DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2015/94

Water4Coast

Realtime groundwater salinity monitoring - data transfer, management and visualisation on interactive web servers

Klaus Hinsby, Paul Thorn, Peter B. Scharling
& Jacob Gudbjerg

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
DANISH MINISTRY OF CLIMATE, ENERGY AND BUILDING

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G E U S

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This report is published as part of the Water4Coast project, which is part-funded by the Eco-Innovation program of the Danish Ministry of Environment and it is written in collaboration between public and private partner institutions by the following authors:

Klaus Hinsby, Geological Survey of Denmark and Greenland
Paul Thorn, previously Roskilde University and the Danish Nature Agency, now Rambøll
Jacob Gudbjerg, HydroInform
Peter B. Scharling, previously Grontmij now COWI.

1. Summary

Saltwater intrusion in coastal aquifers is of increasing concern for drinking water supply in coastal regions globally and efficient monitoring and control systems to assess and control salt water intrusion in coastal aquifers is of increasing importance.

In the Water4Coasts project we initiated work on developing and testing new monitoring sensors for measurements of chloride concentrations and efficient data upload systems to provide the necessary data for the development of a future real-time SCADA (Supervisory Control And Data Acquisition) framework for control of salt water intrusion.

The obtained data and the developed SCADA system are mainly required for controlling salt water intrusion and protecting fresh groundwater resources at coastal water wells and water works. However, it will also be well suited for sustainable management of aquifers further inland, which are affected by intrusion of saline waters from either old marine sediments or evaporation (in arid or semi-arid areas).

In this technical report we describe the outcome and main recommendations and conclusions of the conducted work towards the development of new SCADA systems for efficient control of freshwater abstraction and salt water intrusion at water works based on the monitoring of chloride concentrations in groundwater. We believe that we have developed an efficient approach for monitoring, data handling and visualisation of chloride concentrations etc., which will be key parameters for the development of future efficient SCADA systems to control salt water intrusion in aquifers. We have encountered some technical problems with the long term stability of field sensors, when they are located in surface water, and with the performance of data loggers, which have to be improved before a fully operating system is in place. However, we believe that it is possible to overcome the technical problems in the near future, and the project group will continue to develop the acquisition of data required for SCADA solutions etc. for controlling salt water intrusion in existing and future related projects.

2. Background

Coastal aquifers are affected by saltwater intrusion globally, and have been under pressure for many decades especially in densely populated areas with significant groundwater abstraction for water supply (Post and Abarca, 2010; da Silva and Montenegro, 2012). Such problems are especially known and managed (controlled) in aquifer systems along coastlines of U.S.A. and Northern Spain (Sheahan, 1977; Iribar et al., 1997; Misut and Voss, 2007; Barlow and Reichard, 2010; Custodio, 2010), but problems appear in an increasing number of coastal aquifers in different climate zones, globally, including many coastal aquifers in northeastern Brazil (Bocanegra et al, 2010; da Silva et al., 2010) , China (Wu et al., 1993; Xue et al., 2000, Liu et al., 2001; Han et al., 2011) and Denmark (Andersen et al., 2005; Jørgensen et al, 2008; 2012, Thorn, 2011; Rasmussen et al., 2013), and measures need to be implemented in order to ensure freshwater supplies in these regions in the future.

Climate change is projected to affect precipitation patterns and increase sea levels globally and thereby increasing the risk of saltwater intrusion and deterioration of coastal water resources (Kundzewicz et al., 2007; Hinsby et al., 2012; Loaiciga et al., 2012). Although the extend of the saltwater intrusion highly depends on the geological setting (Werner and Simmons, 2009; Chang et al. 2010), and also may stem from other sources than recent seawater such as old connate waters in former marine sediments (Buckley et al., 2001; Bonnesen et al., 2009; Tran et al., 2012) and even may include highly saline brines (Xue et al., 2000; Han et al., 2011). Especially low-lying areas and areas that receive less precipitation, and experience falling water tables, will be under severe pressure (Essink et al., 2010).

