REACT

Securing a clean drinking water resource

Ideas, thoughts, development and progress for phase 1 – together with an outlook for future work

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Geological Survey of Denmark and Greenland

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Motivation behind the project

The motivation behind the project “Ren Drikkevandsressource” / “Clean drinking water resource” is to create an visit and exhibition platform in a living lab sense, that you can visit both online and in a physical form. The platform is targeted to both domestic and foreign interested people who are curious about groundwater exploration and utilization in Denmark, and setting Danish competences on Water in a bigger context, than the individual solution. This is will facilitate system exporting of entire value-chains, strengthening the individual solutions by seeing them in the big picture.

In the creation of the exhibition platform, we have in this initial phase of the project sought to cover the basics and prepare the next phase of the project. The platfom has both a physical and a digital side, which supplement each other and enables both exploring details, seeing the big picture and actually going in the field and seeing what you have visited online.

By combining the physical and digital in the platform, a full panorama view of the Danish acquisition, digitalizing, modeling and decision making is presented and is now easy accessible whether you are in Denmark or another country.

The content contributors to the projects are both the participants: GEUS, NIRAS, Region Midt, Aarhus University and several companies including NIRAS, Ramboll, AGS, AGI, SkyTEM and I-GIS have contributed to the proof of concept platform, with each of their defining competences within the value chain.

Exhibition platform

To create a full-view of the Danish groundwater exploration and management within acquisition, modelling, and decision support, both a digital and a physical platform will be made – fully representing the digital and the physical elements for the groundwater Story Map. Within this phase, phase 1, the focus will be mainly on the digital platform.

Introduction to ‘Living lab’ concept.

Laboratory – the place for experiments and tests of theories. That is exactly what is tried to be achieved for the Danish groundwater management within this project – as a presentation for outside stakeholders and groundwater-curious individuals. The ‘Living Lab’ is divided into two parts to give the best feeling of our methods – the digital version and the physical version. The two are connected, where guest can visit the sites digitally, before the physical visit. The digital part broadens the story, and connects locations in the physical part with digital content through a series of signs, carrying QR codes linking to the digital version explaining what you are seeing and setting it in a larger context.

Digital exhibition platform

As a prototype of the digital 'living lab', an online platform was created in a for evaluation by possible end users, questioned in the project about the applicability and interest.

The webpage introduces the concept, the technologies and the physical demonstration areas. From the front page, it is possible to dive a little deeper into four different topics 'Data Collection', 'Data Management', 'Modeling', 'Decision Support' and 'Project Sites'. Data Collection gives a comprehensive overview of the acquisition methods, stretching from towed TEM to SkyTEM to ERT with figures and descriptions with pros and cons. ‘Data Management’ shows some already existing online portals with available onshore geophysical and borehole data, and how these data, when extracted, can be visualized, and interpreted. The 'Modeling' dives a little deeper into how the acquired/extracted data can be used to create subsurface models and structures, especially from the visualized resistivity contrasts from the different TEM data. A modeling example has been illustrated with the groundwater-containing glacio-fluvial buried valleys together with a full 3D video animation. Finally, from real-life site examples have been provided to illustrate the easy accessibility of TEM acquisition on Endelave together with resistivity maps showing contrasts of deeper lying structures.

The digital platform is meant to be accessible for everyone interested in the complete workflow and overview of the Danish methods of handling groundwater with stepwise illustrations and description. To support the digital version, the linked to physical sites enables visits and demonstration facilitation. Both before a visit by a potential customer, and after.

The online storymap can be visited on www.cleandrinkingwater.dk

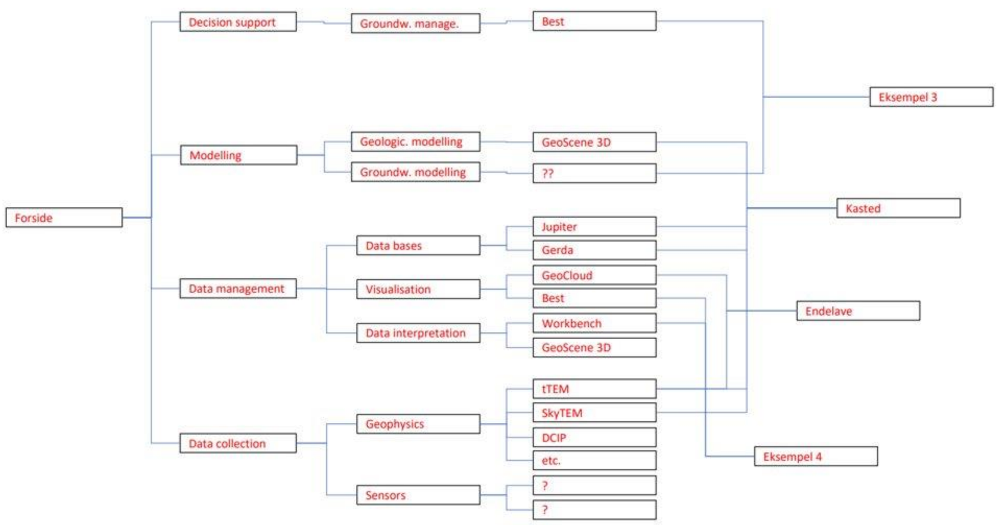


Figure 1: Tree-schematization of Story Map, starting from left towards right. At each split, one gets deeper into the specifically chosen theme, ending up in real-life examples.

