MAPPING OF AGRICULTURAL SUBSURFACE DRAINAGE SYSTEMS USING TIME AND FREQUENCY DOMAIN GROUND PENETRATING RADARS

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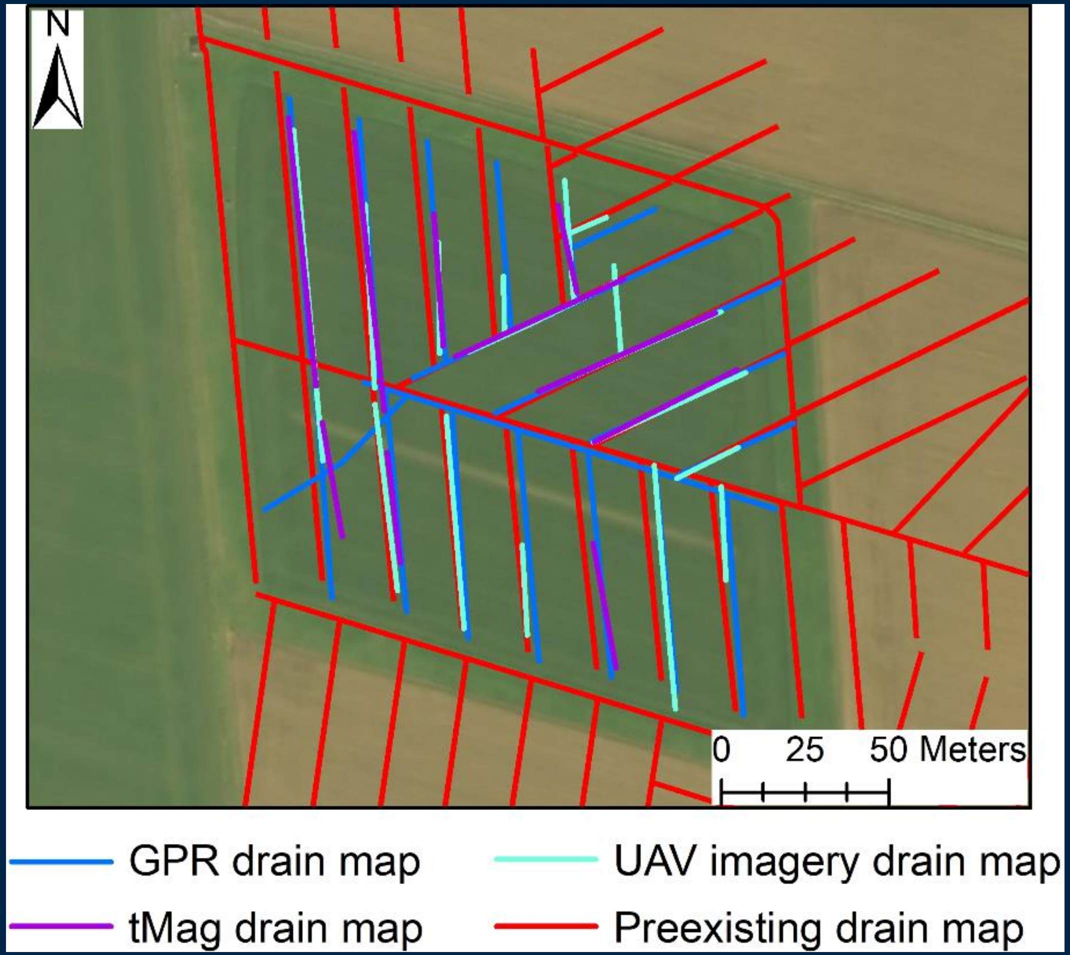


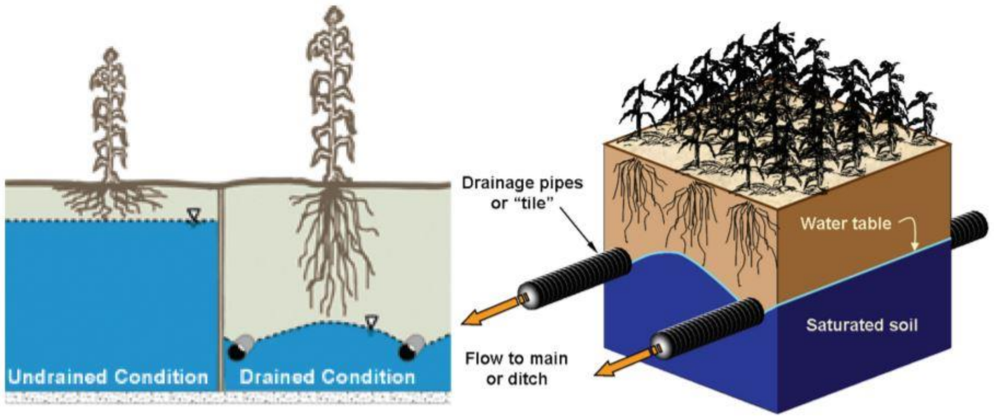
BACKGROUND

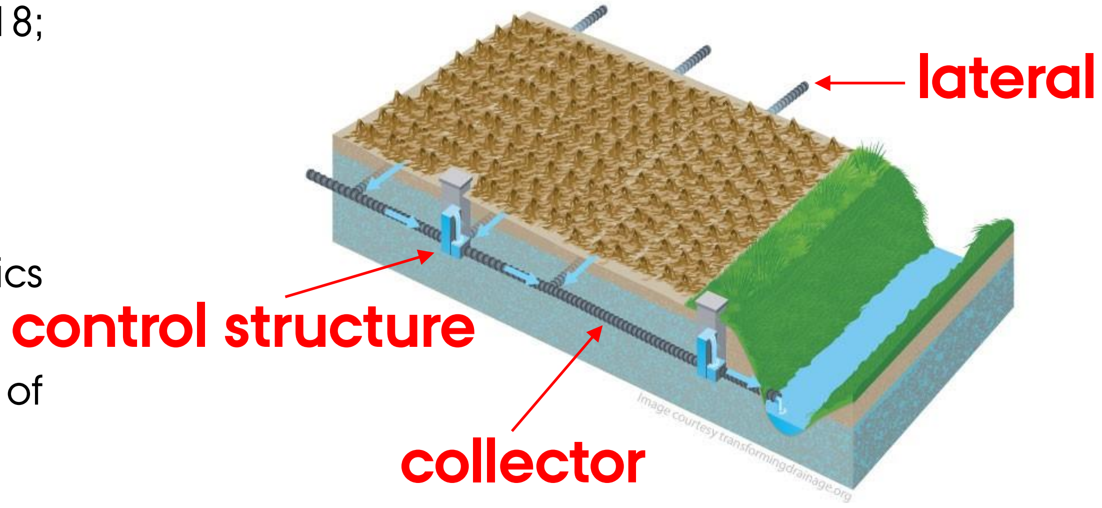
Agricultural subsurface drainage sytems (aka tile drains):

