Resistivity measurements as a tool for optimizing groundwater protection at a highway construction in Sweden

Roger Wisén Corresponding / primary author
Rambøll Danmark A/S, Denmark; Lund University, Sweden, rgw@ramboll.dk

Elisabet Hammarlund
Ramböll Sverige A/S, Sweden

Torleif Dahlin
Lund University

ABSTRACT
The Swedish road administration is planning to increase the capacity on highway E22 to a 4 field motorway outside the city of Kristianstad in southern Sweden. The sedimentary bedrock of the Kristianstad plains compose a large and very important groundwater aquifer. The government of Sweden have approved the construction of the road on the condition that necessary protective action is taken so to assure that the aquifer is not polluted. There are means to design the road with groundwater protection but this is costly and as an alternative it has been suggested to allow the clayey soils in the area to act as groundwater protection. Site investigations with a range of geotechnical, hydrogeological and geophysical methods have been performed to determine the protective properties of the natural soils in order to ensure that they constitute a sufficient protection of the aquifer. It is well known that electrical resistivity is strongly connected to the hydrogeological conditions of geological materials and it was therefore suggested that Continuous Vertical Electrical Sounding (CVES) should be used for continuous mapping along the planned road. The CVES results constitute the basis for determining if the upper soil layer is a natural barrier for surficial pollution or if there is need for active protection design of the road. There is a clear relationship between the content of fine grained material in the soils (clay and silt) and the resistivity. Since the fine grain content is also strongly connected to the hydraulic properties a resistivity section gives a continuous image that reflects the hydraulic properties of the ground along a road stretch. For the majority of the road it was concluded that the geological materials act as a sufficient protective barrier while a small part of the area requires design with a protective barrier to protect either surface water or groundwater.

Keywords: Groundwater protection, site investigation, hydrogeology, geophysics, resistivity measurements.

1 INTRODUCTION

The Swedish road administration is planning to increase the capacity on highway E22 to a 4 field motorway outside the city Kristianstad in southern Sweden. The 14 km stretch to be constructed starts at the northern slope of the Linderöd horst structure, and then crosses a part of the Kristianstad plains and thereafter the glaciofluvial deposits of Helgeåsen. The sedimentary bedrock of the Kristianstad plains composes a large and very important groundwater aquifer. Figure 1 shows a schematic map of the new road stretch.

1.1 The environmental and road planning process and their influence on the road design

The government of Sweden have approved the construction of the road on the condition that necessary protective action is taken so to

