CLIWAT CLIMATE & WATER NEWSLETTER

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Application of time domain induced polarization to the mapping of lithotypes in the Hørløkke landfill site.

by Aurélie Gazoty, Gianluca Fiandaca, Jesper Pedersen, Esben Auken, Anders Vest Christiansen and Jes Pedersen

During the spring 2010, researchers from the HydroGeophysics Group, Aarhus University, carried out a survey in the decommissioned municipal landfill, Hørløkke (Denmark). Induced polarization measurements (IP) and electrical resistivity tomography (ERT) were used to define the spatial boundaries of the dump site and to study the lithology of the surroundings. The joint application of these two methods, together with borehole information, may allow the discrimination of lithotypes displaying an identical signature in resistivity.

Introduction to the study

In Denmark, many landfills operational between 1950 and 1980 were designed without any type of capture system underneath, leading to percolation through the waste and into the underlying geological layers and aquifer systems. In these cases, the predicted changes in winter rainfall due to climate changes will probably increase the risk of leaching of contaminants which would, in turn, increase the outwash of chemicals from landfills to nearby aquifers. **(cont'd./. . . p.2)**

Editorial

Dear Reader.

The Blueprint to Safeguard Europe's Water will be the EU policy response to future water-related challenges including climate change. It aims to ensure good quality water in sufficient quantities for all legitimate uses. The time horizon of the Blueprint is 2020 since it is closely related to the EU 2020 Strategy and, in particular, to our planned Resource Efficiency Roadmap.

The CLIWAT project has during its duration collected results that can improve the response to the challenges of climate change. Within the project we have found methods to map the changes in groundwater systems. This is done via incremental and radical innovation of geophysical and geochemical methods, and through the use of existing methods in new combinations.

CLIWAT has shown that detailed groundwater and integrated hydrological models on both regional and local scales are capable of forecasting the challenges that matter to coastal regions, local communities, and individual houseowners. The CLIWAT project demonstrates that the ability to integrate results from local and regional scales is necessary to cope with the many challenges posed by climate change.

This December 2011 issue focuses on the results and perspectives of the CLIWAT project. Furthermore, it links to the other InterReg IVB projects dealing with climate change and water.

The main findings of the CLIWAT project will be delivered to the WaterCAP project. The WaterCAP project is a cluster project within the North Sea Regional development fund InterReg IVB which includes results from six existing projects and bring the knowledge to decision makers at the EU level (www.watercap.eu).

The final CLIWAT final conference will be held on **the 5th of January 2012**. The project's results will be presented at the conference. During the conference you will have the chance to meet project participants and people from different sectors who have contributed to the project with ideas, knowledge and input. It will be a full day event with interesting presentations and there will be time to network with participants and attendants.

This is the last of a series of six newsletters within the CLIWAT project.

All newsletters can be downloaded from the CLIWAT homepage www.cliwat.eu

Enjoy the reading.

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Table of Contents

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

The CLIWAT project focuses on the effects of climate change on groundwater systems. CLIWAT is identifying the challenges caused by higher water levels, and developing climate scenarios focusing on surface water and water supply as well as the impacts on the built environment. The changes to groundwater quality caused by salinisation, outwash from point sources and new demands for irrigation are some of the issues that are being investigated. This applied research will enable the North Sea Region to respond more efficiently to the consequences of climate change. The project is building on and improving existing geophysical and geochemical methods; these are being tested in the partner regions in order to develop groundwater models and recommendations for the North Sea Region on how to address the consequences of rising groundwater levels.

(Continued from p.1)
Landfills without leachate collection systems thus provide a high risk to future groundwater quality due to changes in groundwater level. In light of these implications, it is important to have a fast, cheap and reliable technique which is able to depict the sub-surface at high resolution, both in landfill areas and surroundings, and, if present, gain information on pollution dispersal.