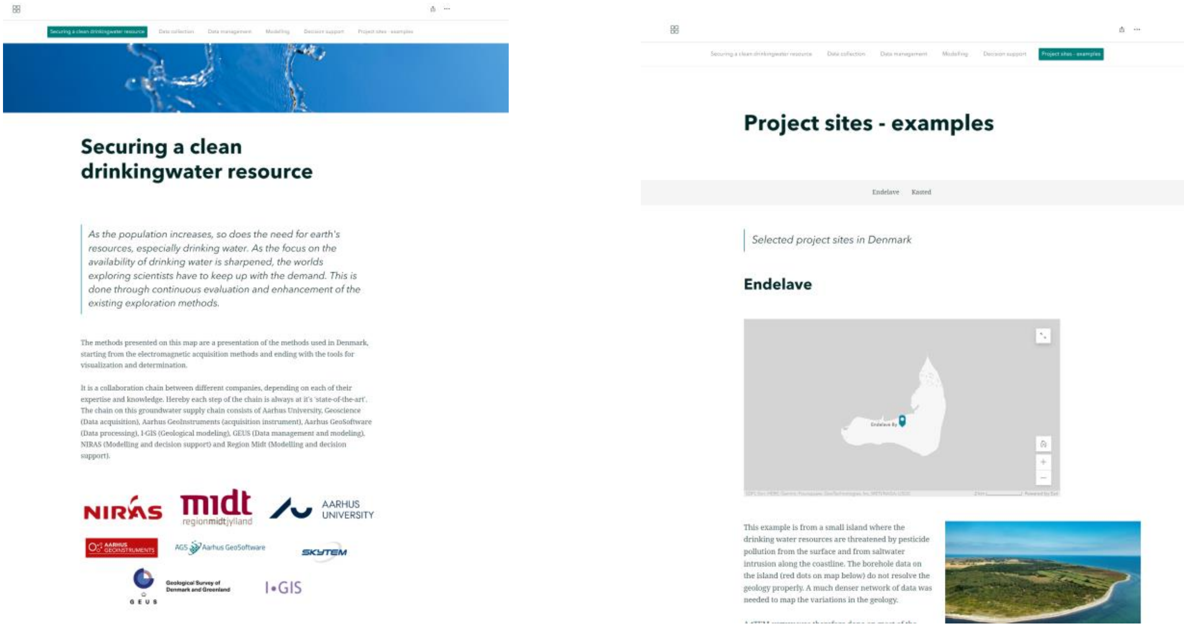


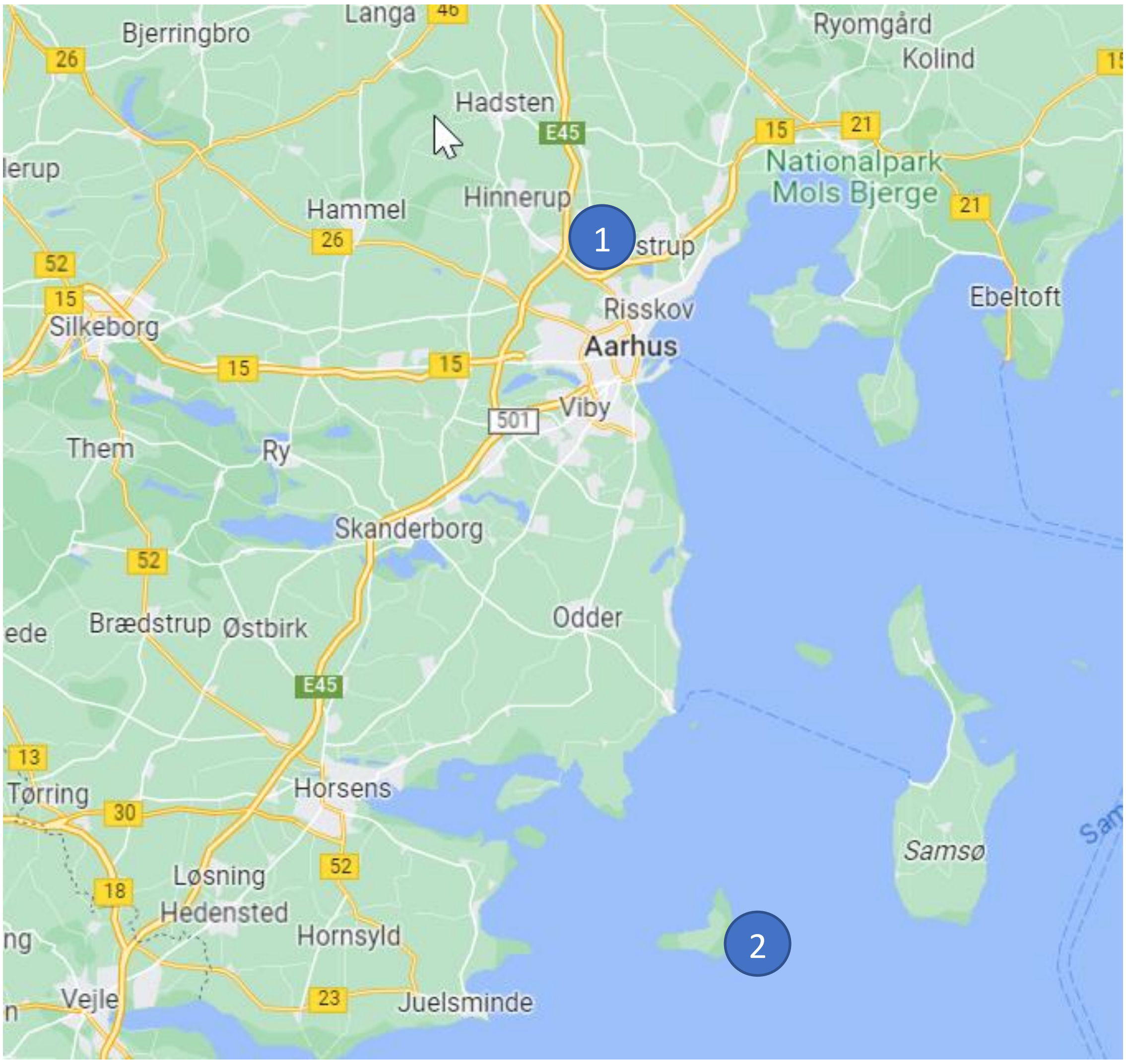
Figure 2: The prototype of the online platform was developed and presented to a relevant audience. See www.cleandrinkingwater.dk

Physical exhibition platform

Two pilot areas where selected as candidates for "living labs", and examined in detail. Both areas having distinct features highlighting different aspects in terms of water and related problems. Also both have different perspectives in terms of serving as visit friendly sites for international guests.