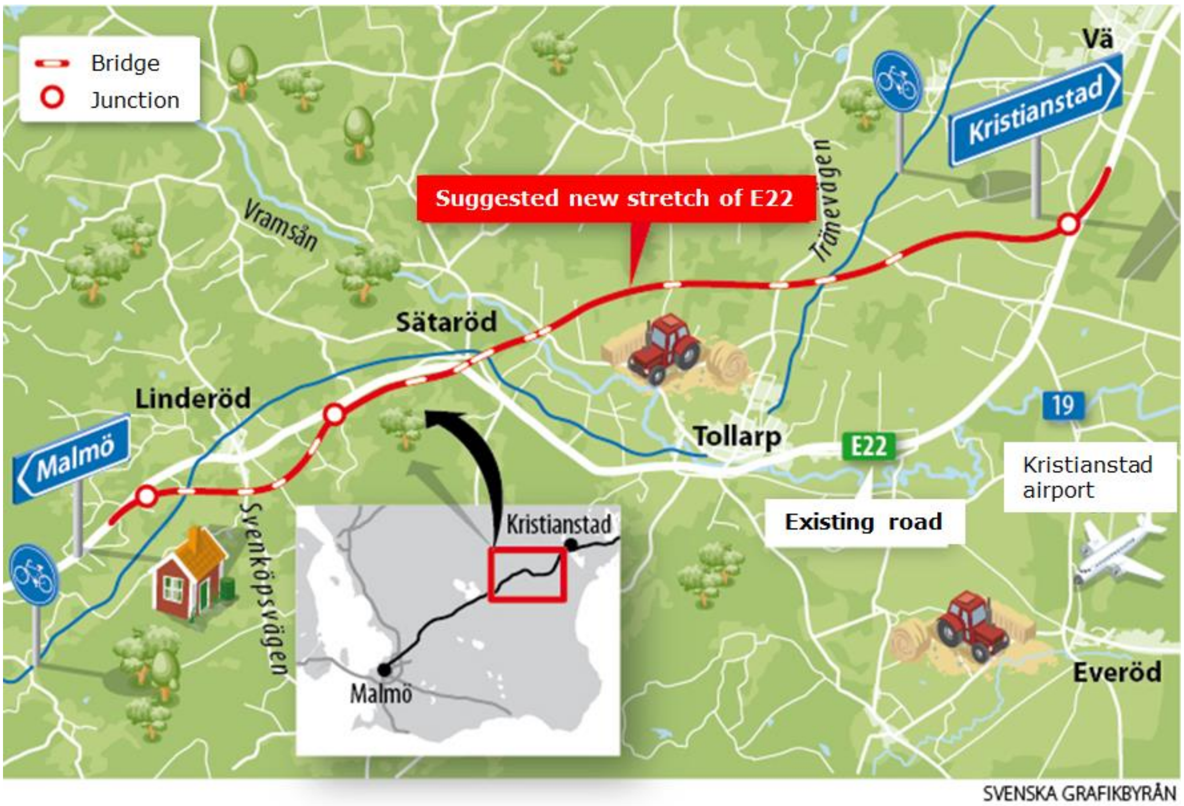

Figure 1 Schematic map of the new E22 stretch south of Kristianstad in southern Sweden (http://www.trafikverket.se/contentassets/ebc058a233d54ad5b9d3b0de6f0eaa97/nyvaglinje_ver6.jpg ***Trafikverket/Svenska grafikbyrån)***

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assure that the aquifere is not polluted. There are means to design the road with groundwater protection but this is costly and as an alternative it has been suggested to allow the clayey soils in the area to act as groundwater protection.

2 THE CONCEPTUAL HYDROGEOLOGICAL MODEL

Information from the Swedish Geological Survey (SGU) was used to create an initial conceptual geological and hydrogeological model to be used as a base for interpretation. Specifically the geological maps for soil and rock as well as SGU's borehole database.

The thick layer of clay till that is present in the majority of the area acts as a long term protection of the groundwater aquifere. The layer of interest here is however the overlaying clayey sand till. If the permeability of this till is sufficiently low it will act as a shallow barrier that will allow immediate remediation of pollutants that accidently is spilled on or next to the road.

3 HYDROGEOPHYSICAL SITE INVESTIGATION

Site investigations with a range of geotechnical, hydrogeological and geophysical methods have been performed to determine the protective properties of the natural soils in order to ensure that they constitute a sufficient protection of the aquifer. There is a clear relationship between the content of fine grained material in the soils (clay and silt) and the resistivity (Archie, 1942). Since the fine grain content is also strongly connected to the hydraulic properties a resistivity section gives a continuous image that reflects the hydraulic properties of the ground along a road stretch. It was therefore suggested that Continuos Vertical Electrical Sounding (CVES) should be used for continuous mapping along the planned road. The CVES results constitute the basis for determining if the upper soil layer is a natural barrier for surficial pollution or if there is need for active protection design of the road. For verification and calibration of the CVES results a combination of geotechnical and hydrogeological tests where performed.

3.1 Resistivity measurements

The CVES method has been used for a long time and is well established for groundwater and geotechnical investigations (e.g. Dahlin, 1996; Wisén et. al. 2008). The measurements were performed with a Lund System setup with 5 m electrode spacing utilizing an ABEM Terrameter LS. Four cables of 100m length make up a 400m long layout that is sucessively moved 100 m at a time in a roll-along manner. A multiple gradient configuration (Dahlin and Zhou, 2006) was used and in this specific case gave a depth penetration of about 70 m.