This study has delineated and characterized the decommissioned Hørløkke landfill and the waste body with high accuracy. It has also shown how the joint application of ERT, IP and gamma ray logging provides a lithological description of the global area to be constructed and depicts the different geological layers with variable clay content at high resolution.

Area of interest

In the CLIWAT project a test site has been selected for the study of a typical Danish landfill and the surrounding geology using geophysical methods, to improve the knowledge needed for further modelling studies of hydrogeology and climate change scenarios. The area of interest is a decommissioned landfill, active from 1968 to 1978. It is located in the vicinity of Vojens, in southern Denmark, and covers an approximate area of 10000 square metres. The total amount of waste deposited is estimated to be 65000 square metres, consisting mainly of domestic waste and sludge from the nearby wastewater treatment plant. Because the site was not controlled since 1972, some chemical waste from a refrigerator factory has also been dumped, but the amount remains unclear. The landfill was established without any kind of membrane, leachate capture or isolation systems. All waste was dumped on the original terrain, yielding a hillock approximately 15 metres high. As a result of percolation through the landfill, contamination has been detected below the landfill itself, and extending 500 metres west as a deep contamination plume (50-60 metres in depth).

Results

The geophysical survey, together with the borehole information, allowed the recognition and the spatial delineation of several geological units important for the hydrology of the area. In particular it was possible to map three key structures that influence the water flow of the site: the clay layer that supports the Billund Creek north of the landfill; a clay-rich sandy layer at depth of 20-40 metres, that likely exhibits a different hydraulic conductivity when compared to the upper and lower clay-poor sandy soil; a deeper silt/clay lens, that extends about 350 metres west of the landfill and that likely supports the pollution flow to the west . A qualitative sketch of the survey findings that summarize these geological units is presented in Figure 1. The use of both ERT and IP data, instead of ERT measurements alone, greatly enhanced the resolution power of the survey, not only for delineation of the landfill, but also for the characterization of the creek aquitard and for the recognition of the clay-rich sandy layer. In particular this last finding is of interest, because the ERT data alone did not show any evidence of the enriched clay content. These results are a perfect example of the potential of the IP method for hydrogeological studies and for landfill delineation, but more care is necessary in the field in order to obtain high data quality in comparison with the acquisition of ERT data only.

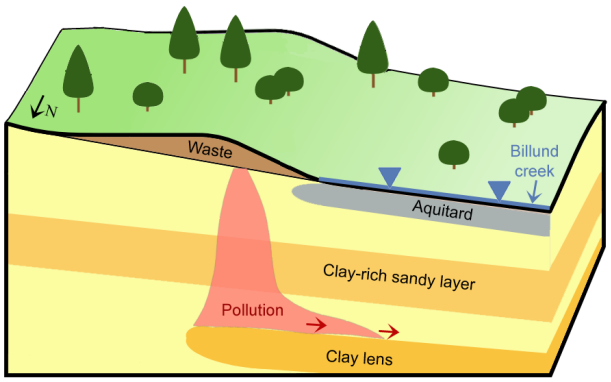

***Figure 1**: Qualitative model obtained from geophysical measurements for a cross section of the landfill (not to scale)*

More realistic scenarios of the variation in the outwash of chemical components from landfills to nearby aquifers, as a consequence of climate change, will be predicted when incorporating such information in the hydrogeological modelling.

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Results from the Belgian Middenkust Pilot Area

by Alexander Vandenbohede

In the mid coastal area of Belgium, CLIWAT researchers from Ghent University have successfully completed their project to simulate future conditions in the fresh and salt water distribution in coastal groundwater systems.

The CLIWAT Pilot Area, Belgische Middenkust, is the central part of the Belgian coastal plain, ranging from Zeebrugge to Nieuwpoort. It is characterized by a shore of about 200 to 500 meters in width with a tidal range up to 2.5 meters in amplitude during spring tides. Landwards there is a dune area which can have a varying width from 50 up to 1500 meters. This results in a large variance in the size of the freshwater lenses underneath these dunes. Behind the dune areas are the polders. This is a low-lying area which is artificially managed by a large network of drainage ditches and canals. These polder areas have a complex fresh-saltwater distribution resulting from the Holocene transgression combined with human intervention during the last 1000 years.