Pilot area 1 : Trige

- Logistically accessible to both highway, Aarhus Airport and trains
- Close to Aarhus and several actors incl. companies, Geological survey and university
- Extensive existing data and knowledge on the subsurface
- Several installations in the area, including a waterwork of new date for visits
- Relevant hydrogeological setting
- Relevant hydrological issues in the area, incl.
    - Contamination
    - Groundwater protection
    - Groundwater extraction
    - Urbanisation issues
    - Climate adaption



Pilot area 2: Endelave

- Excursion friendly, a scenic island with tourist type facilities (e.g. “kaninoen” - a scenic hiking route, the local inn, camping etc.)
- A confined hydrological setting on an island
- Existing data and knowledge
- Relevant hydrological issues in the area, incl.
    - Rising groundwater
    - Typical island problems (many people in summer, few in winter gives strain on supply)
    - Lack of ressources
    - Groundwater protection
- Furtermore several ongoing research projects in the area, incl.:

- Blue Transition
- BioScape

Both pilot areas are well-investigated in the deeper sections, but to fully cover the applicability a decision was made to investigate the shallow subsurface, where we would expect installations of demonstration facilities would be relevant. E.g. via sensor monitoring installations and similar. Therefore, the existing data were combined with new near surface geophysical data in the mapping out of the hydrogeology, giving the data basis for future use of the two pilot areas in a living lab context. An example of the process is described in appendix 1.

The physical living labs were not established in the completed phase 1 of the project, but ideas and thoughts as to how it can be implemented have been made, concrete candidate sites have been pointed out, and examined for suitability through a detailed mapping of the upper subsurface.

Inputs from relevant companies and scientists

After the development of the "proof of concept" digital part of the platform, and the identification and examination of the physical part, a presentation was made for a large group of possible stakeholders and users of the platform was given. Here the platform and project was descriebes, laying out the possibilities and ideas behind it. After this, a survey was conducted among the attendees, aiming at capturing ideas, thoughts and critique and examining the relevance of such a platform.

The presentation of the "REACT – Clean Drinking water" took place on Aarhus University, Geoscience 07/06-2023 with the attendance of several companies and institutions, incl. :

WSP, Rambøll, Ministery of Environment, NIRAS, Aarhus University, The Spring, Aarsleff, AGI, AGS, Bentley, Energinet, GEO, Bargheer Geo, GEUS, Seequent, DMR, Solid Ground, Region Midt, Din Forsyning, Sweco, I-GIS, I-Cloud, Geophysical imaging and ECOS AU.

Figure 2: Participants within the auditorium.

After a brief introduction to highlight the motivation and the vision a questionnaire was presented. To join the questionnaire, each of the participants had to join "Mentimeter" with their cellphone. All the answers were completely anonymous.

Below the questions will be presented together with some of the answers. The answers has been "filtered", as the responses where not all relevant.

Question 1: What targets group do you think this project have or should have?

Delegation visitors	Decision makers and technical experts	Foreign customers and collaborators
Politicians, scientists, consultants	Potentially new customers, especially customers with contamination problems	Students
Primary schools and high schools	Everybody who has interest within groundwater modelling and history	Countries with risks of flooding and already existing flooding problems

(total 81 responses)

Question 2: Who should participate in the project?

WSP	Relevant governmental units	Consultant companies
Municipality units	Instrument technician	City development architects
Aarhus Vand	Nature guides	Groundwater utilization stations
NIRAS	The Spring	GEO

(total 71 responses)

Question 3: Which solutions and competences would be relevant to exhibit?

3D Modelling	VR	Online systems from the field
Reuse of participation	Good geology examples	Mapping methods
Contributing geophysics	NMR	Georadar
Geophysics	SkyTem	Spring source with information

(total 46 responses)

Question 4: In what part of your working flow is this/or could this platform (be) relevant?

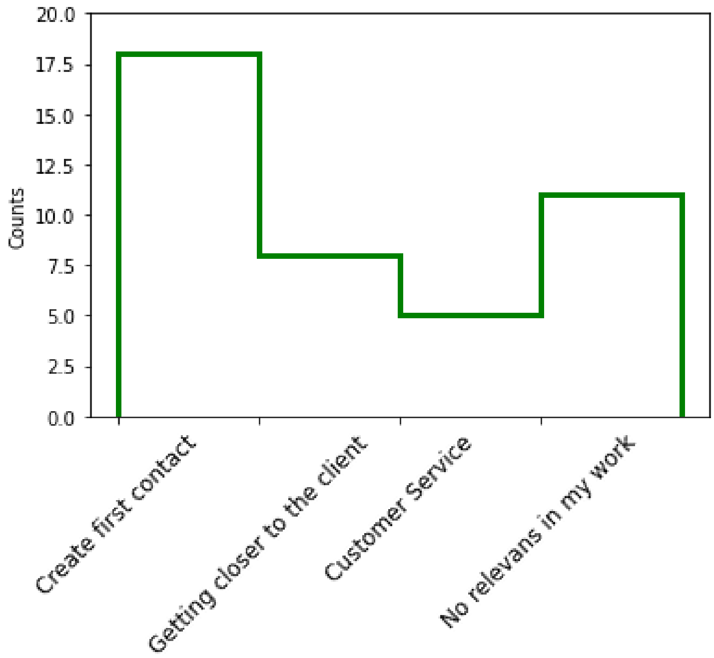


Figure 3: Response from companies whether the online platform has any value to their workflow, and if yes, where.

