Mapping Subsurface Drainage in Agricultural Areas Using a Frequency-Domain Ground Penetrating Radar

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Introduction

- More than 50% of the agricultural area in Denmark is assumed to be artificially drained.
- Leaching of nutrients through artificial drainage systems poses a potential eutrophication risk to the aquatic environment.
- To install new drain lines, it is essential to know the location of the existing subsurface drainage system.
- Traditional methods for drainage mapping such as tile probing and trenching equipment are invasive and labor intensive.

Objective

To assess the suitability of a frequency-domain ground penetrating radar (GPR) on Danish soils for subsurface drainage mapping.

Study Sites

The study was conducted across 12 sites with soil textures ranging from sand to clay till.

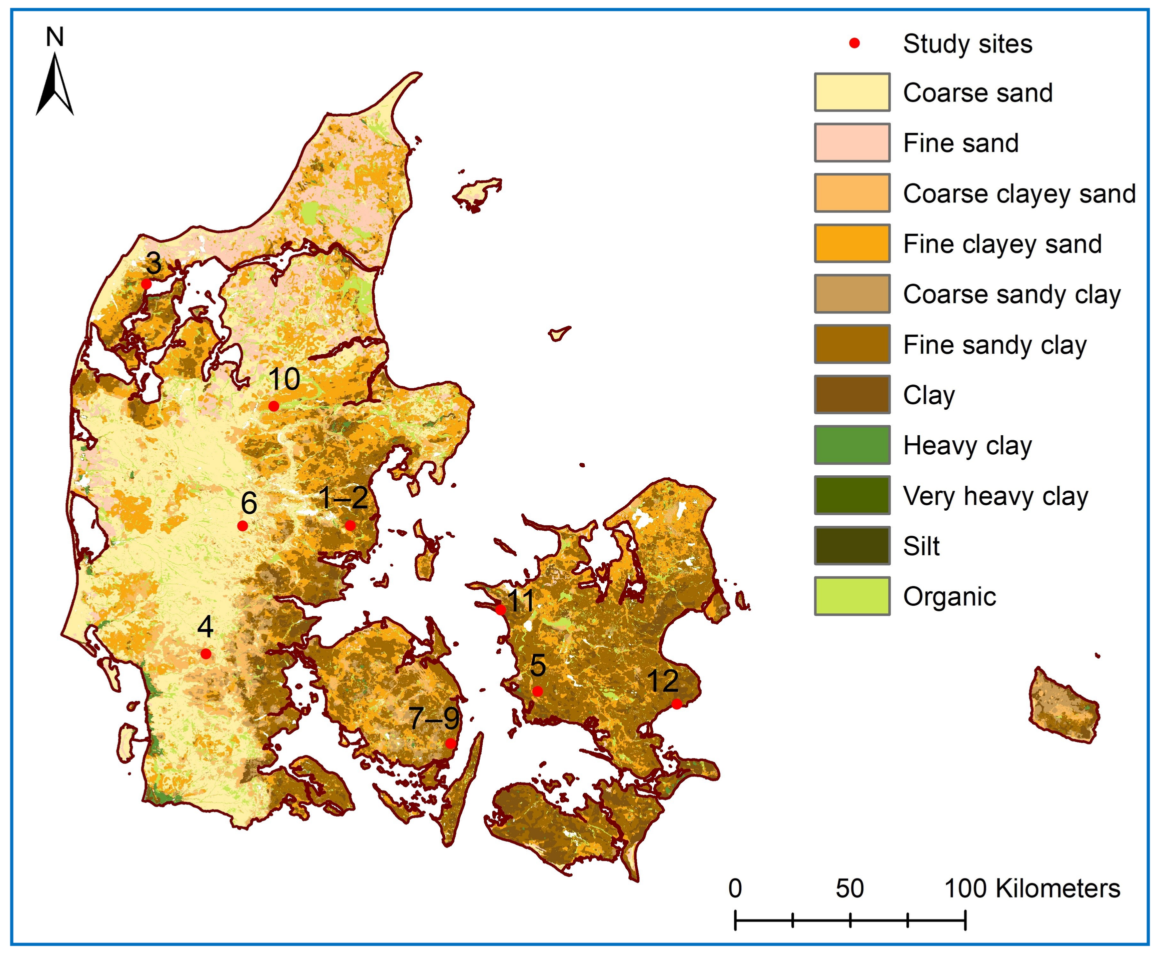

Figure 1. Map of Denmark showing the study sites location and soil types according to the Danish Soil Classification (Madsen and Jensen, 1992).