- Artificial drainage systems installed to transform poorly drained soils into productive cropland and mitigate soil salinization.
- Provides many **agronomic, economic** and **environmental** benefits.
- At present, more than **50%** of the agricultural areas in Denmark and Midwest USA are artificially drained (Møller et al., 2018; Song et al., 2021).

Why do we map them?

- Important to understand the hydrology and solute dynamics and plan effective edge-of-field mitigation strategies.
- To install new drain lines, it is essential to know the location of the existing drainage system.





(Source: transformingdrainage.org; Blann et al., 2009)

PROBLEM DEFINITION

Traditional methods:

- Tile probing
- Trenching equipment

Limitations:

- Labour intensive and tiresome
- Localized and discrete
- Damage risk

GROUND PENETRATING RADAR (GPR)

GPR:

- Works on frequency bandwidth of 10 MHz – 3 GHz.
- Waves get reflected at the interface of media with different **relative dielectric permittivity (RDP)**.
- **Electrical conductivity (EC)** controls the degree of attenuation and hence the penetration depth.

$$\mathrm{PD} = \frac{40}{\sigma}$$

Time-domain

Frequency-domain

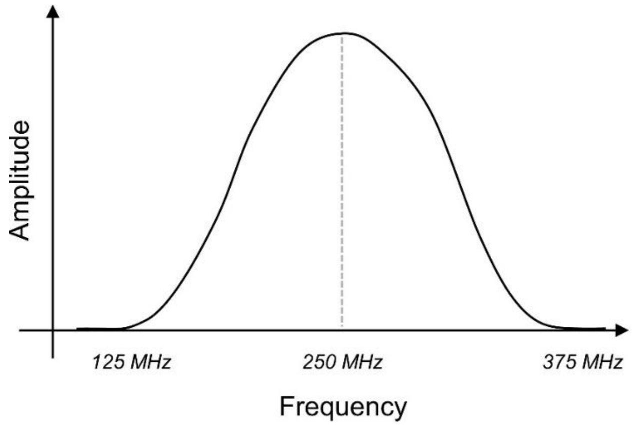
TIME-DOMAIN VS FREQUENCY-DOMAIN GPR

Frequency bandwidth:

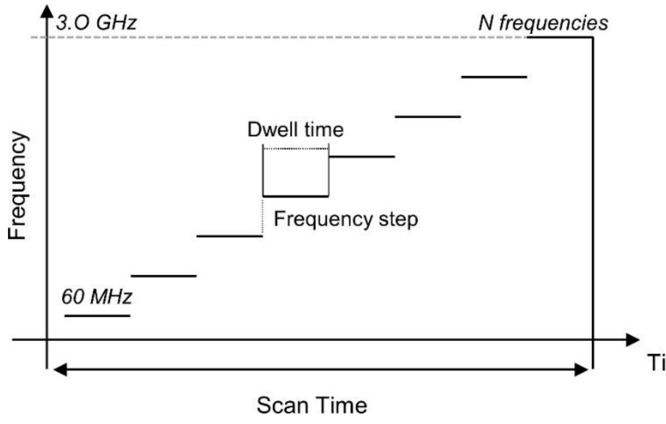
- Limited bandwidth (E.g., 250 MHz)
- Wide band coverage (E.g., 60 MHz – 3 GHz)

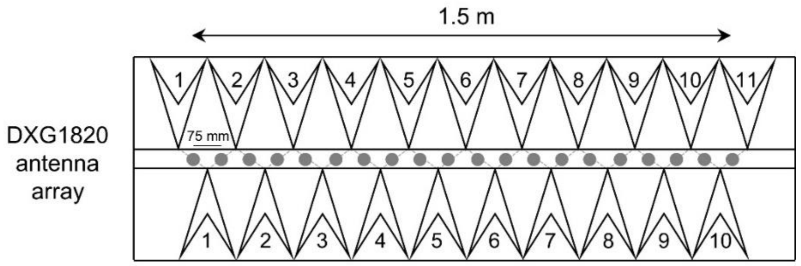
Antenna array:

- Single channel
- 20 Channels – 1.5 m



Time-domain





Frequency-domain

(Modified from: 3d-radar.com)

RESULTS – 3D-GPR

Denmark

3D-GPR

DUALEM

COMPARISON

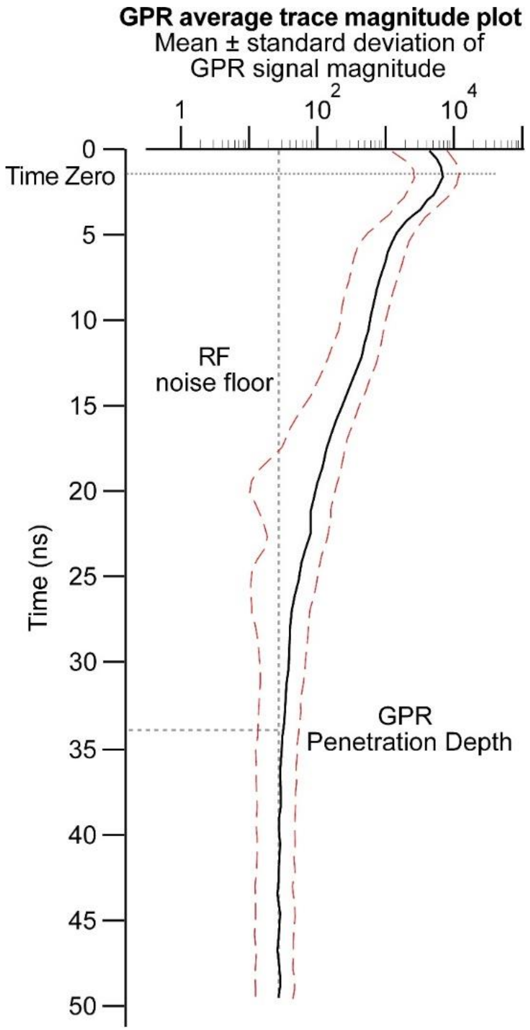
EC < 20 mS m^{-1}

Summary of mean ECa 1 m HCP, EC (0 – 1.5 m), success rate, estimated drainage depth, and average 3D-GPR global PD at different sites.