Hence, salt water intrusion due to climate change, sea level rise and increasing demands constitute an increasing challenge for many water supply companies in coastal regions, globally, and calls for the development of new adaptive and innovative solutions to prevent salt water intrusion, monitor the development and ensure sustainable and high quality water supply in the future (Essink, 2001; Post, 2005; Post and Abarca, 2010; Hinsby et al., 2012, Thorn and Mortensen, 2012; Sulzbacher et al., 2012). Managed aquifer recharge through basins in phreatic aquifers or injection wells in artesian aquifers are both possible solutions, which have been applied and operated at large scales for decades mainly around large cities such as Los Angeles (since the early 1950's) (http://dpw.lacounty.gov/wrd/barriers/historical.cfm), and Barcelona where treated wastewater are injected to avoid saltwater intrusion and ensure water supply for the city (Hernandez et al., 2011; http://portail2.reseauconcept.net/Upload/ciheam/fichiers/OM_A_88.pdf). Freshwater injection and aquifer storage and recovery is furthermore considered for emergency water supply of in New York City (Misut and Voss, 2007). Managed aquifer recharge will most probably be a cost-efficient way to protect water resources globally in the future (Megdal and Dillon, 2014).

Besides the salt water intrusion problem coastal catchments face other important problems that are expected to become more severe due to climate change and its impact on the hydrological cycle, water tables and sea level.
The problems vary between regions and climatological settings, but include 1) Increased flooding risks (Thodsen 2007; Dankers and Feyen, 2008; Sonnenborg et al., 2012) and 2) increased nutrient loadings to rivers, lakes and coastal marine waters in wet temperate regions (Hinsby et al., 2008, 2012; Sonnenborg et al., 2012; Wikner and Andersson, 2012) and 3) drought and declining water resources in arid and semi-arid regions (Ragab and Prudhomme, 2002; Montenegro and Ragab, 2012).

Nitrogen loadings and resulting effects is currently considered to be one of the most severe environmental problems on a global scale (Rockström et al. 2009) by e.g. increasing the risk of eutrophication, harmful algal blooms, hypoxia, fish kills and acidification in many coastal waters (Diaz and Rosenberg, 2008; Rabalais et al., 2009; Cai et al., 2011; Paerl and Paul, 2012) including coastal waters in Brazil, China and Denmark (Diaz and Rosenberg, 2008; Cai et al., 2011; Hinsby et al., 2012). The Baltic Sea most probably exhibits the largest problems at present with oxygen depletion and hypoxia due to excessive nutrient loading, even in a global perspective (Diaz and Rosenberg, 2008; Conley, 2012). Partly for that reason the status of the major part of shallow oxic groundwater in Denmark (located in the Western Baltic Sea) is of poor status and does not comply with EU directives as groundwater threshold values for total nitrogen (“nitrate”), which have been established according to the EU Water Framework and Groundwater Directives to protect associated aquatic ecosystems are breached (Hinsby et al., 2008, 2012). This puts a strong pressure on Denmark to reduce nutrient loadings to coastal waters in Denmark and the Western Baltic Sea, and to find new innovative and cost-efficient ways for this purpose.

3. Introduction

The WATER4COASTS project seeks to developed new and efficient solutions for integrated, sustainable and adaptive management of groundwater and surface water that take into account both surface and subsurface water quantity and quality aspects for protection of water resources and ecosystems in coastal regions. By injecting (managed aquifer recharge) water from waste water treatment plants and drainage canals into for instance artesian anaerobic aquifers the hydraulic pressure increase and reduce the risk of saltwater intrusion, Misut and Voss, 2007; Hernandez et al., 2011), while at the same time nitrate in the injected water and the stage in drainage canals are reduced, as well as the risk of eutrophication and flooding.

The main objective of WATER4COASTS is to develop and demonstrate new efficient tools for sustainable and adaptive water management in coastal aquifers and catchments based on managed aquifer recharge to coastal aquifers in order to ensure good status of water resources and coastal ecosystems and:

1) Prevent salt water intrusion towards coastal well fields
2) Reduce nitrogen loads from coastal catchments to marine waters
3) Reduce the risk of flooding in the hinterland from e.g. drainage canals and groundwater, and
4) Monitor the evolution of groundwater chemical and quantitative status

This technical report describes the outcome of activity 1.5: *Development of cheap chloride and nitrate sensors,* 1.6: *Data handling and water information technology, and* 3.2: *On-line dissemination on interactive webserver.*

4. Sensor development, testing and data transfer

4.1 Sensor development

Sensor Development Background and Goals:

Previous studies by Thorn and Mortensen (2012) and Thorn and Urish (2013) have illustrated the potential for the use of a simple chloride electrode for continuous monitoring of groundwater salinity at concentrations lower than what conductivity measurements can provide. The sensors consisted of a simple oxidized silver rod in a plastic casing. Combined with a reference electrode, the sensor can provide an inexpensive system for continuous measurement of chloride concentrations as low as 5 mg/l. However, these measurement were conducted after the sample water was pumped up from the well and not in-situ.

