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CLIWAT & Contaminated Sites

by Tom Birch Hansen

Contaminated sites pose a risk to our drinking water, ecosystems and health. When our climate changes in the future, it may result in more contamination leaching into the groundwater and waterways, posing a threat to our drinking water and to ecosystems. This is particularly true for point sources such as landfills, which are typically located in low lying meadows or gravel pits.

Introduction

In CLIWAT Pilot Area G, several large municipal landfills are situated in low lying meadows next to the River Århus. The river flow is affected by precipitation, groundwater from the hills and saltwater from the bay. The river has been known to flood some of the landfill area in winter. This is partly due to increased flow in the river but also to high-water level events in the bay.

Climate models predict increased precipitation and more importantly, the increased likelihood of heavy downpours. The sea level in the bay will also rise, particularly during storms. This rise in sea level combined with increased downpours, will lead to higher fluctuations in the river's flow and water level. Thus, it is likely that the landfill area will be flooded more often and this flooding will be more extreme. As the hydraulic dynamics of the landfill sites change, it may result in more contamination leaching into the groundwater and the river. The decomposition of landfill waste and the associated production of methane may also change. In addition, it may put stress on the current remediation system, resulting in increased maintenance and remediation costs. The CLIWAT project addresses these challenges. **(cont'd./... p.2)**

Editorial

Dear Reader,

One of the goals of CLIWAT is to raise awareness of the climate-related challenges in the water sector, with special emphasis on groundwater. Local communities, municipalities and stakeholders must take actions to deal with the consequences of these challenges. How they move forward depends partly on their own adaptation strategy and upon the responses of their respective national governments within the EU. The CLIWAT project has involved a large number of people, and their awareness has already resulted in some sectors and institutions responding to climate change impact. For example, the Danish Road Directorate has increased its focus on the stability of new highways in Denmark. The roads have to be climate proof for the next 100 years. To ensure this the directorate has to include the effects of groundwater changes, especially when building roads that penetrate deeply into the topsoil. Therefore, precautions have to be taken against groundwater intrusion and instability. These precautionary measures can easily be included in the planning stage of construction. Current road building will now be adjusted to deal with predicted volumes of groundwater based on robust models.

This October 2010 issue features the issue of climate change and contamination from point sources like land fills. Among other research topics the CLIWAT project examines how climate change affects the contamination associated with former industrial sites and landfill sites. In this issue's main article we provide an example of a Danish landfill site to illustrate some of the challenges we can expect in the future.

Furthermore, CLIWAT researchers apply cutting edge technology to explore groundwater layers. Seismic reflection methods are known from oil and gas exploration. However, their application to groundwater modelling is innovative.

A special highlight of this issue is the field report of CLIWAT geologists visiting the volcano Eyjafjallajökull on Island. The eruption of this sub-glacial volcano has not only affected European air traffic for a couple of weeks, but also the life of local farmers.

The date of the final CLIWAT conference is the **22nd of June 2011**. The project's results will be presented at this meeting. During the conference you will have the chance to meet project participants and people from various sectors who have contributed to the project with ideas, knowledge and input. Apart from exiting presentations there will be time to network with other participants. Mark the date in your calendar if you want to attend. You are also invited to visit the project at our website: http://www.cliwat.eu

Enjoy the reading

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Investing in the future by working together for a sustainable and competitive region

About CLIWAT: Adaptive and sustainable water management and protection of society and nature in an extreme climate

The project will focus on the effects of climate change on groundwater systems. CLIWAT aims to identify the challenges caused by the higher water levels, and to develop climate scenarios focusing on surface water and water supply as well as the impacts on buildings. The quality changes of the groundwater resource caused by salinisation, outwash from point sources and new demands for irrigation are some of the issues which will be investigated. This will enable the North Sea Region to react more efficiently to the consequences of climate change. The project will build on and improve existing geophysical and geochemical methods; these will be tested in the partner regions in order to be able to develop ground water models and furthermore recommendations for the North Sea Region on how to deal with the consequences of increased groundwater levels.

(Continued from p.1)

The site

Pilot Area G consists of four landfill sites that are located next to the river, east of Århus (s. figure 1). The landfill sites commenced operation in the 1930s, and were most active in the period between 1950 and 1980. All of the landfills were uncontrolled and established without any kind of membranes, leachate capture or insulation systems. Today the landfills are covered with a clean layer of topsoil and the area is partially used for recreational activities, allotments and some unused sections.