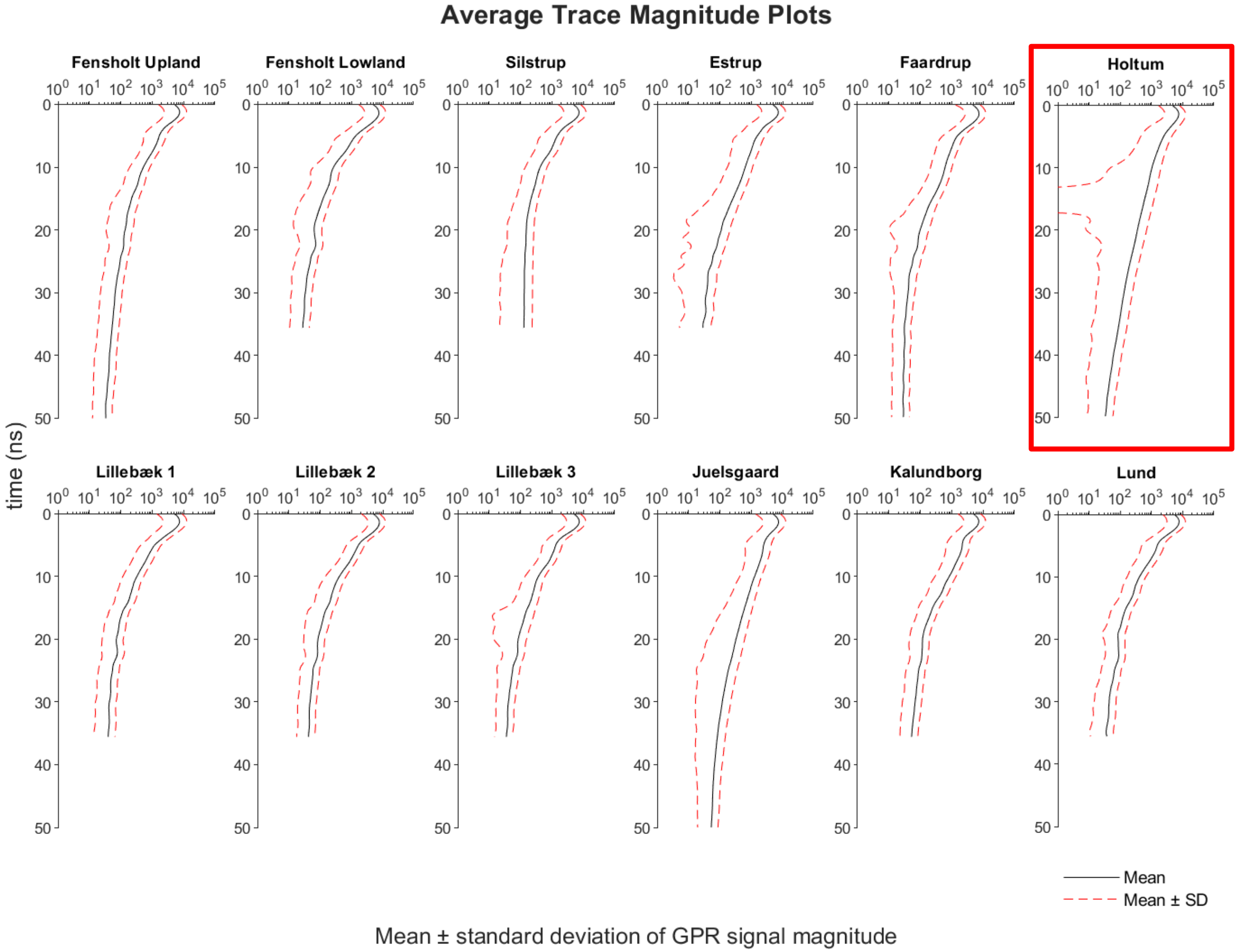
Study site	ECa (0 – 1.6 m)	EC (0 – 1.5 m)	Success rate (%)	Estimated drainage depth (ns)	Estimated drainage depth (m)	3D-GPR global PD (ns)	3D-GPR global PD (m)
Fensholt upland	17.7	22.3	10	10 – 18	0.4 – 0.8	13 – 24	0.5 – 1.0
Fensholt lowland	22.3	32.2	75	12 – 18 22 – 33	0.5 – 0.8 1.0 – 1.5	22 – 33	1.0 – 1.5
Silstrup	18.2	22.7	0	15 – 22	0.7 – 1.0	22 – 33	1.0 – 1.5
Estrup	28.6	33.0	5	17 – 29	0.7 – 1.2	24 – 36	1.0 – 1.5
Faardrup	14.8	21.3	99	14 – 20	0.6 – 0.9	23 – 35	1.0 – 1.5
Holtum	5.9	9.0	High	10 – 39	0.5 – 2.3	34 – 42	2.0 – 2.5
Lillebæk-1	21.1	26.4	25	9 – 16	0.4 – 0.7	14 – 27	0.6 – 1.2
Lillebæk-2	20.0	24.8	15	10 – 17	0.4 – 0.7	14 – 27	0.6 – 1.2
Lillebæk-3	20.8	24.9	25	9 – 16	0.4 – 0.7	14 – 27	0.6 – 1.2
Juelsgaard	6.7	9.3	90	20 – 29	0.8 – 1.2	48 – 59	2.0 – 2.5
Kalundborg	11.3	13.2	70	10 – 25	0.4 – 1.0	24 – 36	1.0 – 1.5
Lund	16.0	23.0	0	15	0.6	15 – 29	0.6 – 1.2