Bendikov (2005) described the potential for producing relatively inexpensive, solid-state sensor, similar to those that can be found on the market for approximately $150. However, these sensors use an organic based film as its sensing surface, which have not been tested outside of laboratory conditions. Thorn (2010) found difficulties in using similar organic films for sodium sensors in the field, and therefore more testing on field application needs to be done.

The primary goal for sensor development is to construct a simple array that can be placed either in a groundwater monitoring well or surface water body, which then can be connected to a data-logger with GPRS connection to send the signal real-time to a server for further data presentation and analysis. In order to achieve this the specific objectives are:

- Construct a sensor array with chloride and nitrate sensors, assessing signal degradation between the sensors and data logger;
- Assess the durability of the sensors for continuous, long-term application in both groundwater and surface water;
- Assess the possibility for continuous, real-time data transmission from the data-logger to project servers.

Theoretical Background for Ion Selective Electrodes (ISE):

Ion selective electrodes use the principles of potentiometry in order to determine the specific ion concentration being measured. Potentiometry, in its basic sense, is the measurement of voltage between two electrodes in an electrochemical cell, in order to measure concentrations of dissolved ions in a solution (Harris 1996, Manahan 2001). The Nernst equation is used to account for the effect of the different ion activity in this electrochemical cell. Since activity is essentially equivalent to ion concentration, the Nernst equation states:

$$(1) \quad E = Eo - \frac{2.303RT}{nF}\log[a]$$

where E is the measured potential, Eo is the standard electrode potential, both measured in volts, R is the molar gas constant, T is the absolute temperature, n is the ion valence, F is the Faraday constant and [a] is the concentration of the ion. Using a standard reference temperature of 25ºC, the Nernst equation simplifies to:

$$(2) \qquad E = Eo - \frac{0.059}{n}\log[a]$$

From this equation, it is apparent that the potential is proportional to the log of the concentration for the measured ion. Therefore, under ideal conditions, there is expected a change of 59 mV per every decade (10-fold) increase in concentration for the chloride and nitrate sensors. This slope, of course is an ideal "Nernstian" slope. When dealing with ion-selective electrodes, the actual response of the electrodes will often be less than that of the ideal Nernstian slope (Brown et al. 1976, Bühlmann et al. 1998, Hobby et al. 1983, Sutter et al. 2004). This can be accommodated through calibration of the electrode through standards of changing ionic concentrations. Through the calibration of the sensor using known concentrations, both the slope and Eo can then be calculated for the ISE. Thus, the calibrated slope can be used in place of the ideal slope, and the ISE can then be used to calculate (measure) the concentrations in unknown samples.

4.2 Sensor Array Construction

<u>Chloride sensors</u>**:**
The chloride sensors were constructed using silver rods, 2.5mm in diameter and 2.5cm long. They were encased in customized plastic housing for installation, with one end of the rod flush with the end of the plastic housing (Fig. 1). The other end was attached to a BNC cable electric cable, which is connected to the data logger.

<u>Nitrate sensors:</u>
The nitrate sensors used in this study were solid film ISE sensors from Vernier, which use a similar sensing surface to that developed by Bendikov (2005). Like the chloride sensor, the nitrate electrode was attached to a BNC cable, which was then connected to the data logger. The Vernier sensors were tested in order to see if the technology can work in the field before further development of the technology described by Bendikov (2005) was applied.

