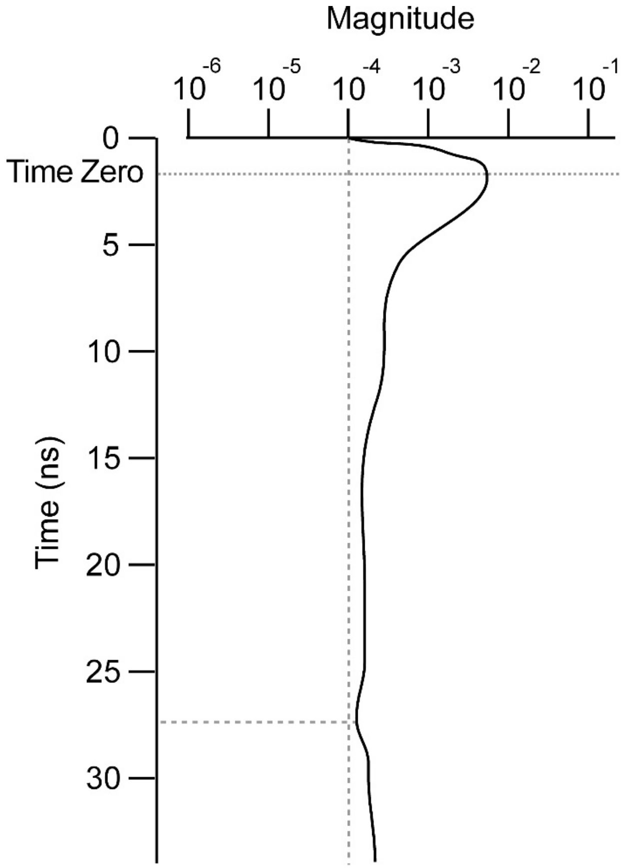
1 m PRP = 0 - 0.5 m ; 1 m HCP = 0 - 1.6 m ; 2 m PRP = 0 - 1.0 m ; 2 m HCP = 0 - 3.2 m