50%

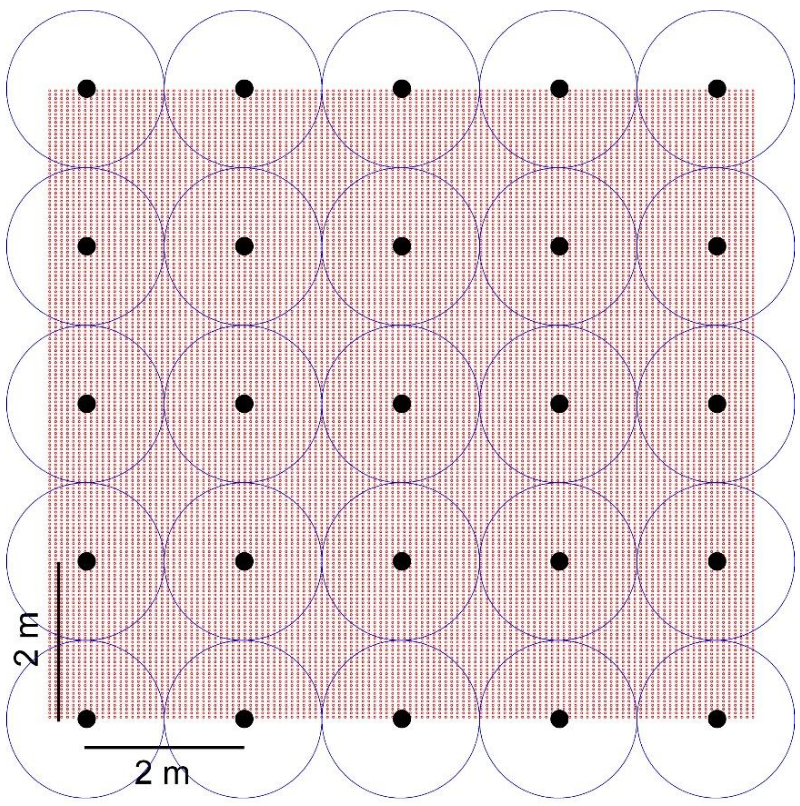
GLOBAL PENETRATION DEPTHS



ATM plots

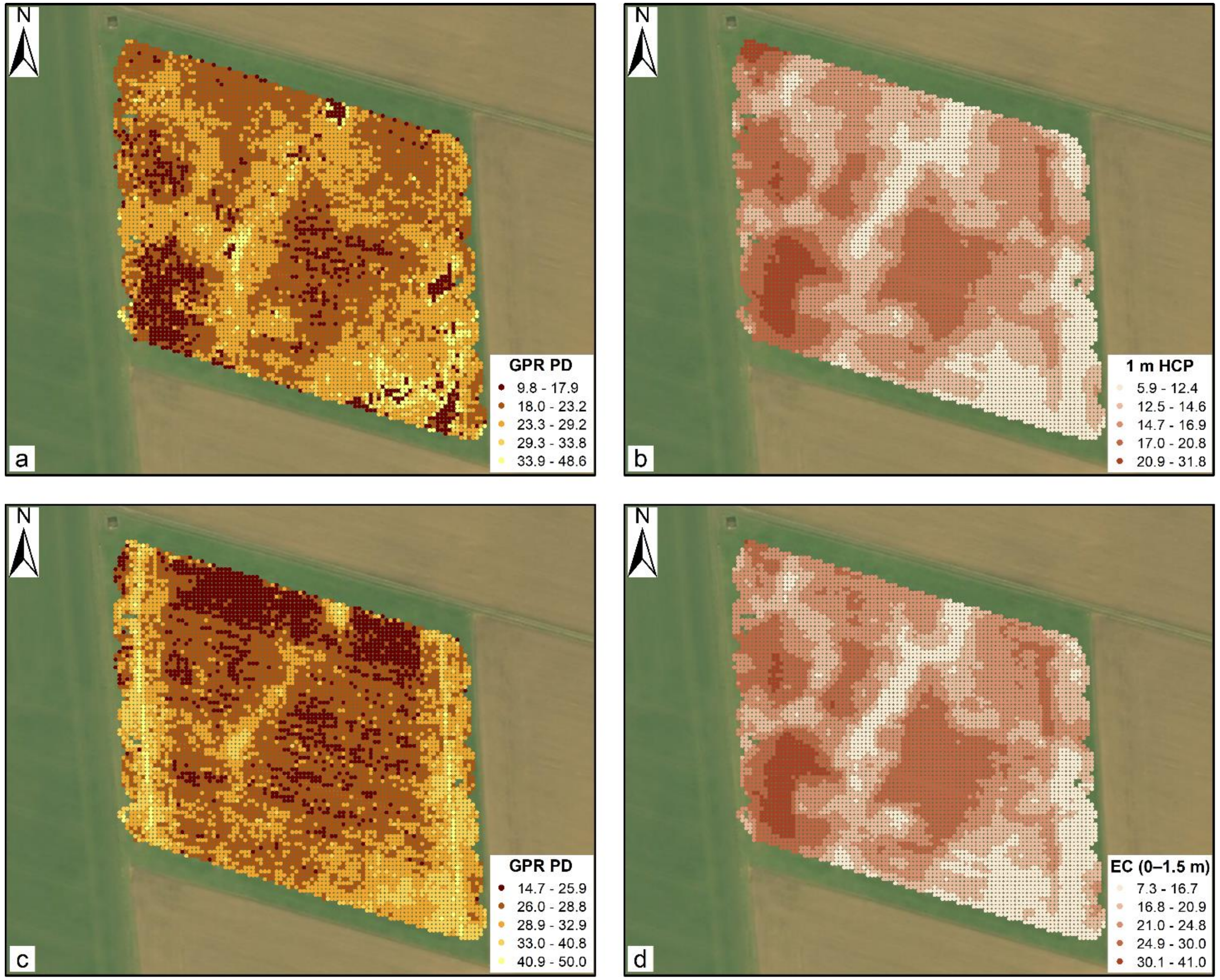


LOCALIZED PENETRATION DEPTHS



(b)