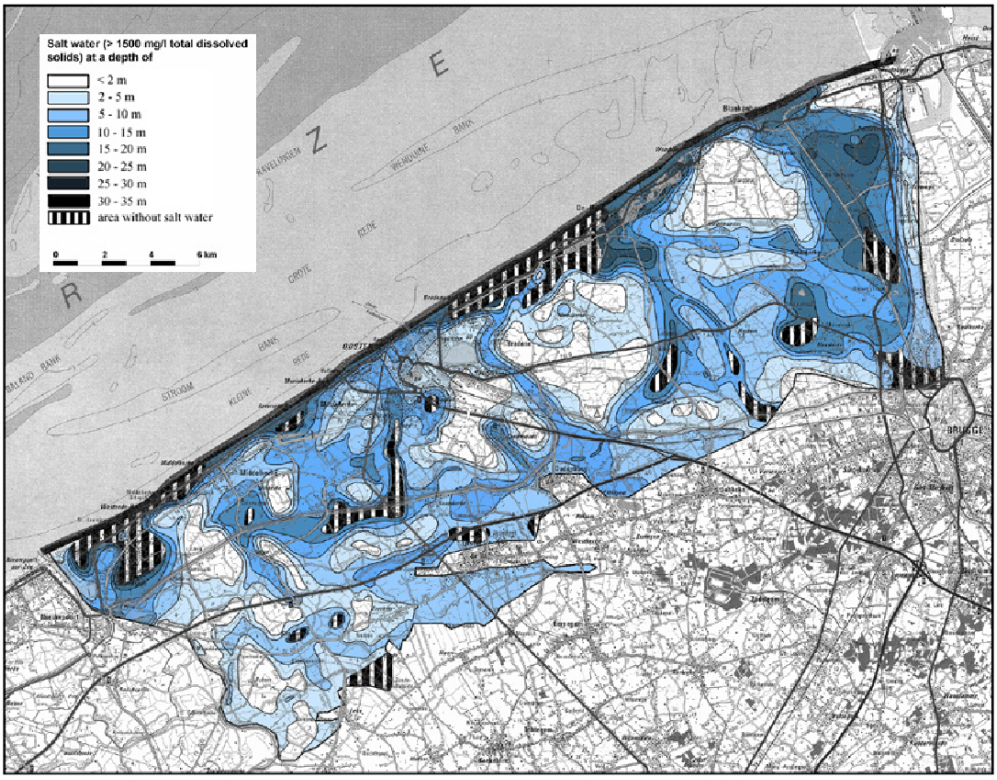

***Figure 1**: Fresh-saltwater distribution in groundwater in Belgian pilot area. The depth to the fresh-salt water interface (1500 mg/l) is depicted.*

Measuring the current hydrochemical situation

In order to simulate the future state of fresh-salt water distribution, an update of the 40-year-old map depicting the fresh-salt water distribution was made for the present situation in the pilot area. The update generally agrees with the previous fresh-salt water distribution map. Aside from locations where hydraulic interventions were made, the current fresh-saltwater distribution is in equilibrium with the hydraulic boundary conditions. The map (Figure 1) provides an accurate, representative distribution of fresh and salt water distribution at a large scale. At a smaller scale additional research is recommended by the research team.

Further research was performed on the geochemistry of the pore water (water between sediment grains). Two hydrosomes (bodies of water of the same origin) can be found in the groundwater reservoir: a brackish and saltwater body dating from before the impoldering and freshwater bodies that developed after the impoldering. The water quality in the reservoir is determined by the mixing of these two bodies and a range of chemical reactions that take place. Overall, a clear chromatographic sequence due to cation exchange is visible in the freshwater hydrosome. This hydrosome originates because of the displacement of saltwater with freshwater as a result of the impoldering. Older brackish and saltwater contains the signature of both freshening and salinization, illustrating the complex evolution of the coastal plain from the last ice age until the impoldering.