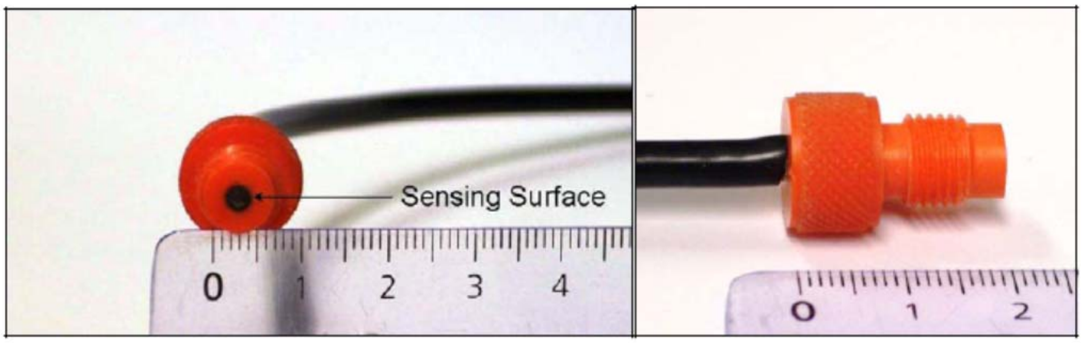

Figure 1. Chloride sensor used in the constructed sensor array (scale in cm).

Reference electrode:

The reference electrode used in the sensor array was a double-junction glass electrode produced by Sigma-Aldrich. The reference electrode was attached to a BNC cable, which then was connected to the data-logger.

Sensor array:

The sensors were sealed in 2,5 cm diameter PVC tube. The sealed tube was necessary to keep the contact between the sensors and the BNC cable dry. The tubing was also weighted with dried fine gravel in order to allow the sensor array to sink in water column, and provide more stability for application in surface waters. Length of the BNC cable between the sensors and the data-logger varied from 5m to 25m.

Data-Logger:

The data-logger used in the study was produced by ComSystem A/S (www.comsystem.dk). The data-logger was able to receive potential signals at +/- 500 mV as well as temperature. The data-logger came with GPRS capabilities, which then sent the collected potential and temperature data to the receiving server. Data was logged once every 15 minutes, and then sent via GPRS once every hour.

Figure 2 shows the constructed sensor array and data logger.

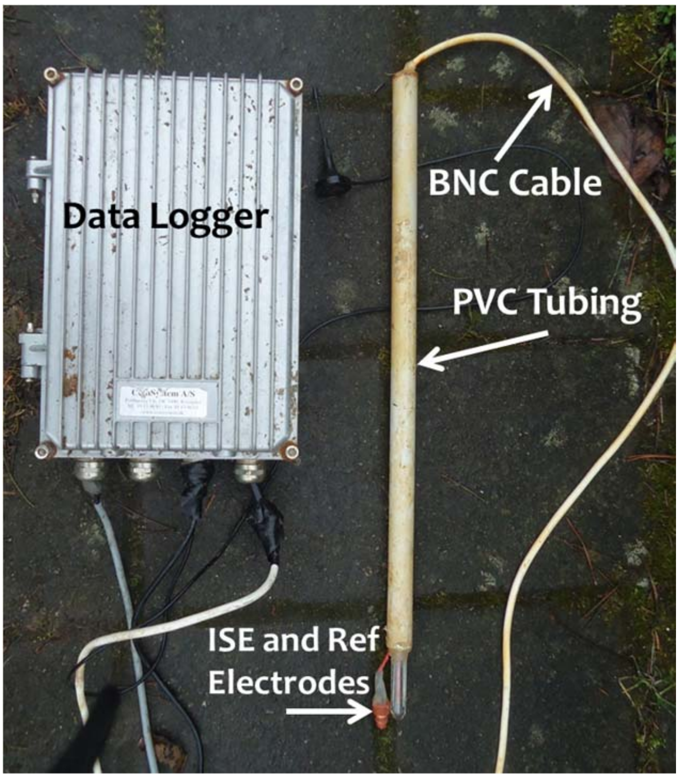

Figure 2. Photograph showing the sensor array and the data logger. The sensor array in this picture contains the chloride sensor and reference electrode at the end of the PVC tubing connected by a BNC cable to the data-logger.

4.3 Sensor testing

Sensor Calibration:

The first step is determining how well the sensor array/data-logger used in the field compares to ideal application in laboratory conditions. The purpose is to determine and quantify the signal degradation between the sensor array and data-logger. For ideal conditions, both the chloride and nitrate sensors were connected directly to a laboratory voltmeter. The potential was measured in solutions with nitrate and chloride concentrations between 10^{-5} and 10^{-1} mg/l, producing the ideal calibration curves for the sensors. The sensor array, connected to the data-logger to be used in the field was then tested on the same solution concentration ranges, and compared to the ideal conditions. The testing was conducted in the laboratory.