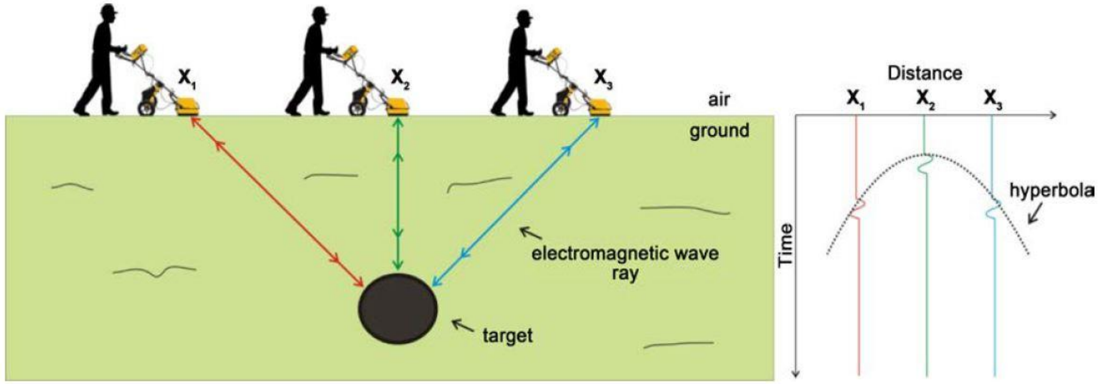
Faardrup



TYPICAL DRAINAGE PIPE SIGNATURE

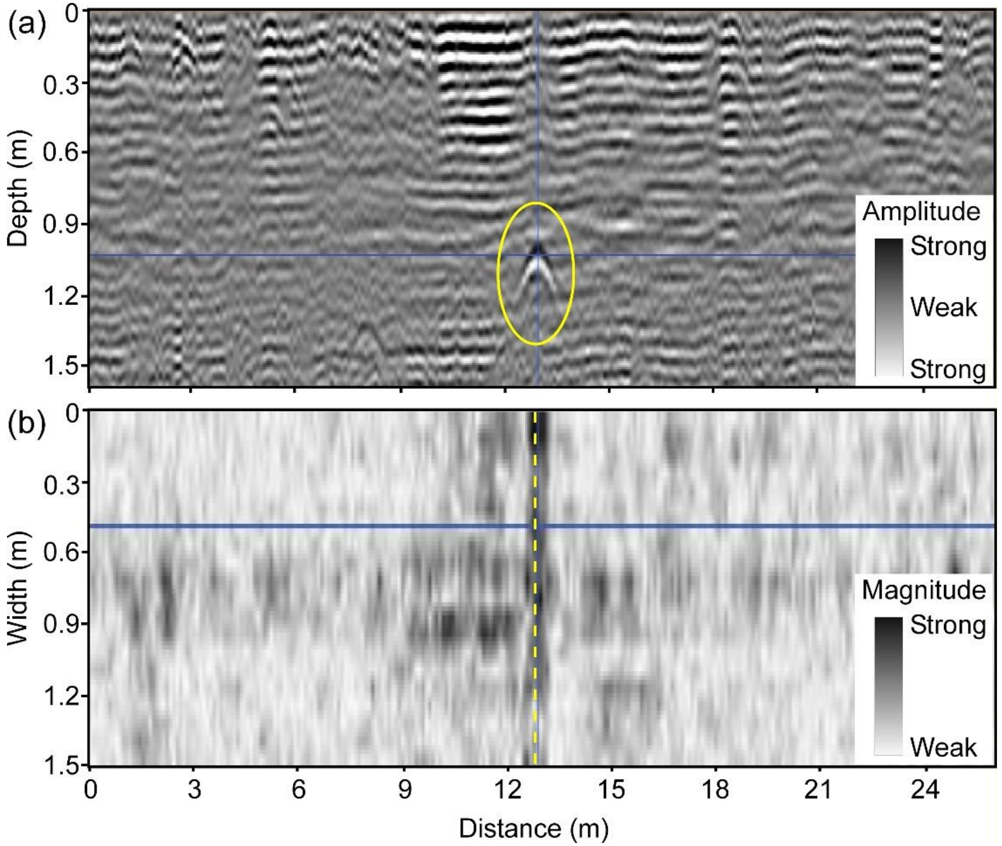
Perpendicular to drain line orientation:

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

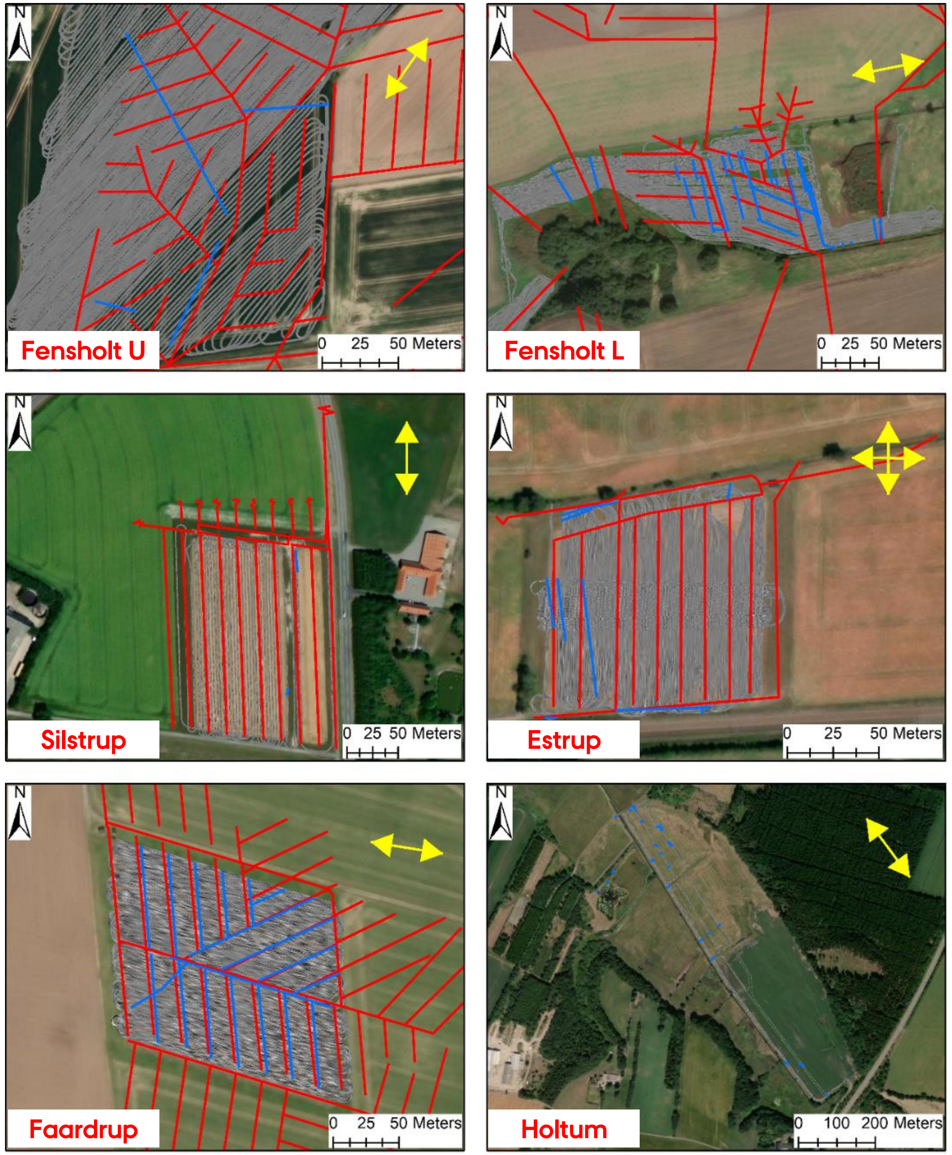


(Source: Poluha et al., 2017)

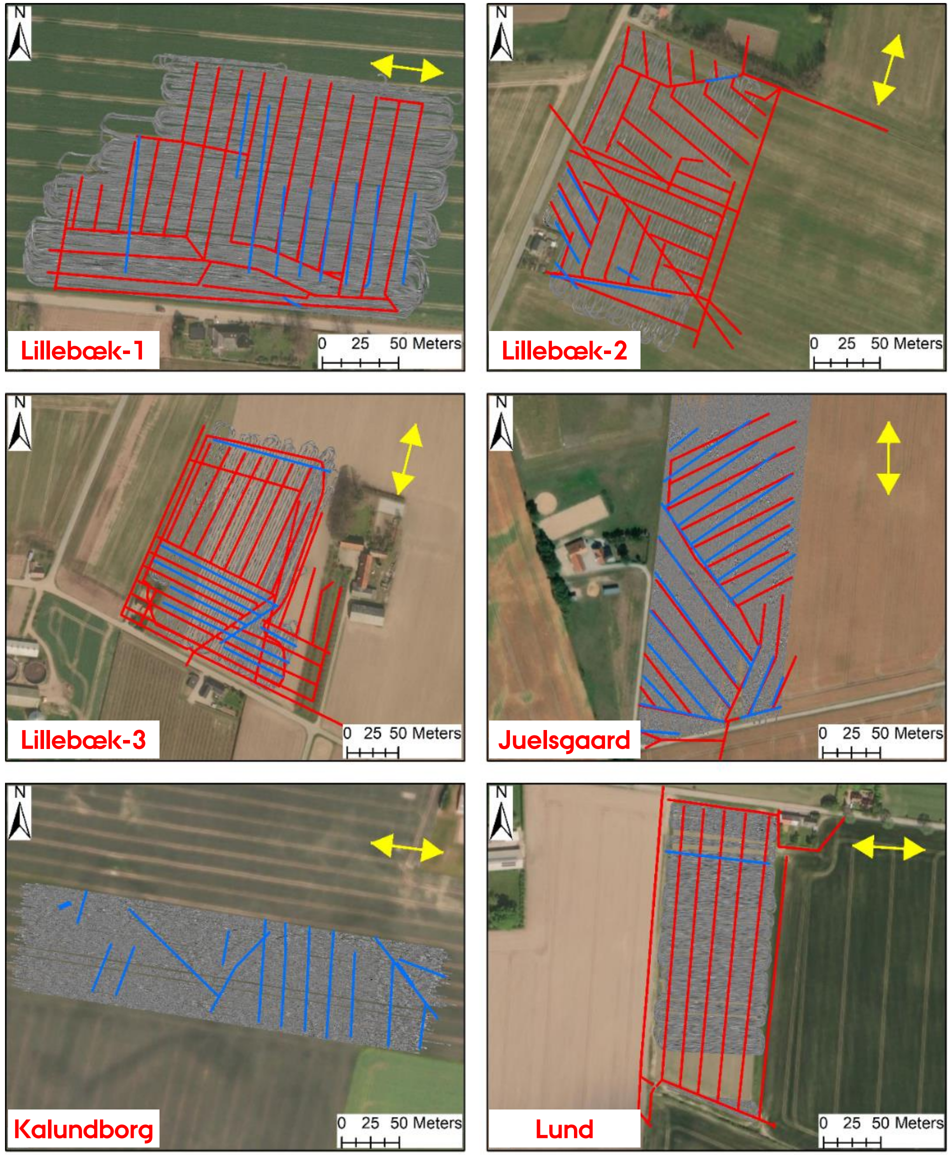
Vertical Profile



Depth Slice



GPR drain map
Preexisting drain map



GPR drain map
Preexisting drain map

RESULTS – COMPLEMENTARY USE

Midwest USA

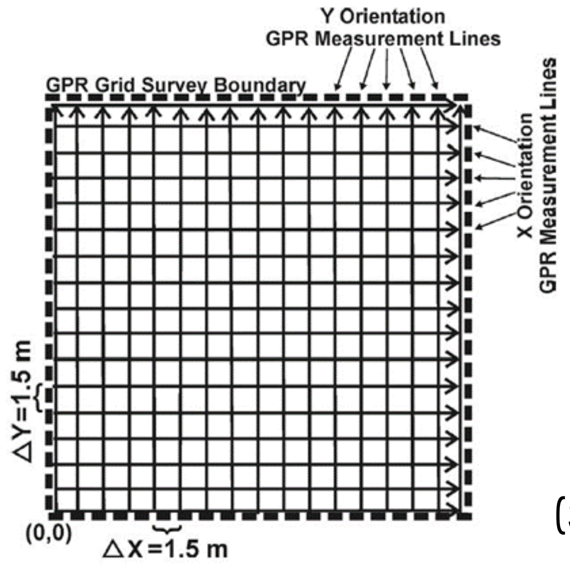
UAV Imagery

GPR

COMPLEMENTARY USE

Optimal survey configuration?