Question 5: Assess the below-listed question whether you agree/disagree

This question is divided into 3 parts. The first question is ranged from No Value to High Value and the rest Disagree/Fully Agree. Each participant can vote 1 time for each of the question, and behind the labels, it is ranged from 1 – 5. The calculated average weighted mean is also listed here:

Question	Average weighted mean
Q1	3,78
Q2	3,14
Q3	3,02

With the distributions:

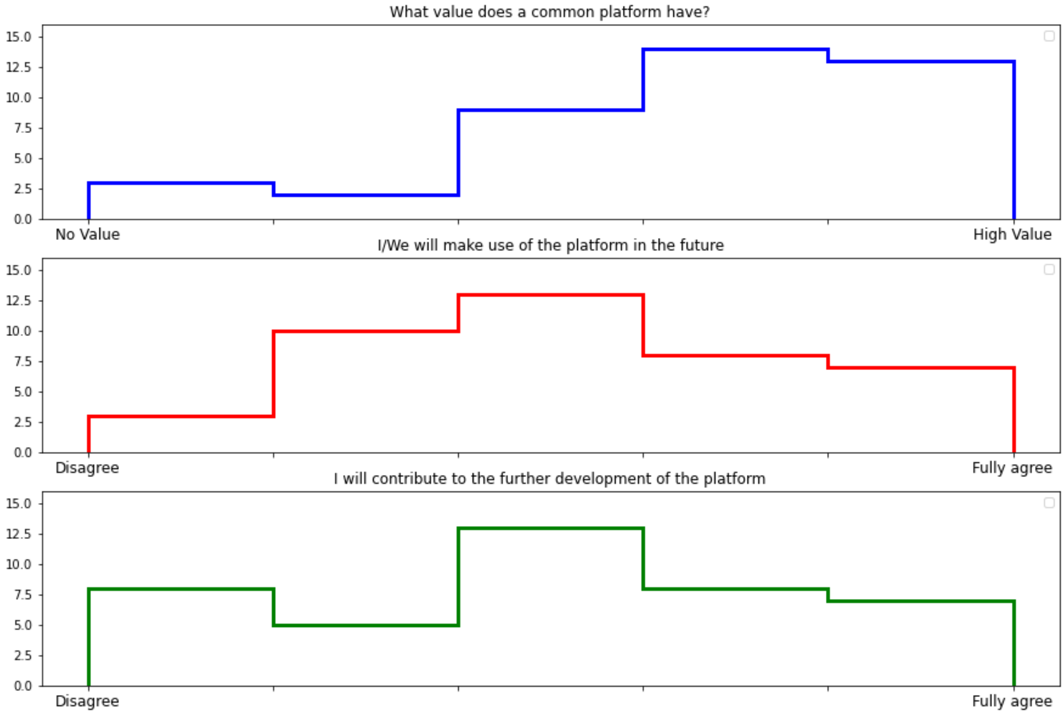


Figure 4: Three different histograms containing the replies of the participating companies, showing a shift towards the left, seen from above.

Question 6: Do you have any final thoughts or general input to the platform?

DTU should be included	Interactive dashboards	Two language option on the online platform
Make use of QR codes	Video content	Let the user build a simple model on the webpage
Podcasts with interviews	Hands on interactive 3D modelling	More case studies / examples

Selected answers to the research question posed.

Analysis

To get a broader view of the potential for the platform, the project was presented to relevant companies and scientists in the annual Geophysical Forum on Aarhus University. Here each of the participants were provided with reflecting question on their mobile phones, and we could acquire anonymous replies for possible changes of the platform from the participants. Here we got new insights for potential new collaborators and companies who hasn't contributed yet, possible online implementations, such as more languages and etc.. More importantly, we acquired knowledge of how each of the companies and consultants see any value of the platform within their own work – and if yes, in what part of their working flow it would have the highest value. From figure 5, a bimodal distribution has been visualized, revealing a yes/no-value for the companies, that is, they will mostly use it for potentially new customers, or they see no value at all. Here the companies were asked whether they can see a potential in the platform, and if they want to make use of it and contribute to the further development. From figure 6, 3 normal distributions have been plotted for each of the questions. The behavior of the distributions shows a shift towards the "no value" end, with calculated average weighted mean value of 3.78, 3.14 and 3.08 – revealing the ones who wants to make use of the platform has the tendency of not wanting to contribute within the further development of the platform – but the range is 1 -5, so they still lie within the positive end of the mean. It can be concluded from figure 6 that the companies rather want to make use of the platform than contribute with the development in the upcoming phases.

The general response is that, even though the vast majority likes the platform, only a few will provide content and a significant of the responses will not use it in their work. Those who will use it will primarily do so in an initial contact with clients, getting the first introduction. The ideas and comments where many, and good ideas with other types of end users, like high schools and education in general, are things the project group had not contemplated going into the project. Thus, the people who were engaged in the idea where both responsive and gave feedback, while a large number of people where less interested. This suggests that IF a platform existed, it would be uses, but only a small number of people can be expected to contribute in the making or maintenance of the platform.