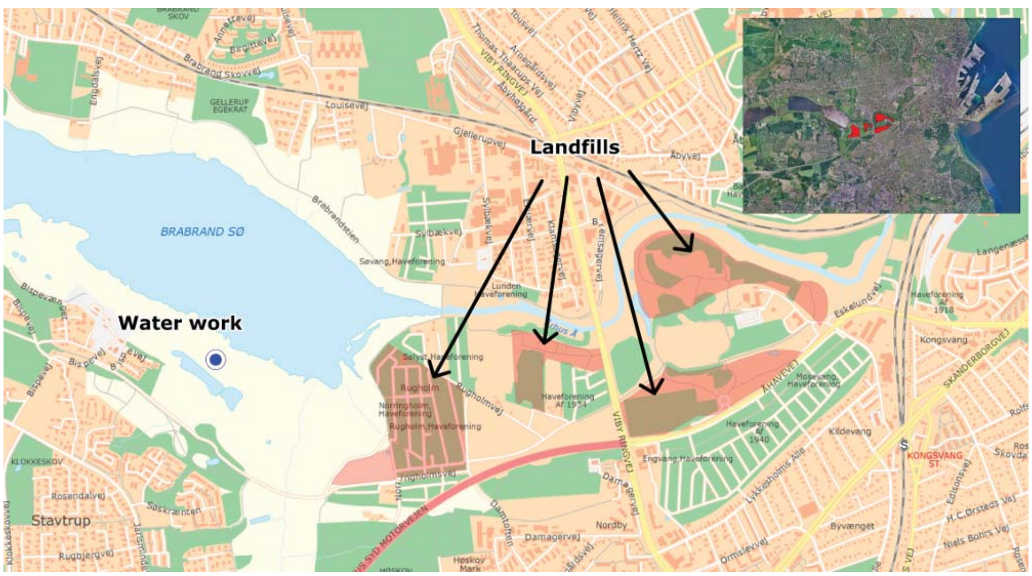

Figure 1:*Map of the CLIWAT pilot area*

Much of the waste disposal in the landfill sites took place in the meadows surrounding the river. The river course was even moved north, to give way for more waste disposal. There is no natural barrier between the landfills and the river. One of the city's main drinking water wells is located less than 1.5 kilometres from the area. Although the aquifer well pumps are about 60–100 metres below the surface, the groundwater draw down from the pumping extends beyond the landfill area.

A remediation system has been in operation since the late 1980s, pumping leachate-impacted groundwater from below the site and from a peripheral drainage system. Although water quality has improved over time, there is still high levels of non-volatile dissolved organic carbon (NVOC), iron , salts (high conductivity), benzene, naphthalene and polycyclic aromatic hydrocarbons (PAHs).

Geology

The site is situated in a pre-Quaternary Period buried valley, oriented east to west. The valley has been filled with glacial till and alluvial sands from several glaciations of the Quaternary period. During the end of the last glacial period, the sea flooded much of the area. Later the land rose and thus we find beach and marine deposits in the low lying river bed. This is evident by the gravel and peat sediments that can be found in several places in the area. Figure 2 displays a west-east geological profile of the area, modelled using GeoScene3D.

Hydrogeology

The many glaciations and changes in river flows over time have created a rather complex system of sand and till sediments, making it difficult to model and understand the hydrogeology. Despite the many investigation wells dug in the area, it is still unclear to what extend the secondary aquifers below the landfill sites are connected with the primary drinking water aquifers below. However, generally there exists a primary aquifer (no. 1), a coherent aquifer composed of sands and gravel outwash deposits located just above the pre-quaternary clays.
Below the landfill a secondary sandy aquifer (no. 2) can be found. Finally, a tertiary aquifer, consisting of sporadic gravel beach deposits can be found. Although this layer is very thin, its high hydraulic conductivity makes it important in understanding the flow of leachate.

The CLIWAT field work

The primary goal of the field work in this area is to understand how the landfill and hydrogeological system is impacted by climatic changes. The CLIWAT work consists of several field campaigns aiming to provide better knowledge of the system. The fieldwork has been carried out in cooperation with CLIWAT partners. Fieldwork to date:

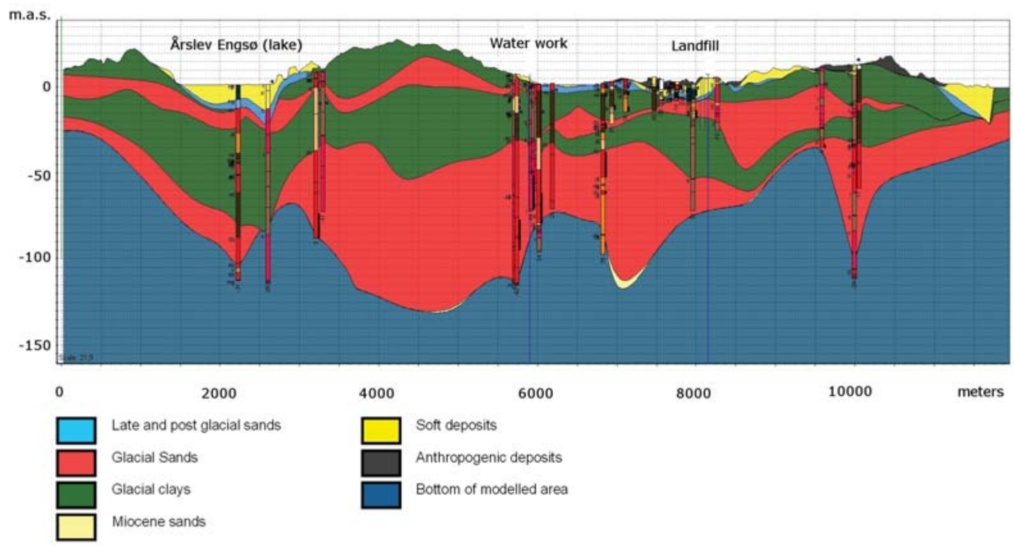

Figure 2:*An west-east geological profile along the Brabrand buried valley. Y-axis is meters above sea level*

- ➢ Investigation of groundwater flow to and from river using hydraulic head data loggers (Central Denmark Region (CDR));
- ➢ Methane production, locating hot spots and estimating total flow (CDR and Fluxsense AB);
- ➢ Pumping test to better understand contact between aquifers and river (Leibniz Institute for Applied Geophysics (LIAG) and CDR);
- ➢ IP measurements to identify landfill leachate plume (Århus University) Shut-down of remediation system to monitor hydraulic impact (CDR);
- ➢ Increased data collection of water level and conductivity (CDR);
- ➢ Well logging and age-dating of groundwater (The Geological Survey of Denmark and Greenland (GEUS)).