- UAV imagery – 100 ha in 30 to 45 minutes
- GPR – 100 m^2 in the same time
- Use both?



(Source: Allred et al., 2005)

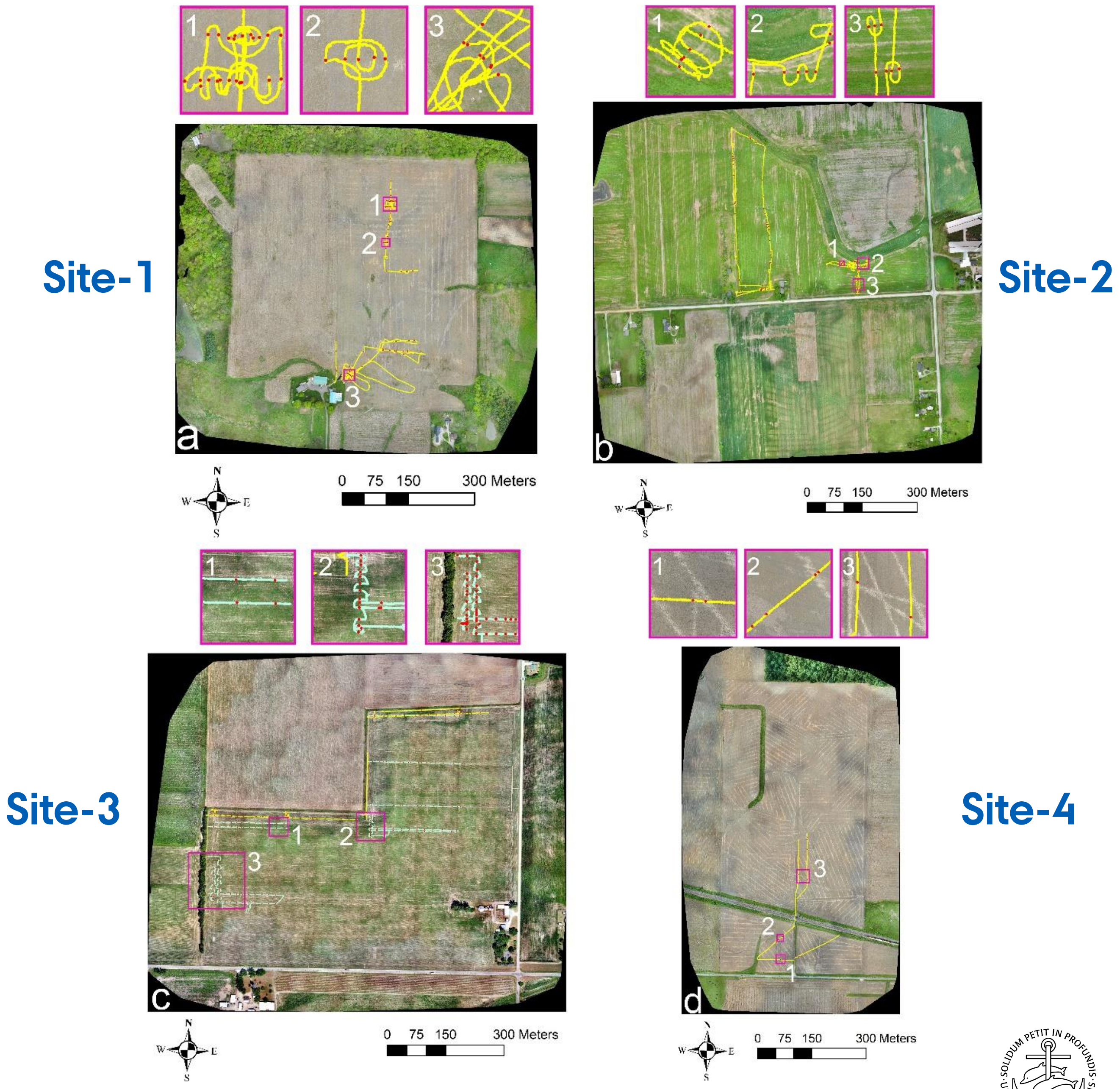
Site-3

COMPLEMENTARY USE

Summary:

1. At **Site-1**, both the UAV imagery and GPR were equally successful.
2. At **Site-2**, while the UAV imagery was successful in one section of the field GPR proved to be useful in the other section.
3. At **Site-3**, less to no success was observed in finding the drain lines using UAV imagery captured on bare ground conditions, whereas good success was achieved using GPR.
4. At **Site-4**, the UAV imagery was successful and GPR failed to capture the drainage pipes' location.

❖ Thus, GPR was useful as both a mapping and validation technique and provided information on the drainage pipes' depth.