The results of the sensor calibration are shown in Figure 3.

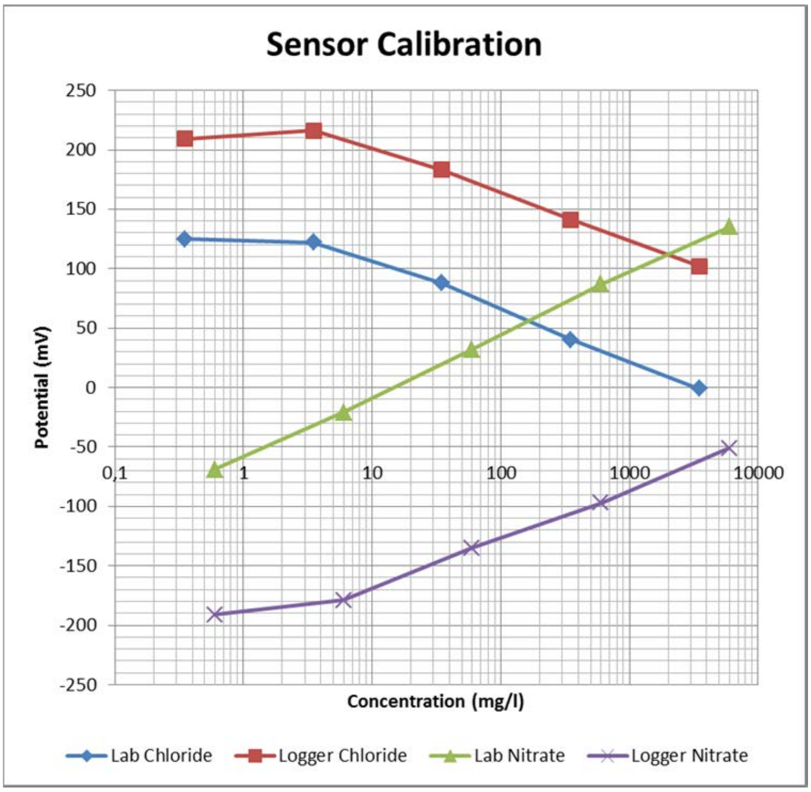

Figure 3. Calibration curves for the sensors before field application. Lab Chloride and Lab Nitrate show the curves for the sensors when connected directly to the voltmeter in the laboratory. Logger Chloride and Logger Nitrate show the curves for the sensors in the sensor array connected to the data-logger to be used in the field tests.

In this case, there was a 5 m cable between the sensor array and data-logger. For the chloride sensor, there was very little difference between the calibration curve for the sensors connected directly to the laboratory voltmeter and the sensor array connected to the data-logger. In both cases, the minimum concentration for detection was about 5 mg/l chloride, and the relationship of approximately 45 mV decrease in potential for every decadal increase in chloride concentration. This is slightly less than the Nernst ideal of 59 mV decrease per decade concentration. The chloride sensor was also tested with a 15 m and 25 m cable between the sensors and data-logger with similar calibrating results.

The nitrate sensor revealed a slightly degraded signal between the measurements from the laboratory voltmeter and the sensor array connected to the data-logger (Figure 3). This is, again, with a 5-meter cable. In this case, calibration curve for the nitrate sensor connected to the voltmeter had a response of just over 50 mV/decade concentration change, with a minimum concentration detection of under 0.6 mg/l. In contrast, calibration curve for the nitrate sensor on the sensor array showed a relationship of approximately 45 mV/decade, with a minimum concentration detection limit of 6 mg/l. In spite of the slightly degraded signal in the sensor array/data-logger setup, it is determined that the response is still good enough so that the sensor can be tested in the field.

Field Application – Surface Waters:

The sensor array with both nitrate and chloride sensors were tested in the field in two different sites. The first site tested the nitrate and chloride concentrations of treated wastewater right before it was released into a drainage canal. The test was conducted between August 31 and October 1, 2013 with a shorter follow-up two week test in November 2013. The second site was in a drainage canal near a pumping station, where flow was maintained by the pumping of water from the canal to the sea. Here the test was conducted between March 10 and May 14, 2014. A calibration of the sensors was conducted both before and after each test.