Data were processed as 2D resistivity tomography using the software Res2Dinv from Geotomo software SDN BHD. Also a layerbased pseudo 2D interpretation was done as a complement and for verification. This was done using the Laterally Constrained Inversion (LCI) (Auken and Christiansen, 2006) in the software Aarhus workbench from Aarhus Geophysics Aps.

3.2 Hydrogeological and geotechnical tests

Drilling and installation of standpipes was performed in positions that were selected based on the resistivity results. Slug tests were made in the standpipes of some drillings to get an estimate of the hydraulic conductivity in the different soil materials. Also other geotechnical investigations were performed. The most important information for verification and calibration of the resistivity data was depth to bedrock from drilling, hydraulic conductivity from slug tests and soil grain size distribution from geotechnical analysis.

4 RESULTS, GEOLOGICAL AND HYDROGEOLOGICAL INTERPRETATION

The resistivity in the area varies from 20 to 1000 Ωm. Lowest resistivity, around 20-100 Ωm, corresponds to clay or alternatively clay till. Sandy till is found in the interval 100-300 Ωm. Unsaturated sand near the ground surface gives around 300-1000 Ωm. The bedrock in the area has a resistivity in the interval 300-1000 Ωm and the chalk gives around 120-500 Ωm. Results from the two resistivity profiles that follow the planned new stretch of the highway are presented in figure 2.

Close to the Linderöd horst the soil depth is relatively small, but at the foot of the horst there is a fault zone where soil depths suddenly increase to more than 70 m. The fault zone is noted as zone A in figure 2.

The soil depth in the Kristianstad plain is around 50 m in most of the area and decreases as expected towards northeast. There are 20-30 m thick deposits of clay or clay till that fills out a valley structure in the bedrock. These layers are clearly visible in the results over a stretch of about 8 km. On top of this layer there are clayey to sandy tills. In parts of the area the resistivity result shows two or more tills on top of each other, visible with different resistivity for the different tills. In figure 2 this zone is noted as zone B where two layers of clay till is clearly visible in the results, and as zone C where only one layer of clay till is visible.

In the northern part of the area there are thicker layers of chalk rock. The interpretation of the resistivity results is more difficult in this part of the area since the contrast in resistivity is smaller between the till and the chalk and also between the chalk and the bedrock. This zone is characterized as a zone with more heterogeneoys soil layers and it is noted as zone D in figure 2, the Helgeåsens border zone. Geotechnical sounding have verified areas with sedimentary clay in this zone. However, these clays does not have enough coverage to act as a barrier.