The resulting data is used in building a geological model and a hydrogeological model of the system. Using the hydrogeological model with climate change scenarios, enables us to understand how the site will be impacted by climatic changes. This work is carried out in Århus with help from Alectia A/S, a Danish engineering consulting company.

Pumping test

A pumping test was carried out on one of the deeper wells by the main landfill (Eskelund). This pumping test was accomplished with help from LIAG, who also interpreted all of the pumping tests. The main purpose of these tests was to determine to what extend the upper groundwater is in contact with the deeper groundwater, and whether or not there is leakage from the river. Five monitoring wells were drilled to get adequate draw down data from the pumping test, and most wells in the area were also fitted with data loggers, measuring hydraulic head. The well was pumped for a week, and showed very clear draw down in surrounding wells. The interpretation of the results was complicated due to the irregular geology and evidence of some leakage in the pumping well. This meant that a 2D interpretation could not be made. The pumping test also revealed a (4^{th}) shallow aquifer in some of the monitoring wells. By using a simple 3D model in FEFLOW it was possible to understand and explain the draw down data. The interpretations show that there exists local leakage between three upper screens in the pumping well and it was necessary to include a leaky silt layer, evident in the well's pumping profile (s. figure 3). It was not possible to detect any leakage from the river.

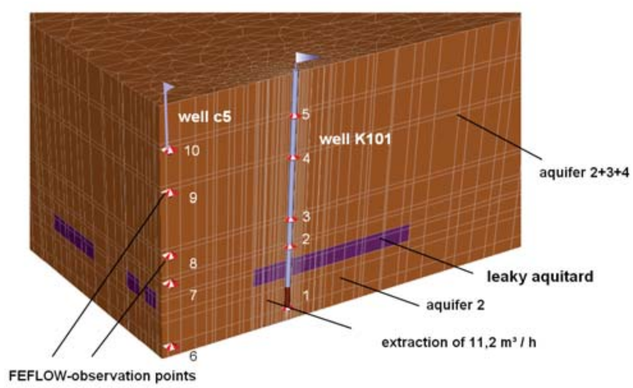

Figure 3: *Simplified FEFLOW model of a pumping well and an observation well*

The pumping test evaluation could not prove there was leakage down to the primary aquifer (aquifer no. 1). The hydraulic contact between the secondary aquifer and the primary aquifer remains uncertain, but if it does exist, it is most likely insignificant.

A deeper well has recently been drilled at the site to gain information on the hydraulic contact between the primary aquifer (aquifer no. 1) and the landfill area. Unfortunately drilling could not be completed because of technical difficulties. However, the geological data down to 100 m below the surface level has provided new information. A report on the pumping test will be published on the CLIWAT website.

Monitoring water head and conductivity

A grid of more than 35 data loggers consisting of water head and conductivity divers have been installed in monitoring wells throughout the site. The logged data provides important information about the hydraulic development and it is being used in the hydraulic model.

Figure 4:*Gas bubbling up through the ice on a small lake by the landfill*

Since February 2010, the existing remediation system has been temporarily shut down. The aim is to explore how the system responds to a cessation of pumping. Will there be an increased downward groundwater flow or does the groundwater flow towards the river? Together with regular water sampling, the conductivity divers will help detecting any migration of a leachate plume underneath the site.

Figure 5: *Iron rich groundwater seeping out of the landfill*

Even before the remediation system was shut down, there was evidence that leachate-impacted groundwater was escaping the remediation system, and entering the river. Figure 4 shows methane bubbling through the ice on a small lake by the river bank, suggesting that methane-rich groundwater is flowing out towards the river at this spot. Figure 5 is a photo along the landfill site, looking toward the river and shows evidence of iron-rich groundwater seeping out of the ground toward the river.

Modelling the hydrology

By setting up a hydraulic model of the area it is possible to run model scenarios of how climatic changes with increased precipitation events and rising sea level will impact the hydraulic surface water and groundwater system. First, a geological system has been modelled using GeoScene3D. The software allows 3D modelling and visualisation of the geology. A 3D visualisation will be published on the CLIWAT website along with a free GeoScene3D viewer.

The Hydrogeosphere system has been selected as the hydraulic system model engine. This system is a finite-element system, as opposed to modular finite-difference systems such as MODFLOW and FEFLOW. Hydrogeosphere has been selected because it can fully integrate the river and drain flow without using separate modules and easily allows small grid sizes close to the landfill site.

The drawbacks are that it is still a university grade system, without adequate user support. Furthermore, it demands a lot of computational power, and still does not support multi-CPU calculations. This means that it takes a long time to run the models.

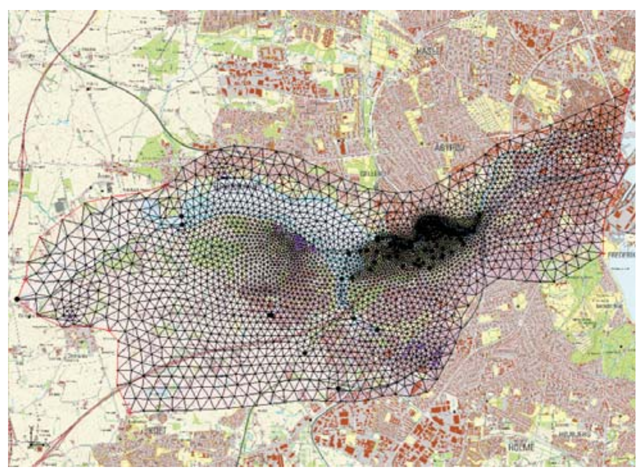

Figure 6: *An example of the modelled finite element grid area*

Figure 6 displays an example of the modelled finite element grid area. Here the land filled area has a much smaller grid size. Figure 7 shows a 3D example of the hydraulic model layers.