In a subsequent study an integration of geological, hydrological, geophysical and geochemical data was made to depict the importance of a multi-disciplinary approach to the complete understanding of a coastal groundwater system, which is a prerequisite for simulating effects of climate change. Temperature measurements, 3H/3He (age dating), hydrochemical data, head measurements, borehole logs and an aquifer test were used to obtain insights into the groundwater flow and fresh-saltwater distribution of a small section of the pilot area (Snaeskerkepolder).

The model code SEAWAT was used for this data integration. In addition to a better understanding of the groundwater system, a cross-verification of the results is obtained through the use of different data, as some of these measurements can be the result of the same processes. Another advantage is that the model provides information at various scales. Some of the gathered data are the result of small scale hydrogeological processes, while other data result from large-scale or general processes.

Measuring hydraulic conductivity of the groundwater reservoir

A method was developed to estimate the equivalent horizontal and vertical hydraulic conductivities of a defined depth

interval of sediments based on geophysical borehole logs (electrical conductivities of deposits and natural gamma radiation) and on a limited number of electrical conductivities of extracted pore waters. This method is developed using the observations of two double pumping tests performed at two different sites in the Belgian pilot area. In this estimation method a number of well-established relationships are applied. In addition to the equivalent horizontal and vertical hydraulic conductivities of well-defined depth intervals, the depth variation of the total salt content in pore water, the porosity and the electrical matrix conductivities are estimated. These data concerning the electric and hydraulic parameters derived from geophysical analysis, then permit the schematization of the groundwater reservoir (succession of pervious and semi-pervious layers and their heterogeneity). As a result, the borehole data delivers data on the present salt-fresh water distribution but also the hydraulic conductivity of the groundwater reservoir. These are both valuable data for the 3D density-dependent flow and transport model.

Model results: effects on salt load

As a final step of the study, the effects of future sea level rise on the fresh-salt water distribution near Oostende (a central location of the pilot area) was assessed. The estimated sea level rise has been assumed to be 0.6 meters per century for the next 350 years. MOCDENS3D, a 3D density-dependent model was used to simulate this particular influence of climate change. The present fresh-salt water distribution was used as the starting point in the model. The model reveals that the estimated sea level rise results in a decrease in the volume of freshwater present beneath the dunes, thus a further restriction on the already limited freshwater reserves. A second effect is an increase in the salt load in the upper part of the aquifer. Some of these results are visualized in Figure 2. These figures show the mineralization of the groundwater (in mg/l) at the top of the aquifer. The highest increase in the salt load (shown in yellow and red) is to be expected within the first kilometer inland from the coast. This will have consequences for land use and culture in this area. Further inland, sea level rise results mainly in an increased flow of brackish and saltwater to the drainage channels. An increase in salt load on land behind the dune area will be limited.