LOCALIZED PENETRATION DEPTH

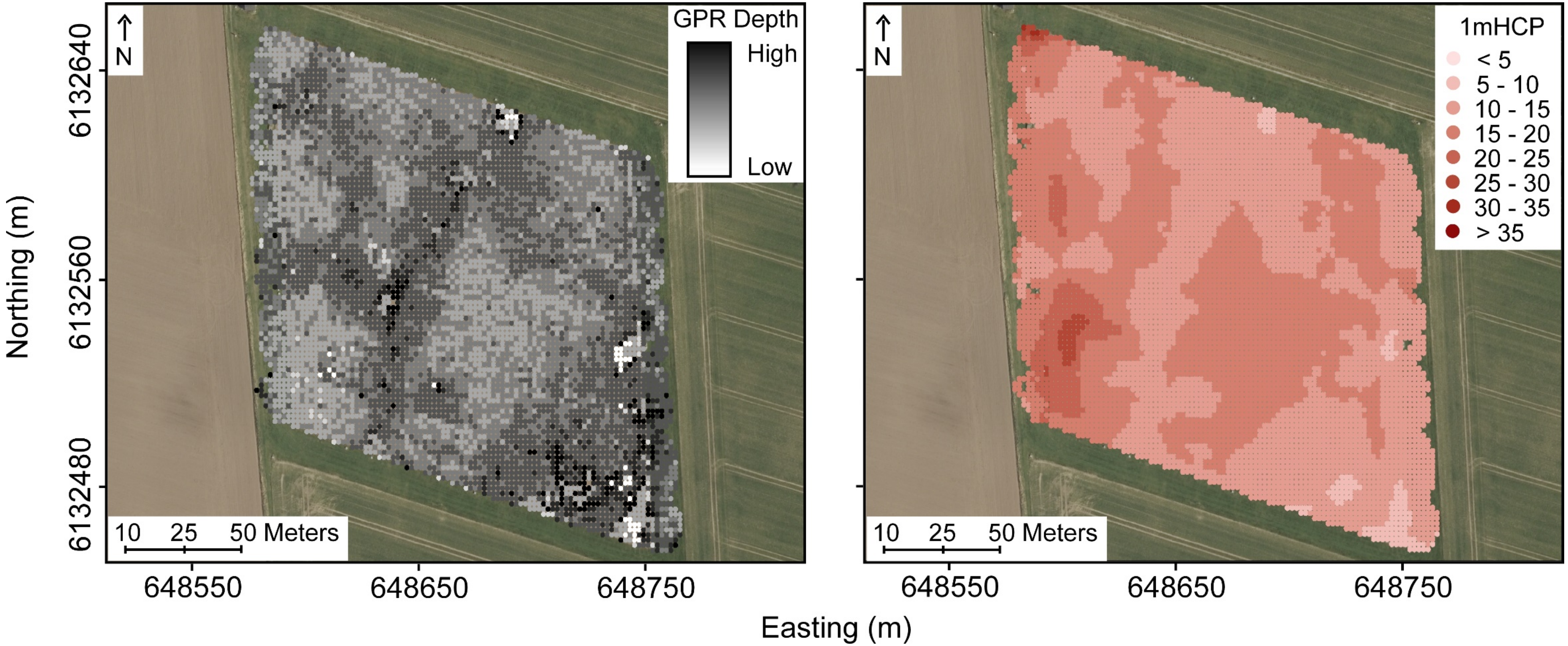


$$R = \frac{\sqrt{\varepsilon_2} - \sqrt{\varepsilon_1}}{\sqrt{\varepsilon_2} + \sqrt{\varepsilon_1}}$$





LOCALIZED PENETRATION DEPTH VS ECA



CONCLUSION AND FUTURE OUTLOOK

Conclusion:

- GPR was successful in finding the drains at 3 out of 9 sites.
  - Organic, sand and sandy clay till
- Good correlation was observed between **localized penetration depth** of GPR and **electrical conductivity**.

Future Outlook:

- Assess quantitative relationship between **penetration depth** and **electrical conductivity**.
- Predict the suitability of GPR based on EMI measurements.

- Additional methods:
  - Drone Imagery
  - Magnetic Gradiometer

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REFERENCES

- McBratney, A. B., Santos, M. M., & Minasny, B. (2003). On digital soil mapping. Geoderma, 117(1-2), 3-52.
- Annan, A. P. (2009). Electromagnetic principles of Ground Penetrating Radar. In Jol. H. M. (Ed.), Ground Penetrating Radar Theory and Applications (pp. 4 - 40). Amsterdam, The Netherlands: Elsevier Science.
- Conyers, L. B. (2004). Ground-Penetrating Radar for Archaeology. Geophysical Methods for Archaeology. Langham, United Kingdom: AltaMira Press.
- Van De Vijver, E. (2017). Proximal soil sensing in the context of urban (re)development: an evaluation of multi-receiver electromagnetic induction and stepped-frequency ground penetrating radar at landfills and industrial sites (Doctoral dissertation). Ghent University, Ghent, Belgium.
- Reynolds, J.M., (1997). An Introduction to Applied and Environmental Geophysics. John Wiley and Sons New York.
- Poluha, B., Porsani, J. L., Almeida, E. R., dos Santos, V. R. N., & Allen, S. J. (2017). Depth Estimates of Buried Utility Systems Using the GPR Method: Studies at the IAG/USP Geophysics Test Site. International Journal of Geosciences, 8(05), 726.
- Allred, B. J., Daniels, J. J., Fausey, N. R., Chen, C., Peters, L., & Youn, H. (2005). Important considerations for locating buried agricultural drainage pipe using ground penetrating radar. Applied Engineering in Agriculture, 21(1), 71-87.
- Visconti, F., & de Paz, J. M. (2016). Electrical Conductivity Measurements in Agriculture: The Assessment of Soil Salinity. In New Trends and Developments in Metrology. IntechOpen.

- Website links: www.suburbanplumbingexperts.com; www.trailism.com; www.veristech.com; www.mydronelab.com; www.math.ubc.ca; www.sensoft.ca; www.em.geosci.xyz; www.3d-radar.com accessed on 23 May, 2019.

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