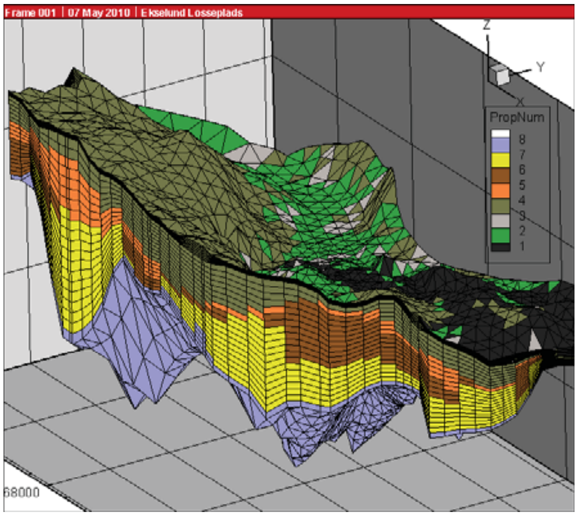

***Figure 7**:3D plot of the layers in the hydraulic model*

The model is expected to increase knowledge about the contemporary dynamics of the hydraulic system and how the system will correspond to future climate scenarios.

Some of the questions that need an answer, are whether or not climate change might modify the flow pattern; or a change in saturation of the landfill might cause an alteration in the chemical environment of the landfill. Will there be seasonal variations resulting from changes in the precipitation pattern?

The model is still in a design and calibration phase. It is currently not ready for running climate scenarios. The work will result in a new risk assessment of nearby wells that supply drinking water.

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Seismic data acquisition in CLIWAT – basis for reliable geological models

by Thomas Burschil, Helga Wiederhold & Steen Thomsen

With seismic reflection methods it is possible to obtain a reliable image of the subsurface without drilling or any damage of the surface. These methods are naturally applied for oil and gas prospection and many data exist in our pilot areas too. But the target depths and thus survey parameters are below 500 m. In addition, data for the nearer surface range are generally scarce. Hence, a target in CLIWAT is to innovate the use of high resolution seismics to obtain relevant parameters for modelling groundwater systems (s. figure 1).

Since CLIWAT project start in September 2008 several seismic surveys are accomplished in pilot area E (Schleswig and Sønderjylland) and pilot area D (Borkum). The seismic team of LIAG recorded about 20km of profiles with different vibro and receiver systems. Seismic methods were common p-wave seismics with planted vertical geophones, shear wave and land streamer surveys with horizontal and 3-component geophones as well as vertical seismic profiles in boreholes. Altogether, LIAG accumulated during the surveys over 4000 vibro-points and more than 32 GB of data. The Environment Centre of Ribe surveyed about 30 kilometres of reflection seismic lines during the month of March 2010.

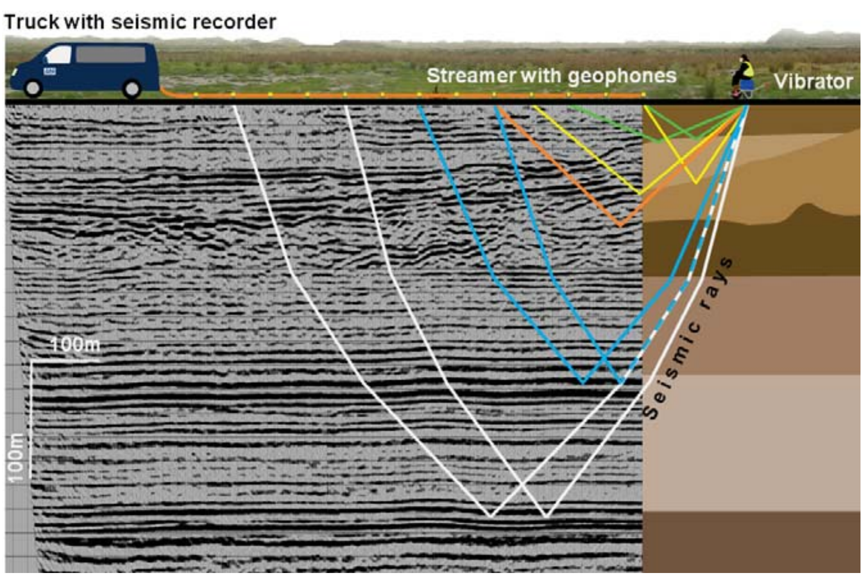

***Figure 1**:Sketch of seismic survey: seismic section from Föhr, layer model and seismic rays (©Thomas Burschil)*

First measurements were organised in May 2009 near the town of Süderlügum in the Danish-German border region to investigate the course of a buried valley. The five profiles with LIAG's vibroseis truck should be extended in August 2009 but this survey was not feasible because of public protests against possible CO_2 storage in this region. Therefore, the North Sea island of Föhr came into focus of our investigations.

SkyTEM results from Föhr show two fresh water lenses in the eastern and western Geest. In the eastern part of the Geest a buried valley system is expected to have strong influence on the groundwater system. The main catchment basin of Föhr's water supply is located in this part. The northern part of Föhr consists more or less of salty marshland **(cont'd./... p.8)**.

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CLIWAT

Transnational project about climate change and coastal groundwater in the North Sea Region

Bold=present at SWIM21

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INTRODUCTION

CLIWAT is a transnational project in the North Sea Region with the main objective to evaluate the physical and chemical impacts of climate change on (coastal) groundwater and surface water systems, and to provide a sound knowledge base for adaptive and sustainable water management and infrastructure. Seventeen institutes from Denmark, Germany, The Netherlands and Belgium work together in this project.