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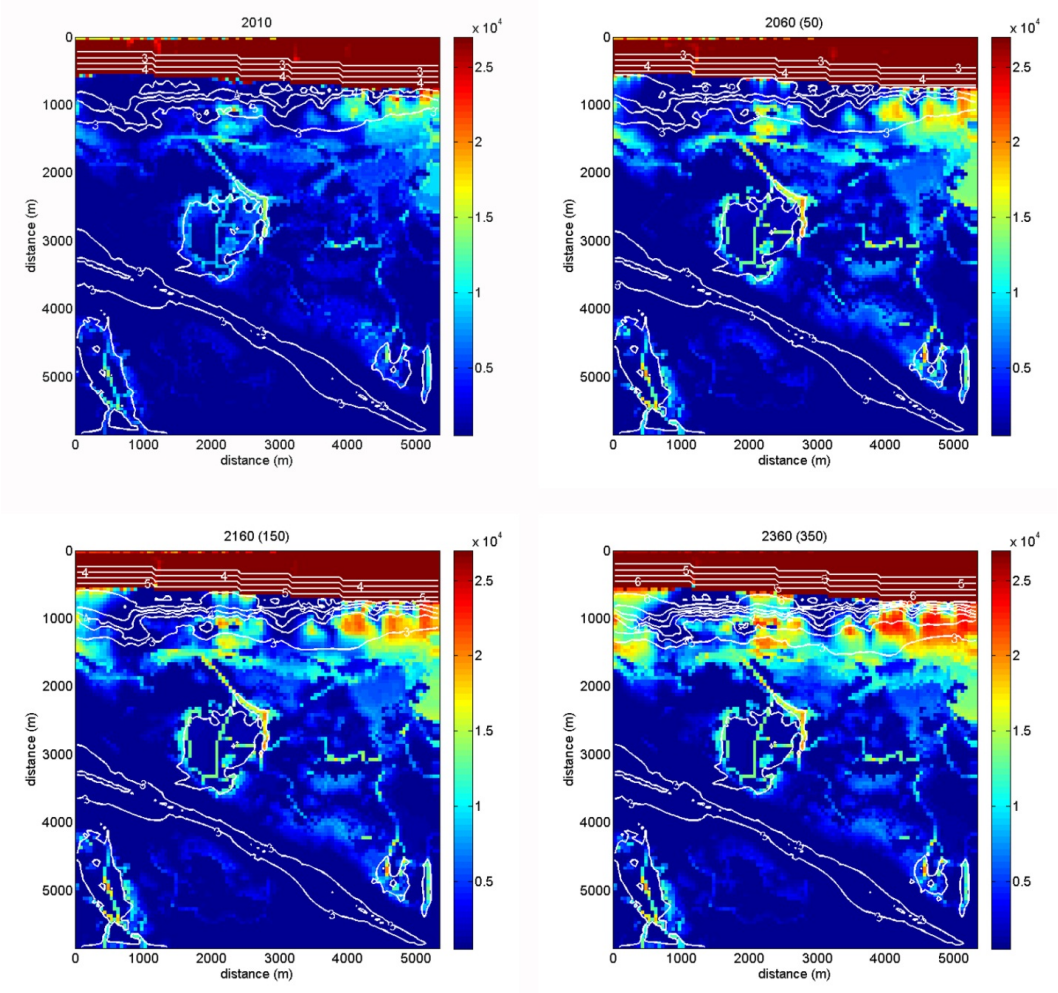

***Figure 2**: Salt load in the upper part of the aquifer in mg/l, top of the figures is the North Sea*

WaterCAP: A cluster project gathering knowledge on climate change adaptation and water

by Rolf Johnsen

The results of the CLIWAT project are being delivered to and elaborated in the new cluster project, WaterCAP. The cluster is gathering results from six existing projects within the Interreg IVB programme. The aim of the WaterCAP project is to raise awareness of the wealth of knowledge that six North Sea projects are generating about climate change impact on the hydrological cycle and to better communicate the results at the policy level. Tools and models developed by or used in the projects will be discussed, making them more accessible to communities and policy makers and information about these will be presented to a broader audience.