Stepped-frequency GPR

- GeoScope Mk IV 3D-Radar with DXG1820 antenna array.
- Wide frequency bandwidth coverage (60 – 3000 MHz) enables usability for wide range of applications.
- The bandwidth can be adjusted depending on the desired resolution and depth of interest.
- Antenna array with wide area swathe (20 channels – 1.5 m) provides extensive coverage of the three-dimensional space.

TReNDS
Transport and Reduction of Nitrate in Danish Landscapes at various Scales

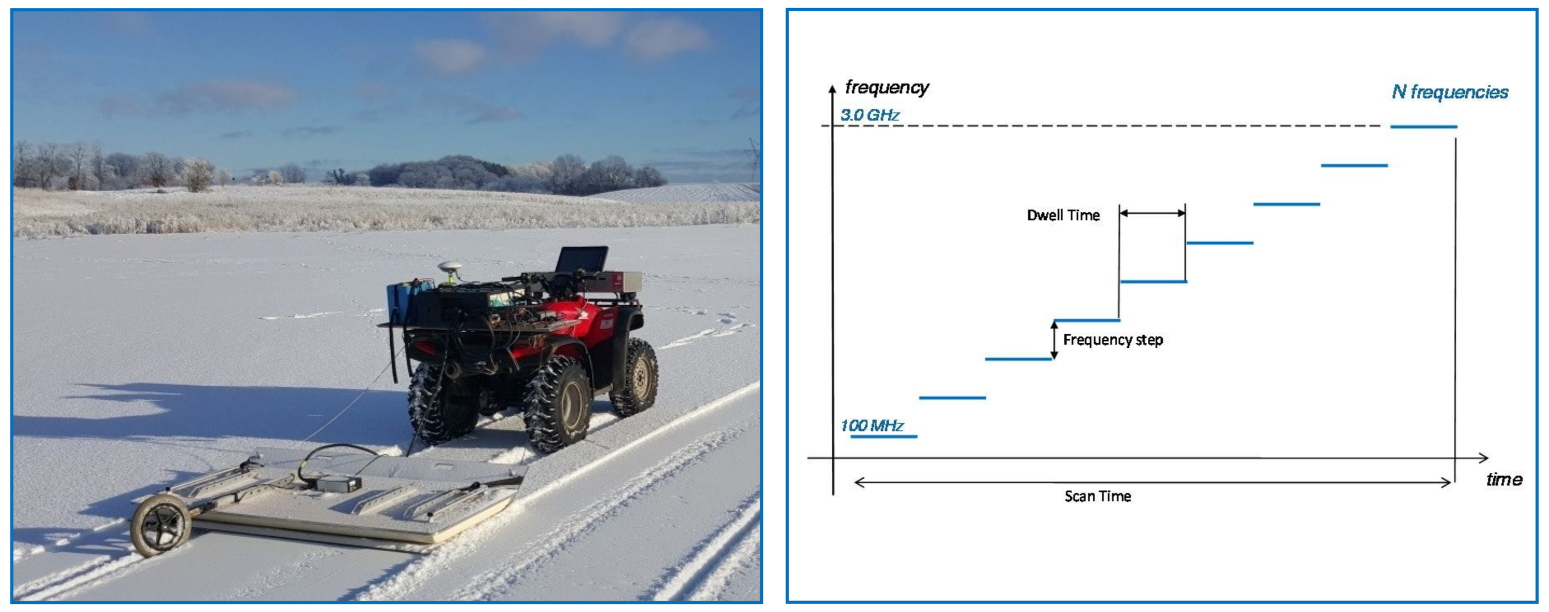

Figure 2. GPR pulled by an ATV (left); stepped-frequency behavior of the transmitted signal (right; source: 3d-radar.com).