METHODS

For this SWIM, we focus on the topic of salt water intrusion. We merge common existing techniques with new innovative methods such as HEM and SkyTEM data (Fig. 2) (Siemon *et al.*, 2009). In the determination of the fresh-brackish-saline groundwater distributions, numerous techniques are combined (e.g. Goes *et al.*, 2009), such as groundwater sampling, geophysical borehole logging, electrical CPT, HEM, EM31, EM34, VES, CVES, GPR and TEC probe data (see Fig. 3 and 4). Furthermore, groundwater dating is applied to support the evaluation of flow velocities and flow dynamics in and around fresh–saline water mixing zones, and pumping- and slug tests are used to estimate the hydraulic parameters of the investigated systems, which is used as input for the groundwater flow models. In addition, variable-density groundwater flow and coupled salt transport at different sites in the area are modelled to assess future changes in the groundwater system (Fig. 5). Different variable density groundwater flow and coupled solute transport modelling tools are used (e.g. MOCDENS3D, SWI, SEAWAT and FEFLOW).

SOME PRELIMINARY RESULTS

In this poster we demonstrate preliminary results of several pilot areas in Germany, The Netherlands and Belgium.

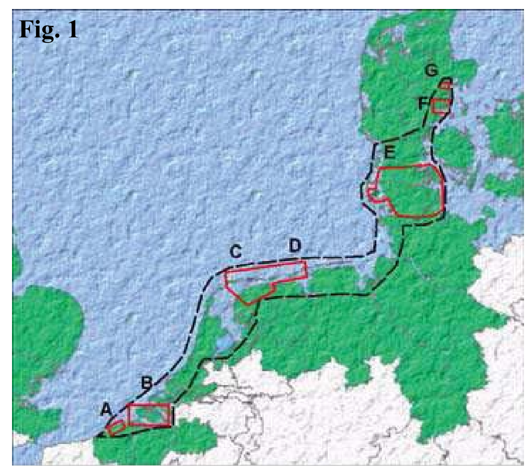

Figure 1: *The investigated pilot areas of the CLIWAT project within the Interreg North Sea Region. Salt water intrusion is the main subject in the pilot areas A, B, C and D.*

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North Sea island, Germany (D, E)

Airborne electromagnetic measurements with HEM (North Sea island Borkum) or SkyTEM (North Sea island Föhr) give 3D ideas of the distribution of fresh, brackish and saline groundwater. This is locally verified by various ground-based measurements (geoelectrical methods, ground penetrating radar, magnetic resonance soundings, drillings, logging, etc). On Föhr, structural constraints are also achieved by reflection seismic surveys. On Borkum, two vertical electrode chains at a depth of 50 to 70 m monitor changes in the saltwater/freshwater transition zone. The integration of the data into 3D geological and variable-density groundwater flow and coupled solute transport models is still in progress...

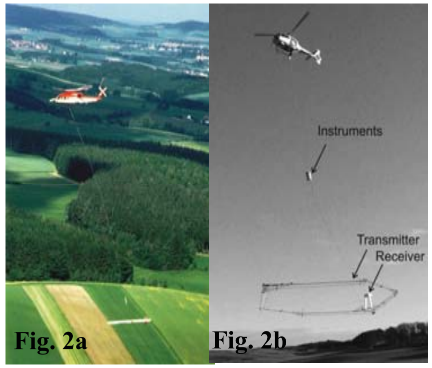

Fig. 2a Fig. 2b

*Figure 2. Helicopter-borne geophysical **systems**: Left: BGR system recording simultaneously frequency-domain electromagnetic, magnetic and radiometric data, Right: SkyTEM system recording time-domain electromagnetic data.*

Zeeland, The Netherlands (B)

The results of a small-scale ground-geophysical EM31 survey in Zeeland are compared with a small portion of a larger-scale HEM survey (Fig. 4). The larger number of frequencies used the HEM data provide not only information on the lateral conductivity distribution but also on vertical conductivity changes such as the freshwater-saltwater interface.

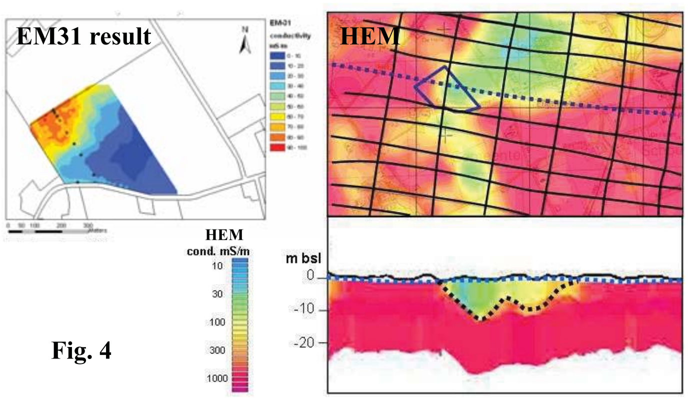

Fig. 4

The map to the left shows the EM31 results and the map to the right the HEM conductivity at 4 m below sea level and the flight-line net.

Figure 4. Combining EM31 with HEM data to map the depth of the fresh–saline interface at a local scale in the Province of Zeeland, The Netherlands. The dotted line marks the location of the HEM cross-section that clearly reveals the groundwater table (blue dots) and the freshwater-saltwater interface (black dots).