Within the WaterCAP project efforts are made to integrate results on climate change adaptation and how we can deal with the associated challenges facing our society and natural habitats. As shown in Table 1, the investigations taking place in the various projects focus on specific themes. However, all six projects share a common principle– the study of the hydrological cycle. Strategic Alliance for integrated Water Management Actions (SAWA) and Impact of Climate Change on the Quality of Urban and Coastal Waters – Diffuse Pollution (DiPol) are dealing with surface water quantity and quality.
CLIWAT addresses groundwater quantity and quality and local community solutions, while Aquarius is focusing on how to include important stakeholders in the challenge to solve climate change impact, such as expanding the role of the farmer to water manager in the future. Climate Proof Areas (CPA) is dealing with the adaptation process and how to start and continue an integrated process. Cradle to Cradle Islands (C2CI) focuses on adaptation to climate change challenges by optimising the hydrological cycle on North Sea Islands with a special focus on quantity and quality of ground and surface water.
The common issues that each project shares are listed in the first three columns of table 1. The three columns on the right side of the table highlight the issues which are dealt with in several of the projects. This WaterCAP cluster project will concentrate on the common issues: Impact analysis, adaptation strategy and water quantity and relate these to current and future national and EU policy.
The main focus will be in extracting key information from the six projects, with respect to tools, methods and recommendations that are of central relevance to national and EU climate policy. To this end, a clustering process has been developed, which includes a document analysis, interviews, three workshops and a conference. Each workshop will focus on one of the common issues: impact analysis, adaptation strategy and water quantity aspects/flood risk. Guiding questions for the workshops will be: What are the lessons learned? How can the findings be integrated? Where are the win-win situations and how can Europe benefit from these outcomes? The results of each workshop will be summarised in a working paper that will include both the projects' recommendations and the main results.
In March 2012, key stakeholders from the EU level are invited to a workshop to discuss how WaterCAP can provide the results for implementation in the work on mainstreaming the EU legislation, guidelines and funding programmes. Furthermore, CLIWAT partners are invited to join on workshops on the three main issues:

Workshop on quantity/quality (UK), 16-17 April 2012
Workshop on impact assessment and tools (Denmark), 15-16 May 2012
Workshop on stakeholder involvement (Germany), 4-5 September 2012

Expected outcomes

The clustering activity will lead to three working papers detailing the projects results on impact analysis, adaptation strategy and water quantity aspects/ flood risk. The papers will provide recommendations for EU and national policies. In the final conference report, these papers will have been evaluated and suggestions for their implementation will be presented. With this we hope to contribute to ongoing and upcoming policy processes, such as the coming revision of the EU Water Framework Directive and the EU Floods Directive.
The cluster project will improve the exchange of knowledge between researchers and water managers and support a common understanding on how to map impacts and deal with a variety of climate change challenges.

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Table 1: Analysis of issues investigated in the WaterCAP cluster projects

	Common issues (all projects)			Common issues (50%)			
Project	**Impact analysis**	**Adaption strategy**	**Water quantity aspects / flood risk**	**Policy regulations & guidelines**	**Agriculture**	**Urban water**	**Water quality**
CPA	X	X	X	X	X		
Aquarius	X	X	X	X	X		X
CLIWAT	X	X	X	X	X	X	X
SAWA	X	X	X			X	
DiPol	X	X	X			X	X
C2CI (water)	X	X	X	X		X	X

CLIWAT contribution to EU workshop on groundwater and climate change

by Klaus Hinsby

A workshop "Climate change impacts on groundwater" organised by the EU Working Group C (WG C) of the Common Implementation Strategy for the Water Framework Directive (http://circa.europa.eu/Public/irc/env/wfd/library**) was held in Warsaw on October 12th. The workshop was held back-to-back with the EU Working Group C (WG C) meeting under the umbrella of the Polish EU Presidency. This event was the initiative of CLIWAT partner institutions (TNO/Deltares and GEUS) as members of the Water Resources Expert Group of the EuroGeoSurveys (**www.eurogeosurveys.org**) and WG C. CLIWAT partners contributed five presentations at the workshop including a presentation of the new North Sea Region Programme cluster project "WaterCAP" of which CLIWAT is a part.**

Furthermore, CLIWAT partners were lead authors of a "Manifesto of Groundwater and Climate Change" adopted by the EU Working Group C on groundwater. The Manifesto identifies issues related to climate change impact assessments and adaptation, which have not yet been specifically covered in EU directives or guidelines, and new topics for groundwater and climate change research. The Manifesto and the programme of the workshop can be downloaded from the CLIWAT website: http://cliwat.eu/eu_policy/index.html in the folder CIS WG C. Via this link it is also possible to locate the most important directives and guidelines of relevance for groundwater and climate change issues.
The workshop and the WG C meeting was used to share information and exchange views among member states, stakeholders and scientists and to establish the knowledge base for groundwater aspects of climate change, which, in turn, provides a basis for the development of climate-proof river basin management plans (RBMP's) and for identifying the needs for future work in climate change impacts on groundwater, both from policy and science perspectives.
The participating organisations decided to move forward in two complementary ways:

1. to support the policy process by making concrete recommendations for 2nd generation of RBMP's on the basis of the established knowledge base, and

2. to promote further research based on the inventory of knowledge gaps, which should lead to an improved understanding of climate change impacts on groundwater for future generations of RBMPs.

Important outcomes of the workshop were:

- the identification of a key issue that the impacts of climate change on groundwater are not limited to water scarcity in southern European countries, but also result in significantly altered seasonal regimes of snowmelt, wetter winters, dryer summers and prolonged periods of droughts in other parts of Europe; and

- the insight that secondary impacts of climate change, caused by human adaptations in energy and water policies have potentially large impacts on groundwater resources, but that there is a lack of understanding of how this will affect groundwater itself, as well as the receptors of groundwater such as ecosystems, surface waters and drinking water abstractions.

The adopted manifesto advocates action and pleas for further research to establish an improved understanding of climate change impacts on groundwater. It recognizes groundwater as a precious resource, that is slowly replenished and is of great importance to European society by providing drinking water, irrigation water and ecosystem services.

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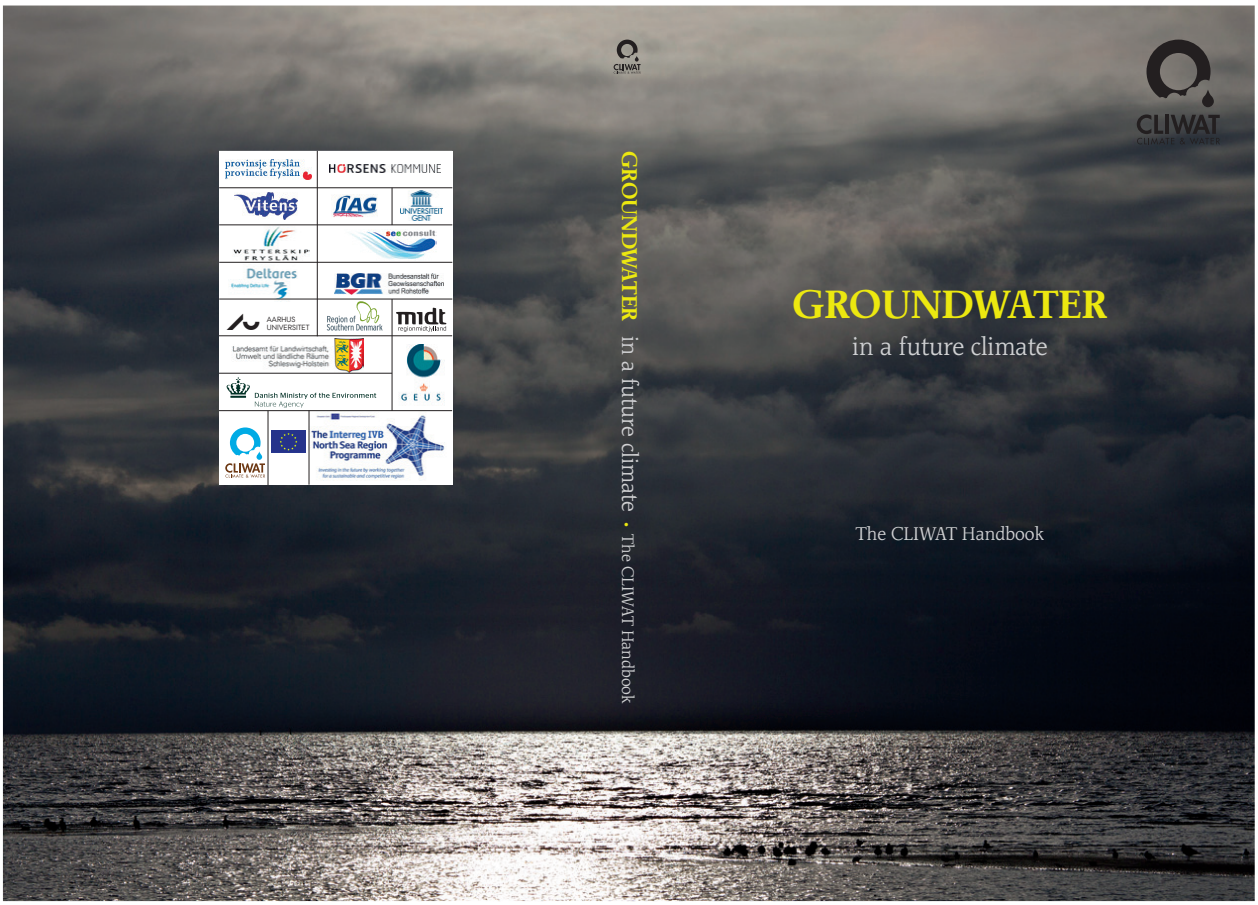
CLIWAT news