Discussion

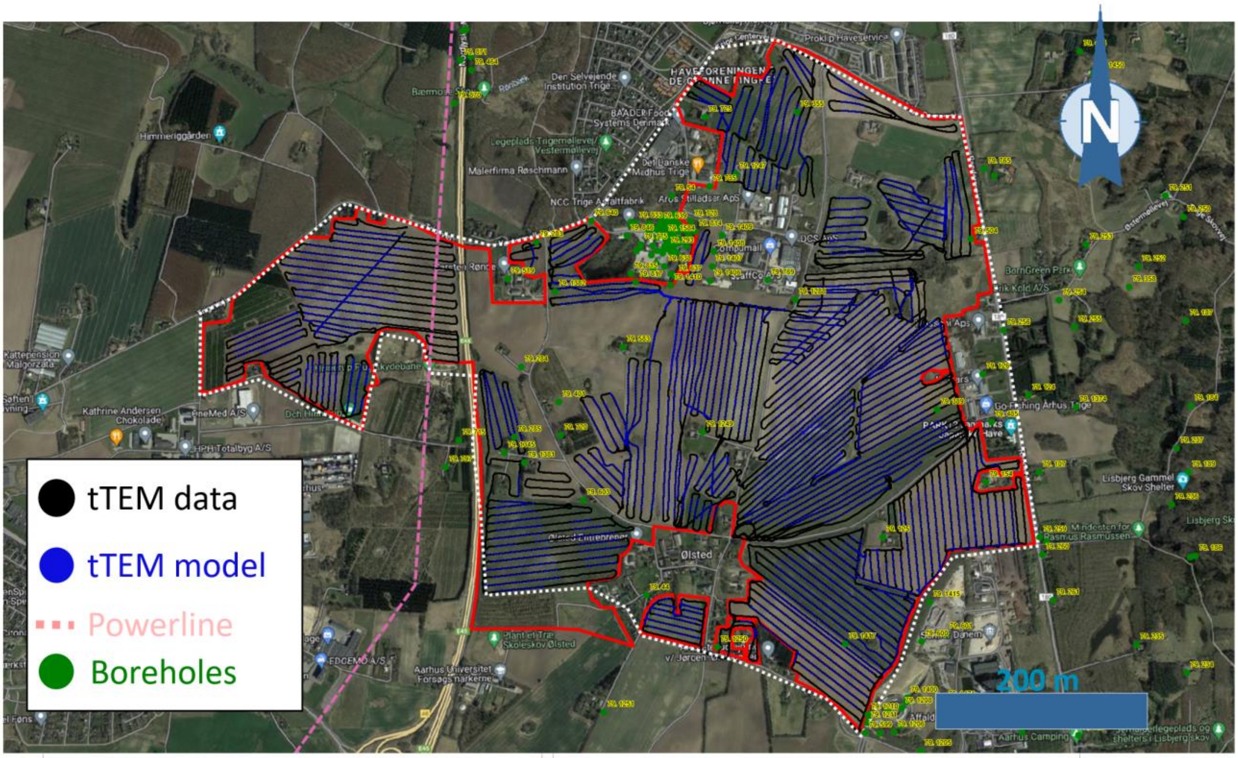
The outlook of the project is to establish a broader platform, both with an online and a physical component. The online part can be extended with the above-mentioned suggestions, given from the participants from the geophysical forum, such as More case studies, VR and inputs from other companies – not only does it need input, but also contributions within establishment of the greater variety of options. When the platform has been fully established, an outreach-committee should be established, making sure foreign collaborators gets to know the existence of the platform, and from there spread the idea. The physical platform should contain the instruments presented on the platform so foreign delegation quickly can be presented to the idea behind the acquisition. This physical platform can also be extended such that people visiting the geological sites presented in the online platform can, e.g., scan a QR code, dive into the geological history and creation of the subsurface – e.g., the propagation of glaciers, outflow the from meltwater and creating the buried valleys.

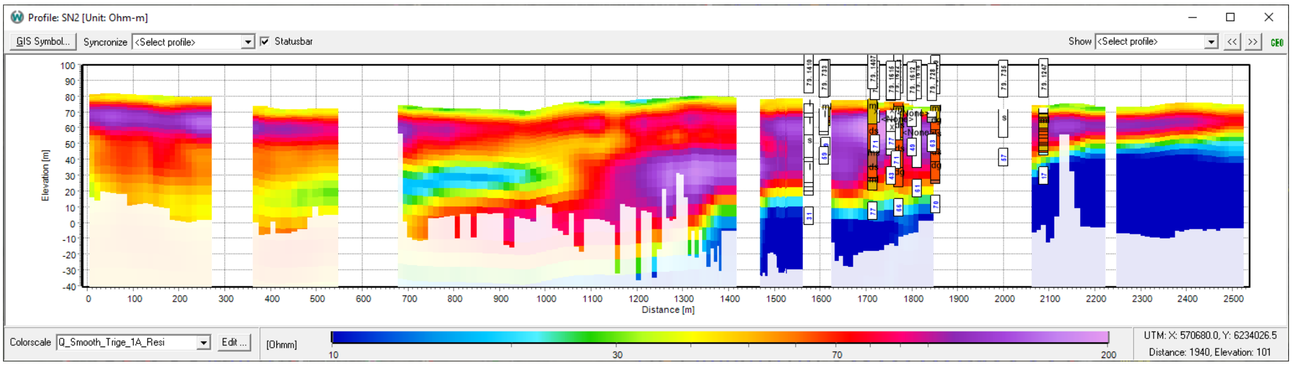
Conclusion

In the project, the foundation of an exhibition platform has been explored. A digital prototype has been developed, and two pilot area sites have been pointed out and explored for suitability. The findings and prototype has been presented to a large audience and questioned for feedback, where the overall feedback is that a platform is relevant, especially for first contact with customers and interested parties. However, if a platform is to work, a dedicated group must be assigned with this, as most do not have the interest in participating in providing content.