Results and Discussion

Typical signature of a drain pipe when the GPR is moved perpendicular to drain line orientation:

- Hyperbolic pattern in the vertical profile of reflections (amplitude).
- Linear pattern in the horizontal slice of reflection strength (magnitude).

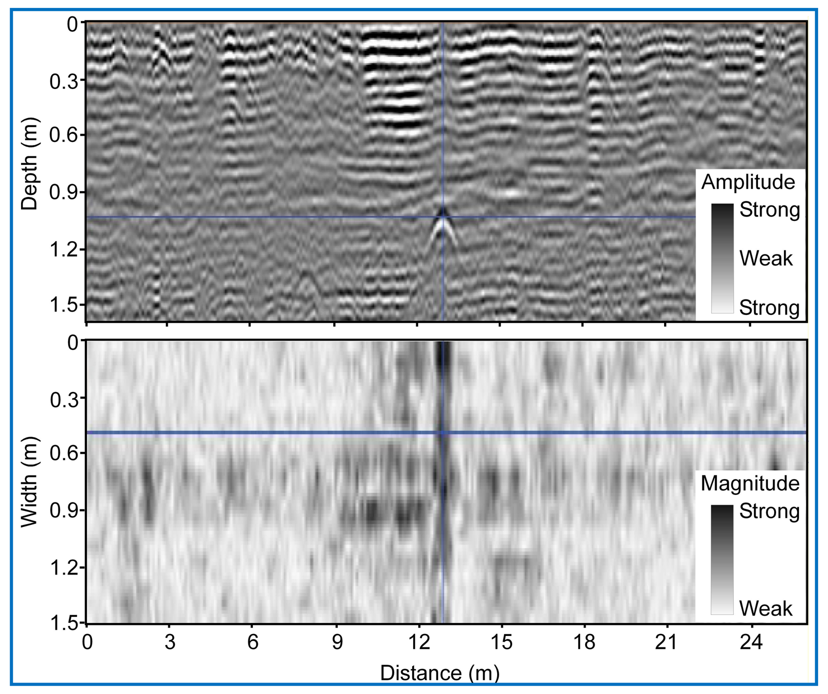

Figure 3. Typical signature of a drain line: hyperbolic pattern in the vertical profile (top); linear pattern in the horizontal slice (bottom).

The wide antenna array eliminates the need to carry survey along multiple parallel transects (Allred et al., 2005) or using spiral and serpentine patterns (Allred et al., 2018) to confirm the presence of the drain line and determine its orientation.

Table 1. Summary of the 3D-GPR surveys at the different study sites.

Study site	Estimated drainage depth (m)	Penetration depth (m)	Success rate (%)
Fensholt (upland area)	0.4 – 0.8	0.5 – 1.0	10
Fensholt (lowland area)	**0.5 – 1.5**	**1.0 – 1.5**	**75**
Silstrup	0.7 – 1.0	1.0 – 1.5	0
Estrup	0.7 – 1.2	1.0 – 1.5	5
Faardrup	**0.6 – 0.9**	**1.0 – 1.5**	**99**
Holtum	**0.5 – 2.3**	**2.0 – 2.5**	***High**
Lillebæk-1	0.4 – 0.7	0.6 – 1.2	25
Lillebæk-2	0.4 – 0.7	0.6 – 1.2	15
Lillebæk-3	0.4 – 0.7	0.6 – 1.2	25
Juelsgaard	**0.8 – 1.2**	**2.0 – 2.5**	**90**
Kalundborg	**0.4 – 1.0**	**1.0 – 1.5**	**70**
Lund	0.6	0.6 – 1.2	0

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

- Maximum success was achieved when the GPR traverse was oriented in a certain angle relative to the drain lines.
- High success rate was observed at 5 out of 12 sites where the GPR penetration depth was estimated to be deeper than the drainage system depth.
- Sites with sandy, sandy loam, loamy sand and organic topsoils showed more favorable conditions for detection.
- Low success rate was associated with clay-rich soils.

