tTEM Whitepaper
Report number 09-06-2019, June 2019
Purpose
The purpose of this whitepaper is to show the applicability of a new towed transient electromagnetic system called tTEM. A number of different problems have been solved in close collaboration with consulting companies and authorities. The problems have in common that they all benefit greatly from having very high-resolution 3D images of the geological layers available.

In the following we briefly describe the system. This is followed by a short description of five cases: point source contamination, geological mapping on land and lake, nitrate retention estimation on farm field scale, raw materials sand and gravel mapping and aquifer vulnerability mapping with establishment of a new well field.

The tTEM system

tTEM is a transient electromagnetic method designed and developed with the purpose to image the upper 30-100 m of the subsurface in very high resolution and in full 3D.

The tTEM system consists of sledges pulled by an ATV (All-Terrain Vehicle) (Figure 1 and Figure 2). All instruments are mounted at the back of the ATV, and a tablet is fixed in front for following where and what is being measured in real time. The front sledge carries a 2x4 m transmitter coil that generates a high current creating a strong primary magnetic field. When the current is turned off abruptly in the coil, the primary magnetic field will decay and create eddy currents in the ground. The eddy currents decays over time and thus they creates a changing secondary magnetic field. The decay rate of the second magnetic field is measured in the receiver coil mounted on the second sledge behind the ATV. From the decay rate, the electric resistivity of the subsurface can be calculated, since the decay of the secondary magnetic field depends on the resistivity, which again depends on the geological layers below the surface. For instance, clay deposits have a low resistivity and the response will decay slowly. In sand or gravel in which the resistivity is high, the response will decay quickly.

All geophysical measurements is georeferenced by a GPS mounted on the transmitter coil.

Mapping is carried out at a speed of 3-5 m per second corresponding to 20 km/h. With this setup, it is typically possible to measure 100 – 240 ha per day with a line density of 10-25 m. The method has a very small sensitivity volume (also called the footprint) that provides a lateral resolution down to 10 m enabling 3D mapping of even small geological structures. The small transmitter coil further offers the advantage that the system can go much closer to noise sources like power cables and other man-made installations that normally disturb electromagnetic surveys. The safety distance, or the distance at which the data gets disturbed, is about 50 m.
The system can also be used on lakes and rivers as FloaTEM (towed by a boat) and on ice/snow as SnowTEM (towed by a snowmobile).

Figure 2. The tTEM system in the first production setup from September 2017. The dimensions are unchanged in the present setup.
Mapping example - Optimized risk assessment of point-source pollution
EU-Interreg Topsoil project with Central Denmark Region

Purpose:
Mapping of clay cover around a pesticide pollution 200 m upstream from water abstraction

Area: VILDBJERG
GEOLOGY: Moraine clay, mica quartz sand, and mica clay.
SIZE/TIME: 29 ha/less than 1 day
LINE-KM: 29
LINE-DISTANCE: 10 m

Results
Pollution with pesticides was found near a machine station outside the town of Vildbjerg. The groundwater flow is southeast directly towards the abstraction wells of Vildbjerg waterworks. From existing wells there is a known mica layer of great thickness, but it is not possible to ascertain whether the layer is constant and without “windows” to the aquifer below. The area between the machine station and the abstraction wells was mapped with tTEM. tTEM provides a detailed image of the local geology enabling an assessment of the risk of percolate spreading, by mapping the spatial variation and volume of the clay and sand layers. The figure below shows the thickness of the clay layer as found by tTEM and drillings (B1, B2 and B3). As shown, the thickness of the layer is more than 15 m throughout the area and there are no windows. This makes for a small risk of the pollution spreading towards the extraction wells southeast. Acquiring this knowledge would have been difficult and costly and would have depended on borehole information alone.
Mapping example - Geological mapping on land and lake
EU-Interreg Topsoil project with GEUS, Central Denmark Region, Herning municipality and Water

AREA SUNDS
GEOLOGY Moorland plain over Miocene quartz-sand and clay from Måde fm.
SIZE/TIME 816 ha/8 days
LINE-KM 326,4
LINE-DISTANCE 25 m

Purpose:
Geological mapping on land and lake to understand the hydrological system around Sunds

Results
The town of Sunds surrounds Sunds Lake in the middle of the heath plain in Western Jutland. The plain is characterized by flat topography and sandy deposits. The groundwater table in the town and the surrounding farmland is close to the surface and reacts quickly to precipitation events, which has often led to flooded basements and fields. This is expected to get worse because of a renovation of the city’s sewer system (which unwanted also was a drainage system) and the future higher precipitation expected due to climate change. A geological mapping with tTEM and FloaTEM systems was made in order to understand the hydrological system around and under the town and lake of Sunds. Before the start of the project, the general understanding of the area’s geology was that it was a giant sand box to large depth. The geophysical mapping has shown that this is far from the truth. Below the first 20 m of glacial sand, glacially deformed clay layers from the Måde fm. appear interchanging with Miocene sand. The layers are greatly disturbed. Likewise, a thick organic silt deposit (10-20 m) under parts of Sunds Lake is found. The spatial extent of the clay and organic silt deposits is important to the hydrological circuit, and it is expected that with this new knowledge, climate proofing of the town and surrounding farmland will be possible.
Mapping example - Field scale nitrate retention mapping
Innovation Fund Denmark project, rOPEN