Appendix 1 – Pilot area investigations

Technical description of tTEM analysis and modelling





410 hectares of tTEM data was acquired between Søften, Ølsted and Trige and processed by Hydrogeophysics Group, Aarhus University, in 2023. With the driving speed and an average subsurface resistivity, the depth of investigation (DOI) is estimated to be around 60 - 70m - but it can vary based on the local geological setting. After processing, the data can be loaded as multiple 1D-vertical profiles into GeoScene3D, covering the area (figure 7A). From here the 1D profiles could be interpolated into a 3D box model, where each pixel represents a specific resistivity value given in ohm-m. By making a 3D interpolation, it is possible to create 2D slices for different elevations within the horizontal plan (figure 7B). From the full 3D view provided by the 'slices', the flow-rhythm of the high-resistive pixels can now be visualized in a more efficient way. The enables mapping of glacio-fluvial incised buried valleys, which are typically high-resistive, relatively to the surrounding tills (figure 7C). To get a confirmation whether the buried valley contains groundwater, the Jupiter-well database is imported into Geoscene3D^{TM} (figure 7C).

Each well is represented by a unique name above the well. Through these wells one has direct access to the well report with the corresponding lithostratigraphic analysis, and whether the substrata are water containing. As the buried valleys were incised with different flowrate, climate conditions, surrounding strata and direction, some of the buried valleys can be more difficult to map compared to others. To overcome this problem in this project, more TEM-data was imported into the area to find surrounding connections. In this case it was SkyTEM acquired in 2015 and 2017 and other tTEM data acquired in 2021 and 2022. Another method to deal with this problem is to calculate an isosurface. The isosurface takes in one value, which is the threshold value. Hereby the isosurface-function return the pixels which contain threshold value or a value above the value. This is also represented in the 3D box, enabling the visualization of these chosen pixels (figure 7D). Figure 7D shows the pixels chosen from the threshold value, seen from below. It shows the value of this attribute, as the top-most pixels in true elevation seem to be noisier. The isosurface in this case with the threshold value of 60 ohm-m shows a complex structure of a buried valley splitting into to independent valleys.

By mapping all buried valleys within the area from the tTEM data, supported by the other acquired, a full 3D map can be made to show the full complexity of the interconnectivity and orientation of these groundwater containing buried valleys, see figure 7E. This figure shows the buried valleys mapped with the help from the new tTEM data. Color code is the elevation within the 3D box, not true elevation. A volumetric estimate of each valley can then be calculated from the isosurface-function, and together with the Jupiter-database, the flow rate and geochemistry of the groundwater can be assessed.

This analysis shows how freshly acquired data quickly can be imported, assessed and modelled together with older data to continuously further develop the subsurface model of the flow path for a given area.