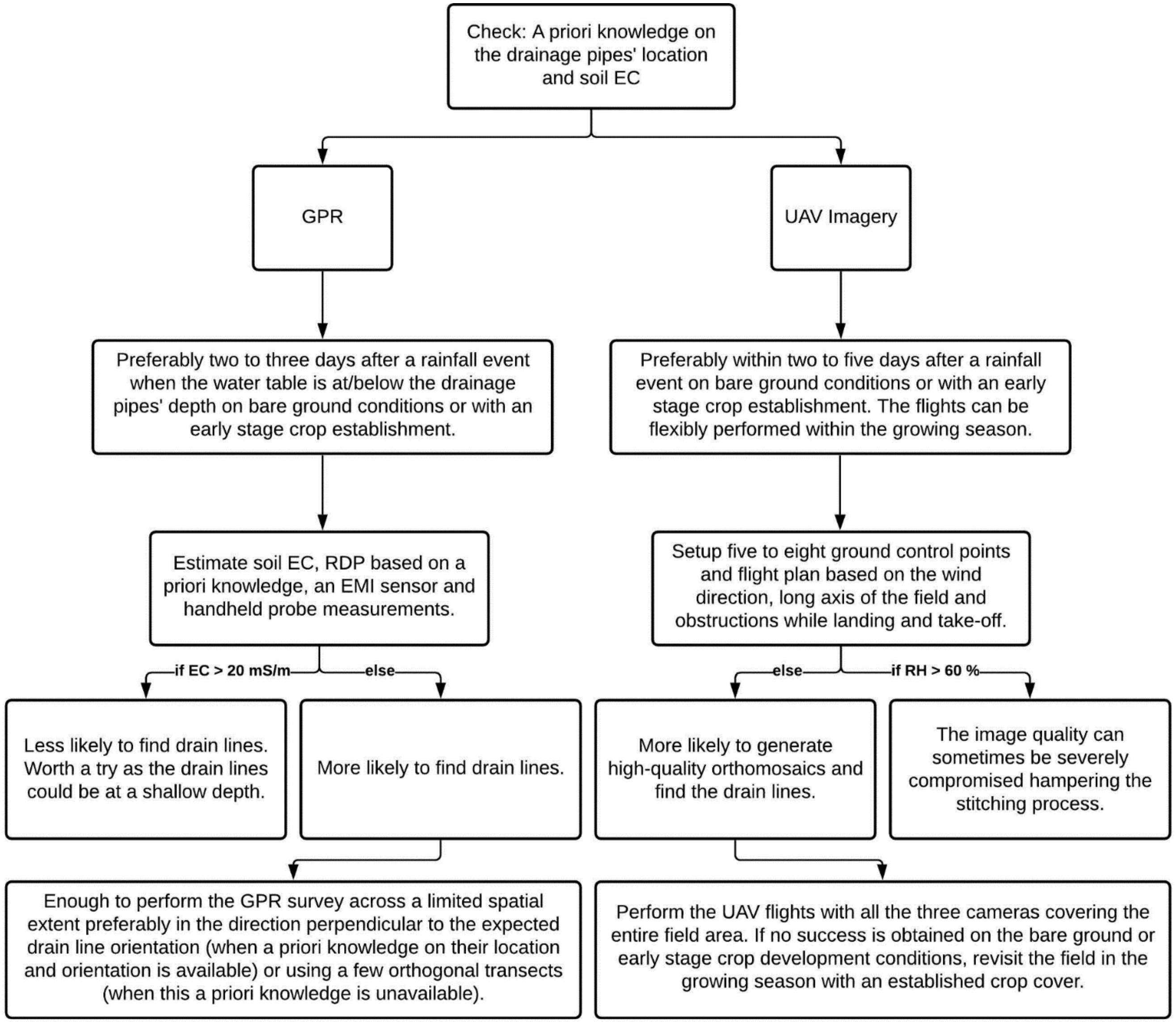


GUIDELINES

Optimal timing for site conditions in Denmark:

- When the water table is at/below the drain lines depth:
  - ✓ In spring (March – April)
  - ✓ In summer after the harvest until late autumn (August – October)

- Surveys during late autumn to winter (November – February) should preferably be avoided.



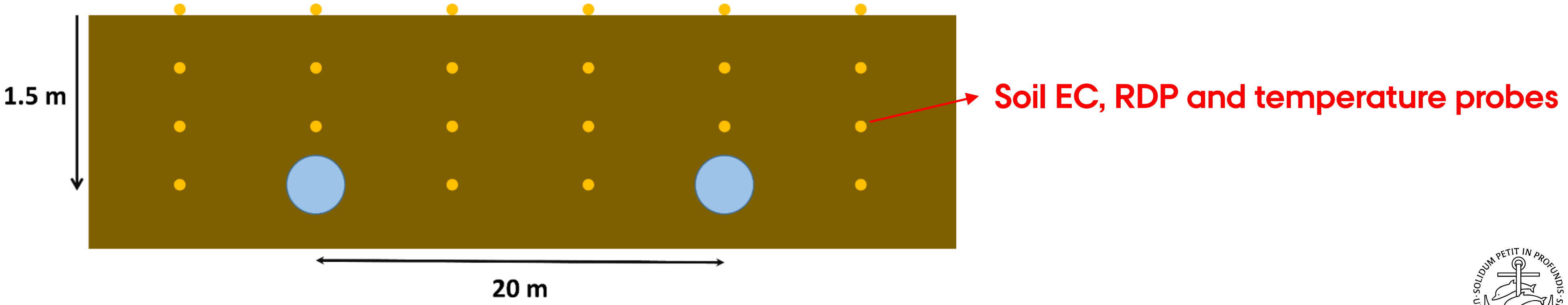
KEY FINDINGS AND FUTURE WORK

Key findings:

- Drainage pipe **diameter** and **depth of installation** are important considerations.
  - ❖ Europe: **50 mm** in diameter
  - ❖ USA: **100 mm** in diameter

To develop a more robust framework:

- Forward modelling of proximal sensors
- Controlled experiment using remote sensing
- Field experiments with all the sensors



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SUPPORTING PAPERS

Journal articles:

I. **Koganti, T.**, Van De Vijver, E., Allred, B. J., Greve, M. H., Ringgaard, J., & Iversen, B. V. 2020. Mapping of agricultural subsurface drainage systems using a frequency-domain ground penetrating radar and evaluating its performance using a single-frequency multi-receiver electromagnetic induction instrument †. Sensors, 20(14), 3922. https://doi.org/10.3390/s20143922

II. **Koganti, T.**, Ghane, E., Martinez, L., Iversen, B. V., & Allred, B. J. 2020. Mapping of agricultural subsurface drainage systems using unmanned aerial vehicle imagery and ground penetrating radar †. Sensors, 21(8), 2800. https://doi.org/10.3390/s21082800

Dissertation:

I. **Koganti, T.** 2021. Mapping of agricultural subsurface drainage systems using proximal and remote sensors. PhD Dissertation. Department of Agroecology, Graduate School of Technical Sciences, Aarhus University, Denmark. 238 pp. http://dx.doi.org/10.13140/RG.2.2.12064.92165

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