Final CLIWAT Conference - January 2012

On January 5^{th}, 2012, CLIWAT will hold its final conference in Århus, Denmark. This event will present the final results of the project and examine future challenges for assessing and managing the impacts of climate change on water resources in coastal regions. For practitioners there will be special sessions focusing on management issues including groundwater modelling as a management tool, and involving stakeholders in groundwater research and management. For the scientific community, a special session on technical studies will focus on issues of saltwater intrusion, groundwater quantity and quality, and groundwater modelling techniques. There will also be a session on what has been learned in the project, and how this can be communicated for awareness-raising and influencing policy. Poster sessions will present the results of the project as well as from related initiatives. At the conference the CLIWAT handbook will be released (see picture below). For more information, contact **Rolf Johnsen**, `Rolf.Johnsen@ru.rm.dk`.

Special issue "Assessing the impact of climate change for adaptive water management in coastal regions"

CLIWAT partners have jointly contributed to a special issue of *Hydrology and Earth Systems Sciences*. The papers in this special issue describe and demonstrate the methods applied in the project and indicate where improvement and new innovative solutions are required to establish a full and efficient toolbox for evaluating current and future status and climate change impacts on water resources and ecosystems. The necessary tools fall in three groups:
1) tools for geological, geophysical and geochemical mapping and characterization of the subsurface including the distribution of freshwater and saltwater; 2) tools for assessing climate change impact on the evolution of water resources quantity and quality and ecosystems status (e.g. density dependent groundwater flow models and integrated hydrological models); and 3) tools for efficient on-line visualization and dissemination of, for example, established models and climate change scenario simulations.
Accepted papers for the CLIWAT special issue can be found at: www.hydrol-earth-syst-sci.net/special_issue149.html



Cover of the CLIWAT handbook written by the CLIWAT group

Schedule of Events

Events				
Date	**Event**	**Content**	**Location**	**Link**
5/01/2012	CLIWAT	Final conference of the project	Århus University, Denmark	www.cliwat.eu
16 – 17/04/2012	WaterCAP	Workshop on Quantity and Quality	United Kingdom	www.northsearegion.eu /ivb/projects/
15 – 16/05/2012	WaterCAP	Workshop on Stakeholder involvement	Germany	www.northsearegion.eu /ivb/projects/
1 – 5/07/2012	6th Int. Congress on Environmental Modelling and Software (iEMSs)	Managing Resources of a Limited Planet: Pathways and Visions under Uncertainty	Leipzig, Germany	www.iemss.org /sites/iemss2012/
4 – 5/09/2012	WaterCAP	Workshop on Impact Assessment and Tools	Denmark	www.northsearegion.eu /ivb/projects/

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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