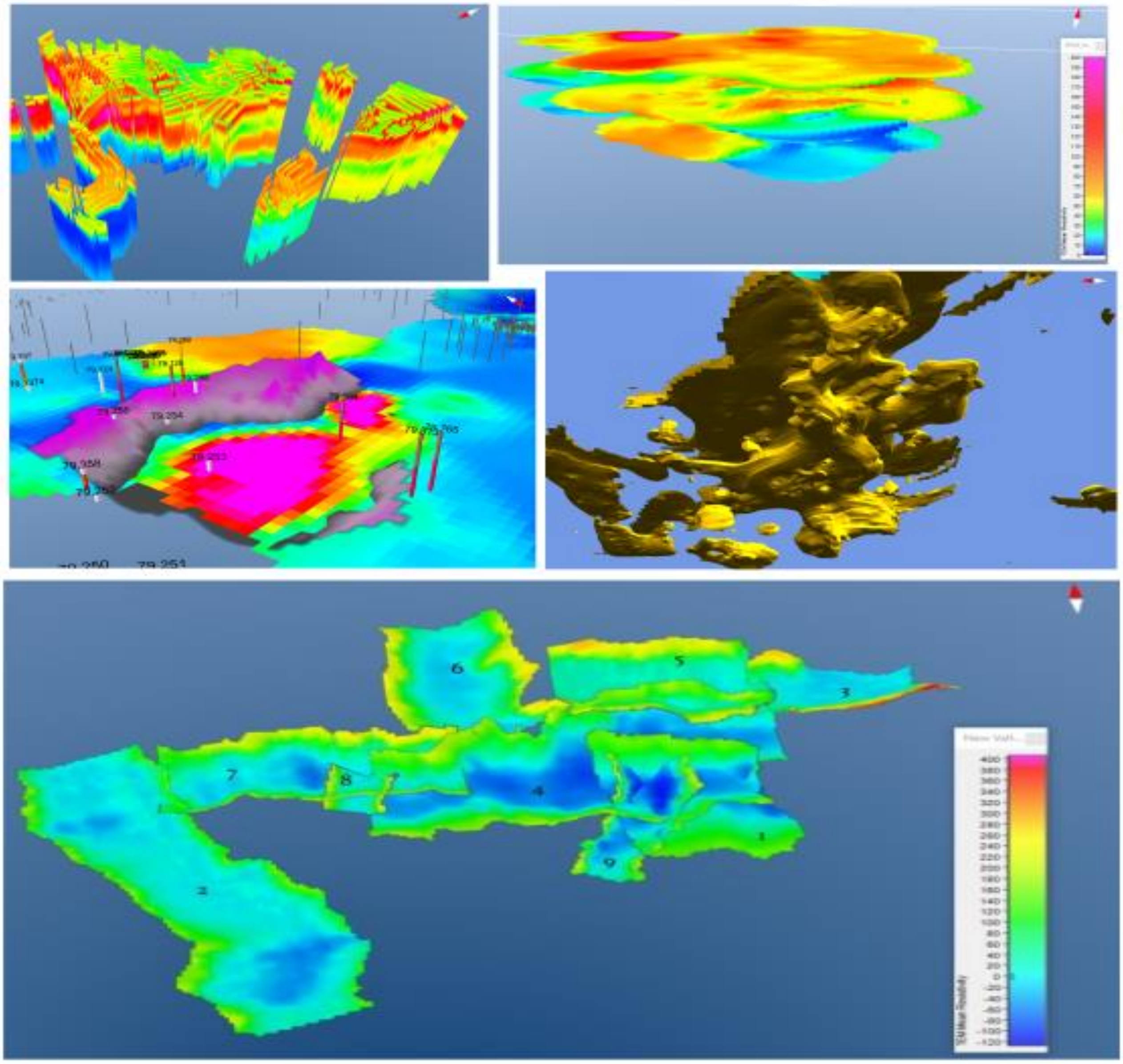


Figure 5: A: 1D vertical resistivity profiles from forward modelled dB/dt vs. time data. B: Sliced 'Inverse Distance' 3D interpolated 1D profiles. Each slice represents a different altitude within the 3D box. C: Mapped valley surrounding high-resistive pixels within the 3D box. Vertical lines show Jupiter-imported wells for lithological analysis. D: Iso-surface seen from below, showing a valley. Iso-value was set to 60 ohm-m. E: An overview plot showing the found valleys within the area. Elevation values represents elevation within the 3D grid.

Figure 7 gives the idea that the valleys were formed in different time as of the different depths and orientation. Some of our buried valleys in Denmark are estimated to origin back to pre-Elsterian until late Weichselian. The sparsity of bore holes in the valleys makes it difficult to use those as a proxy for time-estimation based on valley infill. The orientation and the relative depth can be used as a quick estimation of initiation. Valley 4 and 9 seems to lie deeper than the rest of the valleys, but valley 9 lies on top of the south-shoulder of valley 4, hence the valley 4 must be older than 9. Different processes contribute to each valley incision, where the two main categories are glacial erosion and meltwater erosion. The meltwater erosion is expected to provide more narrow valleys than glacial eroded valleys. It is speculated whether a solely meltwater eroded valley would show a distinct V-shape, whereas valley incised in combination of subglacial and meltwater incision would show a U-shape. If this is the case, valley 9 is expected to origin solely from meltwater-erosion.

Figure 3 shows valley 4 on top of the already mapped valleys. Within the valley a ridge has been mapped. The ridge is perpendicular to the orientation of the valley, which is a characteristic of Eskers. This Esker is truncation to the east together with the valley, so it might continue further to the east with the valley. The origin of the Esker is speculated to origin either from a subglacial cave-structure – possibly revealing a glacial margin - or an incoherent substratum, as the incoherent substratum would alter the flow path of the outwash meltwater.

Results from already existing AEM and newly acquired tTEM

By importing the processed tTEM data into Geoscene3D™, a 3D interpolation was made. Hereby slices, both horizontal and vertical, can be made. This allows to visualize each resistivity within each cell, showing the local contrasts. Generally, the buried valleys containing groundwater are usually of higher resistivities (60 ohm-m and higher) than the surrounding tills and sand. The buried valleys (see figure 2) were found with a combination of the new tTEM data and the older SkyTEM data, as they were overlapping. Valley 6 lies totally within the new tTEM data area.