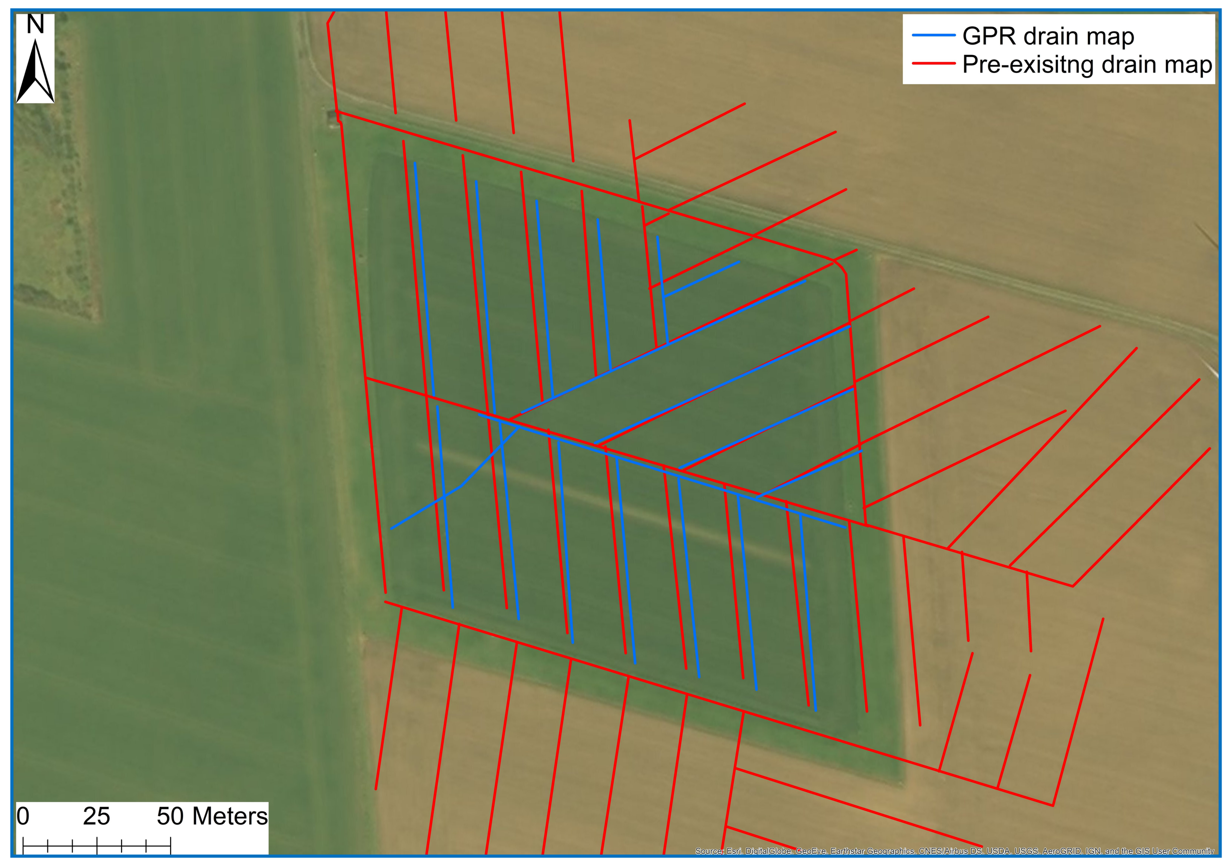

Figure 4. Drain lines mapped using GPR at Faardrup.

- As an example, drain lines mapped using GPR at Faardrup show a slight offset from the pre-existing drain map.

Conclusion and Outlook

- The success of drainage mapping using GPR depends on the environmental conditions. A high electrical conductivity causing a smaller penetration depth of the GPR signal explains the limited potential on clayey soils.
- In this relation, electrical conductivity measured by an electromagnetic induction instrument can act a suitable proxy to explain the penetration depth of the GPR and the success rate.
- Additional methods (drone imagery, magnetic gradiometer) need to be tested with a view of providing guidelines in relation to the choice of sensor.

References

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