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De Haan, Belgium (A)

The impact of sea level rise on fresh groundwater resources is simulated in the Belgian coastal plane, using codes as SWIFLEC3D and MOCDENS3D.

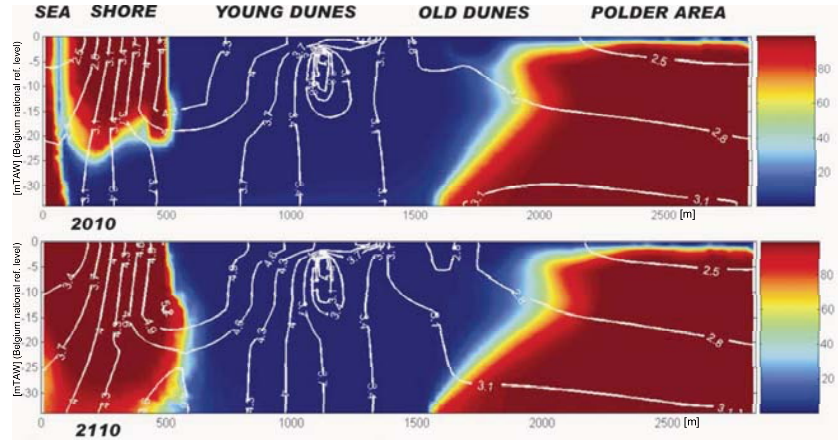

Figure 5: Simulated evolution of the fresh-salt water distribution in north-south cross-section near the village of De Haan. Colors represents the salt water percentage (0% is fresh water with TDS = 500 mg/l, 100% is salt water with TDS = 28 g/l). White contour lines are fresh water heads in mTAW (Belgium national reference level).

Terschelling, The Netherlands (C)

The result of a CVES survey on the island of Terschelling reveals the thickness of a freshwater layer on top of saltwater (Fig. 3). In addition, the island has also been mapped using the SkyTEM method (Fig. 2b). Not only the fresh-salt water boundary below the island is mapped but also clear evidence of fresh groundwater outflow ('*Submarine Groundwater Discharge*') to the North Sea is detected several hundreds of meters from the coast line.

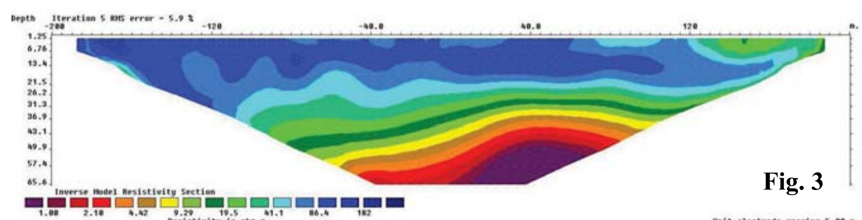

Fig. 3

(Continued from p.5) The survey in August 2009 clarified the structural layering, for instance, the shoulder of a buried valley with dipping reflections. Seismics mean a measurement of the traveltime of a wave but, of course, geologists are interested in depth sections. Therefore exact information on the velocity of the seismic wave is essential and this was measured in situ in an existing groundwater observation borehole. The velocity is also a key to gain information on hydrogeologic parameters like porosity. The investigations continued in April and June 2010.

Figure 2: *Impressions from seismic field surveys (clockwise): seismic vibrator source ELVIS mounted on a wheelbarrow. The coupling of the vibrations to the ground is improved by the weight of our colleague; vibroseis truck on the line and seismic recording unit in foreground; ELVIS and seismic streamer with geophones every meter; passers-by causing "noise" to our measurements (©Thomas Burschil & Helga Wiederhold)*

The good results from pilot area E convinced convinced us to use the seismic method also on the island of Borkum (pilot area D) where the base of the hydrologic model was not clearly defined. Here we used LIAG's 80m long three-component land streamer for the first time. This system consists of 80 geophones which record the full wave field in three components. Two different variants of ELVIS, a compressional-(p-)wave system and a well-established shear wave system were used as sources. Shear wave velocities are lower than p-wave velocities, so with a given frequency they have a higher resolution. Unfortunately, shear waves usually have high absorption rates and bad signal/noise ratios. Additionally, in order to prevent noisy ground roll, we also need a paved surface. The target areas were the very near surface with clay layers down to 20m as aquifer separator and the deeper basement as boundary condition in the groundwater model. Perfect weather and a good pavement should have ensured good conditions, but several school classes and a lot of passers-by made the measurement temporarily impossible (s. figure 2). Within three days, we accomplished about 520m of profile with two sources, so that the measurements were successful after all. Preliminary results of the p-wave data show two significant reflectors in 210ms and 300ms two-way-traveltime, respectively, and show the accessible range to be as large as 400ms TWT. Shear waves show two reflections in 100ms and 210ms TWT, which can probably be associated with the clay layers. More parallel reflections come from down to 1s two-way-travel time but we have to investigate whether these are geological or of artificial origin.

The survey in the Danish part of the pilot area E was conducted by the consulting company Rambøll by use of vibrator and towed geophones. The targets of the seismic survey were buried valleys as well as the faults related to the Tønder Graben. First results indicate the presence of a rather deep valley south of the town of Møgeltønder. This valley is believed to be the northwestern extension of the valley by Süderlügum. Most data are now being fine processed to get interpretable time and depth sections.

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Adaptive management at the foot of a sub-glacial volcano

by Hans Jørgen Henriksen

We were six Danish hydrogeologists who set out on a trip to the Icelandic volcano Eyjafjallajökull. The day was August, 28th of 2010, three months after the eruptions which had so dramatically affected European air traffic had calmed down.