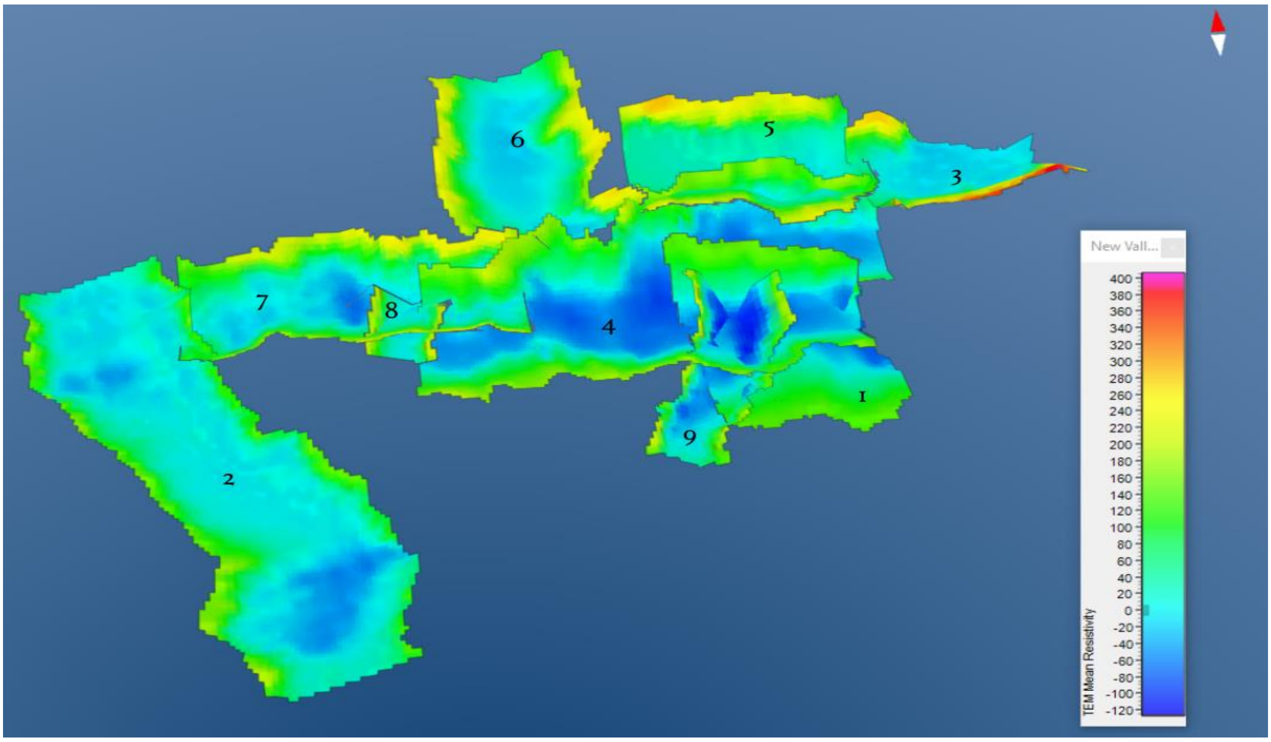


Figure 6:Buried valleys labelled from 1 to 9. Color code indicate relative depth within the 3D grid. Direction is from south towards north.

It was possible to localize in total 9 buried valleys – all with different depths, length and orientation – revealing different time scale and time of initiation. The dominant trend is EW-direction, and a less dominant from north towards south. For a more detailed description of the valleys, see the Appendix.

The idea behind the acquisition of the new tTEM data is to create a 'proof of concept'. This means that we before acquisition had a pretty good idea of the underlying geology.

Valley 4 was a relatively complex valley to map, as the cap-sedimentation was a high-resistive package, making it more difficult to map out the underlying valley, since the contrasts was less prominent. From figure 3, already-existing valleys have been mapped on top of valley 4, showing the coherence between those independent datasets.

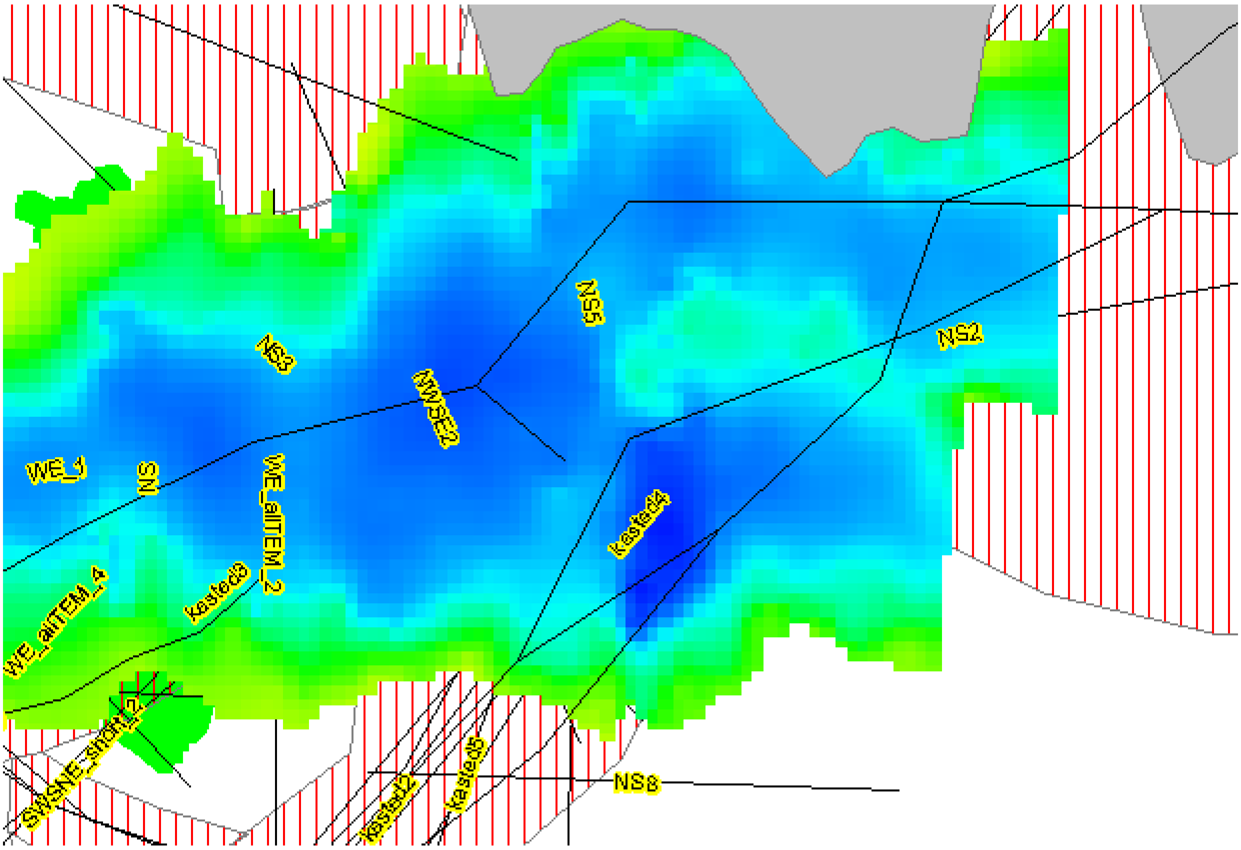


Figure 7: Valley 4 together with already mapped valleys (Black lines)

Sources

A.S. Høyer, F. Jørgensen, P.B.E. Sandersen, A. Viezzoli and I. Møller, 2015. ”3D geological modelling of a complex buried-valley network delineated from borehole and AEM data”. Nr 122, pg. 94-102. Journal of Applied Geophysics.

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