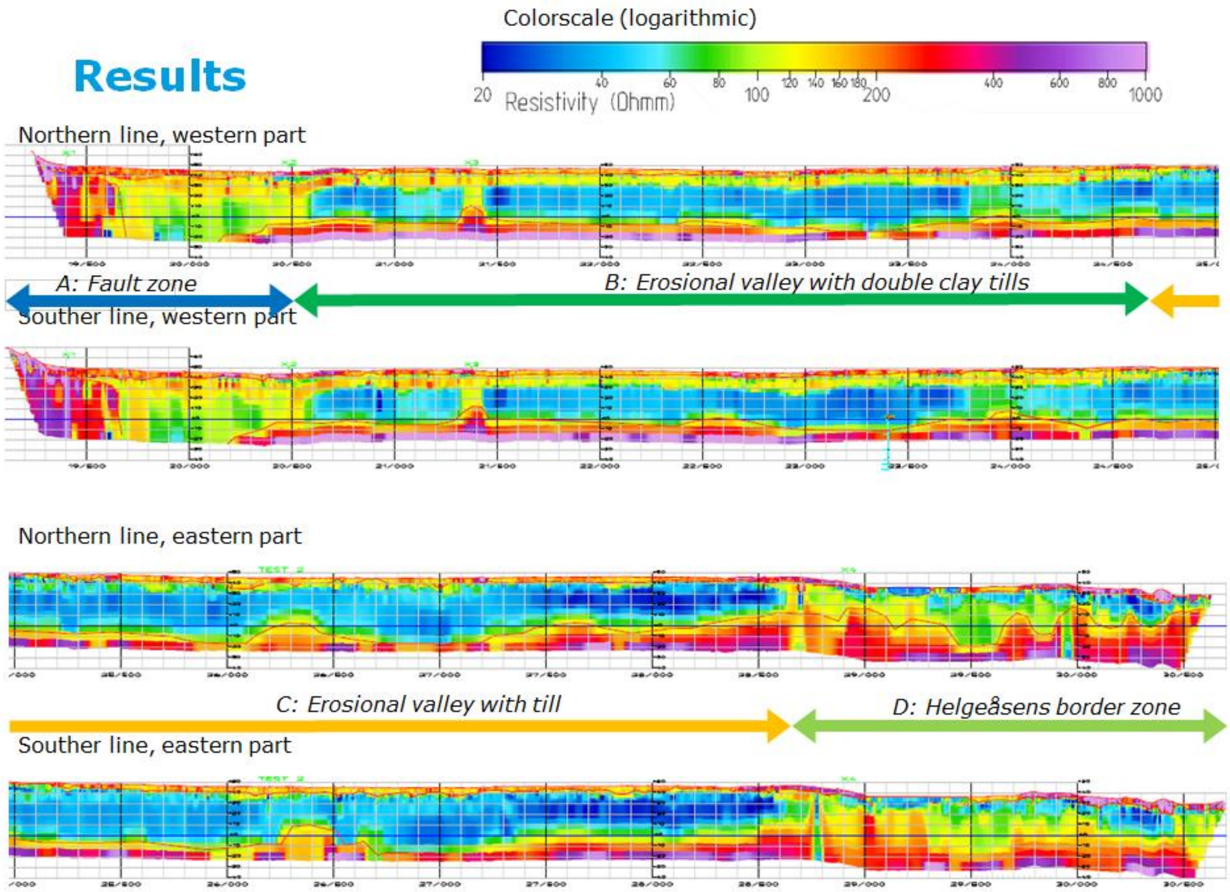

Figure 2 Results from the two parallel resistivity lines. The lines are approximately 11 km long and spaced 25 m apart. The interpretation of the geology is divided into three main zones as shown in the figure: A. The fault zone of the Linderöd horst, B. Erosional valley of the Kristianstad plains with double clay tills, C. Erosional valley with one clay till and D. The Helgeåsen border zone.

There is a clear relationship between the content of fine grained material in the soils (clay and silt) and the resistivity (Figure 3). Since the fine grain content is also strongly connected to the hydraulic properties a calibration of the resistivity results can be made where a certain resistivity range in the soils can define low permeable materials that gives sufficient groundwater protection. In this case it was found that even sandy silty till with a resistivity just above 100 Ωm, that is present in the shallow soil layer in the majority of the area, acts as a protective layer. This allows for example for emergency clean up of pollutants e.g. after an accident. The thick low resistive clay till layer that is also present in almost the entire area acts as an efficient long term protection of the aquifere that is present in the chalk rock below.

On the slope of the Linderöd horst there is bare rock or very thin soil cover that will not provide sufficient protection. In this area it is required to design the road with measures to protect groundwater. At and around Helgeåsen the soil is permeable with a thick unsaturated zone and also in this area it is required to construct the road so that the ground water is protected.