The weather was sunny, and the temperature about 15 degrees as forecasted by Iceland Meteorological Institute. We had recently finished the two day NONAM workshop in Reykjavik discussing differences between adaptive management and adaptation, uncertainty and risk assessment and group model building versus participation. For the discussions in a break-out group at the workshop we had brought the Horsens Fjord case from CLIWAT to Iceland for identifying the steps of a 20 year adaptive management learning cycle. Now we wanted to learn about the volcano eruption impacts at the local level and how people had adapted to this unpredictable situation.

Figure 1*:The glacier Gigjökull and its lake (©Hans Jørgen Henriksen)*

Figure 2*:The glacier Gigjökull after the eruption of the Eyjafjallajökull (©Hans Jørgen Henriksen)*

Crossing the Mid-Atlantic Ridge

As we crossed the rift zone, the sub-aerial part of the Mid-Atlantic Ridge between Reykjanes and Langjökull on our way on Route 1 toward South Iceland and the volcano, the guide on the Super-Jeep briefed us on the geology of Iceland. Eyjafjallajökull - Island mountains glacier, he told, had been built up by eruptions over the past 700,000 years. The mountain is 1666 m high with a central crater on top of some 3.2 km in diameter (the caldera). It mainly flows down to the lowland to the North through the glacier Gigjökull, which before the eruption had a glacier lake at its mouth. However, two major floods from the eruption in May filled up the glacial lagoon at the foot of Gígjökull with 50% volcanic ash and slush (s. figure 1 and 2). The two floods threatened bridges downstream in the Markarfljót river floodplain and the system of levees constructed since 1910 to prevent flooding along this river. Markarfljót previously has been severely damaged many times by violent and sudden floods from subglacial volcano eruptions most frequently from Katla, a neighbouring and much larger volcano. When we crossed Markarfljót an hour later heading toward Sólheimajökull, a glacier tongue easy to reach in a 4x4 from Route 1, flowing toward the South coast from Mýrdalsjökull, we understood the necessity of a Super-Jeep for travelling in remote unpaved areas such as Thorsmörk. There are no bridges, so those who visit, have to cross the small melt water rivers and streams in a car with abnormally large wheels.

The eruption starts

The 2010 eruption started at the Northern slope of a mountain ridge pass between Eyjafjallajökull and Mýrdalsjökull, just in the middle of a popular hiking trail between the Skogerfoss at the South coast and Thorsmörk, North of the two glaciers on the 20th of March. The first visual evidence took the form of a small, photogenic, and relatively harmless eruption, which was in an area easily accessible by motorised vehicles across the glacier to the East. In fact 20,000 people managed to visit the scenic volcano eruption, before it ceased on the 12th of April.
But then the subglacial Eyjafjallajökull took over, and on the 14th of April powerful explosions generated a violent eruption below the icecap with loads of extremely fine-grained ash sent into the atmosphere, which stopped air travel in Iceland and in a large part of Europe for days. The explosive cloud was black with tephra, falling to the ground, leaving a white cloud of steam. Then from April, 18-30 the eruption became calmer again and the ash coarser-grained. From May 5 to 6 air flight traffic was impacted again by finer ash caused by new explosive activity from the volcano. Another burst in activity happened on May 13-14. Finally, on May 23 the volcano calmed down.

Experimental and progressive farming

The farm, Thorvaldseyri, has a long history since its establishment on these meadows back in 1886. Its current owner, Ólafur Eggertsson, very kindly took the time to show us around on his farm and explain a little of its recent history. In the late seventies Ólafur built a new family house, a cow byre for 84 cows, hay silos and a storage building for machinery. After this innovation grass fields and grain production was increased, computerised milking machines and calf feeders introduced. Ólafur told us the story about how he searched for geothermal water, despite scientists' skepticism that hot water would not be found on his land, trusting his adaptive and experimental approach, he drilled a well in the so called Koltungu ravine 2 km above the farm itself, by the old electricity station (s. figure 3), down to 1000 m depth to where the heat reached $116\,^{\circ}\mathrm{C}$. This well produced hot running water, 1 litre per second at $65\,^{\circ}\mathrm{C}$. A year later he established a 2 km insulated pipe from the hole to the farm, which heated up the farm houses and side buildings with water, which also helped drying harvested hay and corn.

Figure 3:*Visit at the Koltungu ravine (©Hans Jørgen Henriksen)*

Around the turn of the century livestock included 65 milking cows, 130 cattle and calves, with an average yearly beef production of 10 tons. The Thorvaldseyri farm has about 230 hectares of flatland and heath, and in total around 1000 hectares, if we include land covered by the glacier mountain. Of this cultivated land was around 100 hectares, with 25 hectares used for the production of grain.

In 2001 the electricity station at the ravine was refurbished, and a 2 km subsoil cable was laid to the farm. The station now produced 16 kW which supplied the entire farm with electricity. Surplus energy was sold on the power company network. In 2006 the annual farm milk quota amounted to 300.000 litres. An automatic feeder was fitted in the cow byre. Distribution of whole wheat flour and barley flour began in 2009. Bread was produced from both Icelandic whole wheat and barley.

Impacts on Thorvaldseyri farm at the Southern foot of the mountain slope

At the South side of the volcano a flooding event caused by the subglacial eruption and melt water rushing down the mountain eroded a 20 m wide and 20 m deep gorge at the foot of the mountain slope, damaged power and water pipelines, clogged drainage ditches and flooded nearby fields on the way (s. figure 4). After this initial flood on April 15 the ash fall became the major concern, due to the danger of fluorine poisoning of livestock. The cattle were moved inside, and the windows had to be taped in order to keep the fine ash out of the buildings.