AREA | JAVNGYDE
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GEOLOGY | Meltwater sand and clay from Måde fm.
SIZE/TIME | 1001 ha/11 days
LINE-KM | 400,4
LINE-DISTANCE | 10-25 m

Purpose:
Geological mapping at field scale for developing automated N-retention maps in ID15 catchments

Results
The objective of rOpen is to develop a tool for assessing nitrate retention at field scale. Two 15 km² catchments (Javngyde and Sillerup) have been chosen as pilot areas, and geophysical, geochemical, and hydrological surveys have been performed in the catchments. tTEM has been used to map the farmland and the results are turned into a hydrostratigraphical model, that will be connected to the agricultural practices and redox mapping in order to produce nitrate-retention maps in a transparent and data driven workflow. The figures below first show the extremely complex geology that is being mapped with tTEM along a profile in the northeastern part of the area. Below is shown a single realization of the auto generated hydro stratigraphic model. An important strength of the rOpen modeling concept is that all uncertainties are being handled in a manner so that together with the final nitrate retention map one also gets an estimation of uncertainties, which is critical for the land use management.
Mapping example - Mapping of raw materials
Development project with Orbicon and the North Denmark Region

**AREA**

**STENDALMARK**

**GEOLOGY**
Meltwatersand and clay deposits. Some marine deposits.

**SIZE/TIME**
365 ha/3 days

**LINE-KM**
146

**LINE-DISTANCE**
25 m

**Purpose:**
Mapping of sand/gravel resources to support development of the infrastructure

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**Results**

Stable supplies of gravel are crucial for extending and maintaining the country’s infrastructure such as roads and railways, as well as for the construction industry. There is a need for finding new gravel pits using a cost-effective method, since drilling alone is too costly and time consuming. In a development project with Orbicon and North Denmark Region, 365 ha were mapped with tTEM in order to assess the method’s ability to locate raw material resources; sand and gravel. The mapping was carried out as part of the Region’s raw material resources planning that has to ensure that sufficient areas are laid out to sand and gravel extraction for a period of the next 12 years. The area was mapped in just three days and large areas with high resistivities were located. By means of the tTEM mapping the Region now has a very precise spatial delimitation of potential gravel deposits and a sound basis for follow up borehole surveys. The left figure shows a 3D image of the subsurface resistivities where conductive clay and till layers will be blue to yellow colors and high resistivity sand, gravel and silt layers is shown in red to purple colors. To the right is an iso-resistivity map with a cut-off value of 200 ohm-m showing only the high resistivity layers which would corresponds to sand and gravel deposits.
Mapping example - Vulnerability mapping and establishing a new well field
EU-Interreg Topsoil project with GEUS and DIN Forsyning

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<thead>
<tr>
<th>AREA</th>
<th>VARDE</th>
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<tbody>
<tr>
<td>GEOLOGY</td>
<td>Meltwatersand and clay from Måde fm.</td>
</tr>
<tr>
<td>SIZE/TIME</td>
<td>906 ha/10 days</td>
</tr>
<tr>
<td>LINE-KM</td>
<td>326,4</td>
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<tr>
<td>LINE-DISTANCE</td>
<td>25 m</td>
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Purpose:
Detailed mapping to localize a buried valley and assess the vulnerability of the potential well field.

Results
Din Forsyning is in charge of the water supply to the citizens of Varde. During later years, BAM has been found in the potable water in the town of Varde and newer surveys have shown problems with the substances DMC and DPC in the water works outside the town. Existing wells are threatened by environmentally unsound substances, and as a consequence of this, the supply company is searching for a new well field. During this process, tTEM was used to map the spatial boundaries of a buried valley near Varde. Another high priority was to assess the vulnerability of the groundwater aquifer. The tTEM method is extremely useful for this purpose, as the system possesses a unique vertical resolution in the upper 30 m. The thickness of the clay layers in the upper 30 m will typically be what decides the vulnerability of an aquifer. The thicker the clay the more robust the aquifer will be towards for instance nitrate or pesticides. The tTEM results show a 2,4 km wide buried valley with a more that 20 m thick clay cover. Early water analyses in the valley have shown that the quality of the water is good and based on the geophysical surveys and boreholes it is expected that a new well field can be established.