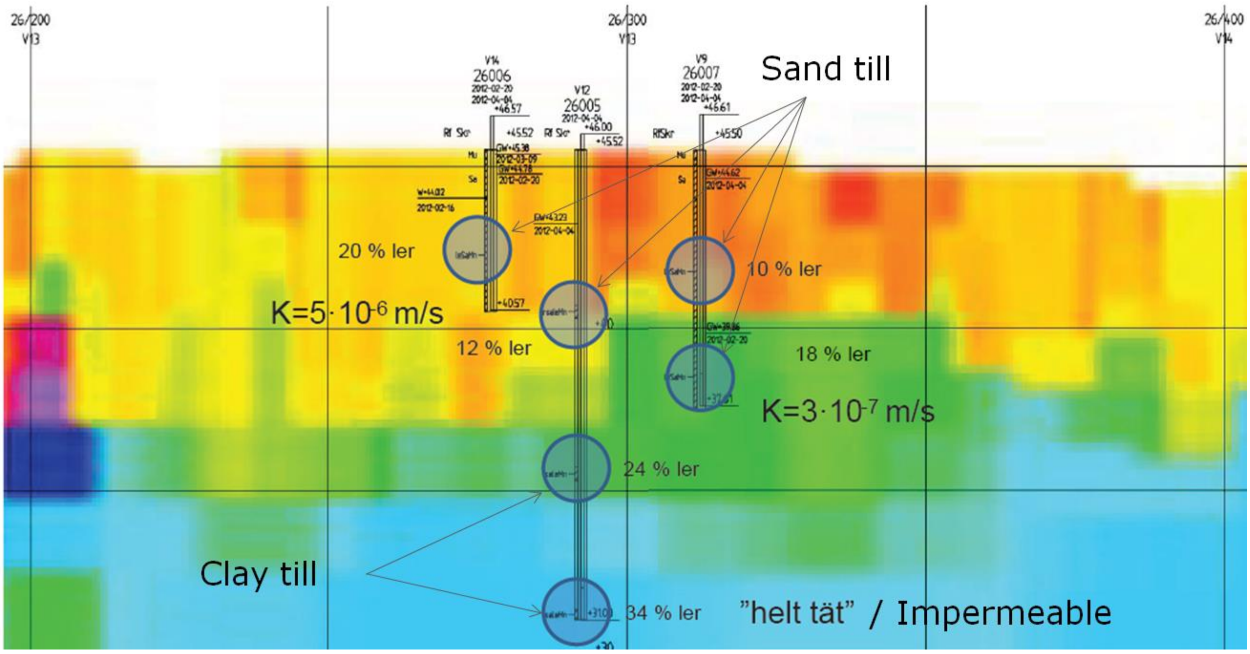

Figure 3 Detail from geotechnical and hydrogeological tests on top of the resistivity model. The amount of clay (ler) is given for 6 samples from geotechnical testing. Four samples from sand till show clay conten from 10-20% and two samples from clay till show clay content of 24 and 34%.

Figure 4 presents a schematic drawing of the result from this investigation. For the majority of the road it is concluded that the geological materials in the area act as a sufficient protective barrier, for some areas it is concluded that there is a need for designing the road with a protective barrier to protect either surface water or groundwater and for about 10% of the area further investigations are needed.

4.1 Reccomendations for groundwater protective measures

For the majority of the road it was concluded that the upper clayey sand till act as a sufficient protective barrier while a small part of the area requires design with a protective barrier to protect either surface water or groundwater. In two areas around the Helgeåsen border zone there is a need for further investigations.

5 CONCLUSIONS

CVES resistivity has been used together with geotechnical and hydrogeological methods to achieve a continuous image that reflects the hydraulic properties of the ground along a road stretch. The purpose was to map the vulnerability for pollutants to penetrate into the precious groundwater magazine under the Kristianstad plains. The investigation shows that a large part of the area is covered by impermeable layers in the form of a thick clay till. Large parts of the area is covered with sandy till over clay till, and this sequence has been determined to have a permeability that gives sufficient protection of the aquifer below. In parts of the area, close to the Linderöd horst where soil cover is thin or non-existent and at the glaciofluvial deposits at and around Helgeåsen it is motivated to construct the road so that the ground water is protected. In about 10 % of the investigated area it will be necessary to perform further investigations to define the need of groundwater protection as part of the road design.

Figure 4 For the majority of the road it is concluded that the geological materials in the area act as a sufficient protective barrier (white lines), for some areas it is concluded that there is a need for designing the road with a protective barrier to protect either surface water (orange lines) or groundwater (blue lines) and for a small part of the area further investigations are needed (purple lines).

6 ACKNOWLEDGEMENTS

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