Figure 4:*The impact of the eruption on the Thorvaldseyri farm (©Hans Jørgen Henriksen)*

Now more than 3 months after the eruption had ceased, we realised that the ice cap on the mountain was covered by a black layer of ash (s. figure 5), and that the ash in parts of the farmland had a thickness of up to 8 cm (s. figure 3). If the tipping point of 10 cm of deposited ash, is exceeded, grass and vegetation can no longer recover. This means that eventually farms are deserted, as it happened at another farm Seljavellir, lying just in the middle of the axis of the main ash fall. We realised, that Ólafur had been extremely lucky this time. Our guide told us that it was the thickness of the ash on the glacier which determined whether the melting of the glacier would speed up or slow down. Next, we sensed how fine the deposited ash was here on the meadow, and soon after crossing the floodplain and the river, we fully understood the scale of the damages to the river floodplain, now filled with sediments from the eruption and flooding, with a need for further securing dikes by removing sediments from the river cross section. Some of the heavy machines used for this repair work were from an ongoing harbour construction project nearby at the South coast.

Figure 5:*The ice cap on the mountain covered by a black layer of ash (©Hans Jørgen Henriksen)*

We then realised that milking cows were kept inside, and only had been out for a short field trip one day in August, the ash still disturbed agricultural production as well as power supply here three months after the eruption.

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Reflection by the geologists and hydrologists

Gyrite Brandt (Local Government Denmark): "Now I remember why I became a geologist. Iceland was 'geology in action' - the present is the key to the past!"
Jens Christian Refsgaard, GEUS: "For me the most striking thing is the strong mentality and resilience which the farmer expresses. He tries to see possibilities in everything".
Gareth James Lloyd, DHI group: "To me the most surprising thing was how quickly things had seemingly gone back to normal. Not just in terms of visual appearance, but also in terms of human behaviour - something we talked about at the time. I thought it has perhaps something to do with the well-documented natural adaptation mechanism people have that allows them to block or minimise the trauma of bad experiences (e.g. childbirth and bad hangovers)".
Jes Pedersen, Central Denmark Region: "I was deeply impressed by the violent events. One example is the glacial lake at Thorsmörk, which in a single, short event was covered by sediments, so that instead of a relatively deep lake, now has an unfertile melt water plain. Yet another example is the floodplain at the farm, where a fine bridge with a couple of meters clearance, today only has a clearance of half a meter, after the floodplain has been covered with new sediments".
Jes also was impressed by the strong will which the farmer possesses: "I am thinking about the farmer, who had planted a forest uphill at the ravine 10 years ago. Today, probably it is half a meter high, covered by ash from the eruption, but he still has not given up".
Rolf Johnsen, Central Denmark Region: "The eye witness report concerning the sound, vibration of the house and windows where very impressive. Windows where taped, to keep the ash out. Furthermore, the report on the the very dramatic ride the farmer had to take in his truck, using GPS for navigating, when the ash was falling with a visibility of only 1-2 meters is impressive. Despite a catastrophic situation three months ago, much is back to normal".

Fourth CLIWAT Partner Meeting in Sankelmark, May 11th to 12th, 2010

by Reinhard Kirsch & Wolfgang Scheer

The fourth CLIWAT partner meeting was held at the European Academy Sankelmark which was founded in 1952 with the idea to contribute to better understanding and cooperation of the countries in Europe. It is located in the Danish-German border region nearby Flensburg, just in the central part of CLIWAT's transnational Project Area E.

The focus of the partner meeting was to exchange experiences from fieldwork, data interpretation and modelling of the seven pilot areas. There was a tight schedule for two days full of presentations and intensive discussions, which showed the good progress the project has achieved. The agenda and the reports from the pilot areas are available on the project homepage www.cliwat.eu.

Figure 1: *Participants at the meeting in Sankelmark (©Reinhard Kirsch)*

One of the highlights of the meeting was the premiere of the CLIWAT film "Water beneath our feet", showing the potential dramatic consequences of climatic change on the groundwater conditions in certain areas – especially in Denmark and in The Netherlands.

As a look into the future Rolf Johnsen proposed a follow-up project to cluster the results of water-related projects in the North Sea Region (e.g. Aquarius and CLIWAT), with emphasis on impact analysis, flood risk, water quality, agriculture, urban water, etc. The clustering of related projects in the InterReg IVB North Sea Region will be supported by the InterReg programme.

The fifth partner meeting will take place in Ghent, Belgium on December the 1st and 2nd.

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Schedule of events

Events				
Date	**Event**	**Content**	**Location**	**Link**
22/06/2011	CLIWAT	Final conference of the project	Århus University, Denmark	http://cliwat.eu/
03/12/2010	Transational board meeting	The transnational use of the CLIWAT results	Ghent, Belgium	www.cliwat.eu
1 – 2/12/2010	Fifth CLIWAT partner meeting	Discussing results from the CLIWAT project	Ghent, Belgium	www.cliwat.eu
November 2010	CLIWAT field measurements	CPT's and water sampling	Zeeland and Fryslan, Netherlands	
October 2010	CLIWAT field measurements	final IP/MEP measurements (AAU)	Århus River, Denmark	
26/10/2010	Hydrologidag 2010	Meeting: hydrological effects of climate change in Denmark	Odense Kommunes Uddannelsescenter, Denmark	http://www.kl.dk/eu/Artikler/75089/2010/09/Hydologidag-2010/

The above dates and locations may change. The editors are neither responsible nor liable for any inconvenience resulting from such changes.

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