The results of the calibration of the sensors before and after the tests are shown in Figure 4. Before the testing in both the treated wastewater (Aug. 2013) and in the drainage canal (Mar. 2014), both the chloride and nitrate sensors had good responses at the same level as the calibration tests described above. However, at the end of the tests, neither sensor had any sort of response. Therefore at some point in both tests, the sensors became no longer sensitive to changes in either chloride or nitrate. It was observed at the wastewater treatment plant that there were snails attached to the sensors which could be a source of fouling and reduced sensitivity. Therefore a fine net was put over the sensor array for all subsequent surface water tests in order to help protect the sensor surfaces, but yet allow water to flow freely through the net. The second short test in November, 2013, however, fouling of the sensor surfaces still occurred, with the sensors unresponsive after just two weeks.

At the end of the tests, both the chloride sensor and reference electrode were able to be cleaned and reconditioned for use. The nitrate sensor, on the other hand, was not able to be reconditioned and had to be replaced after each test.

Because the sensors failed at some unknown point during the tests, it is impossible to evaluate the drift or noise from the sensors applied in the surface waters. Figure 5 shows a plot of the signal received from the sensors in the test near the pumping station in March to May 2014. The signal shows an unstable nitrate signal, however, the sensitivity for nitrate is higher because the concentration is so low (measured at about 3 mg/l). This is also at the lower end of, if not below, the sensitivity range of the sensors as determined in the initial calibration. Therefore the nitrate sensor, because concentrations are so low, is likely not responding to changes in concentration. This was also the case at the wastewater treatment plant, where nitrate concentrations were measured from samples to be 1 mg/l. Because the nitrate concentrations were very low contrary to expectations prior to monitoring, it is not possible to determine when the nitrate sensors stopped working.

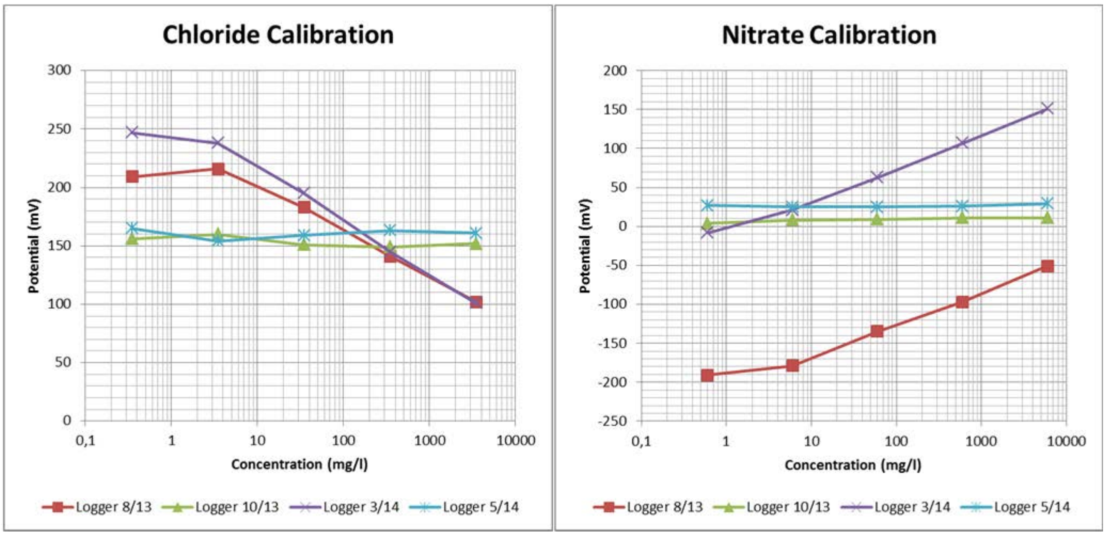

Figure 4. Calibration of the chloride and nitrate sensors before and after the surface water tests. Logger 8/13 shows the calibration before the wastewater treatment plant test (August 2013), with Logger 10/13 showing the calibration after the test (October 2013). Logger 3/14 shows the calibration before the pumping station test (March 2014) and the calibration after the test (May 2014).

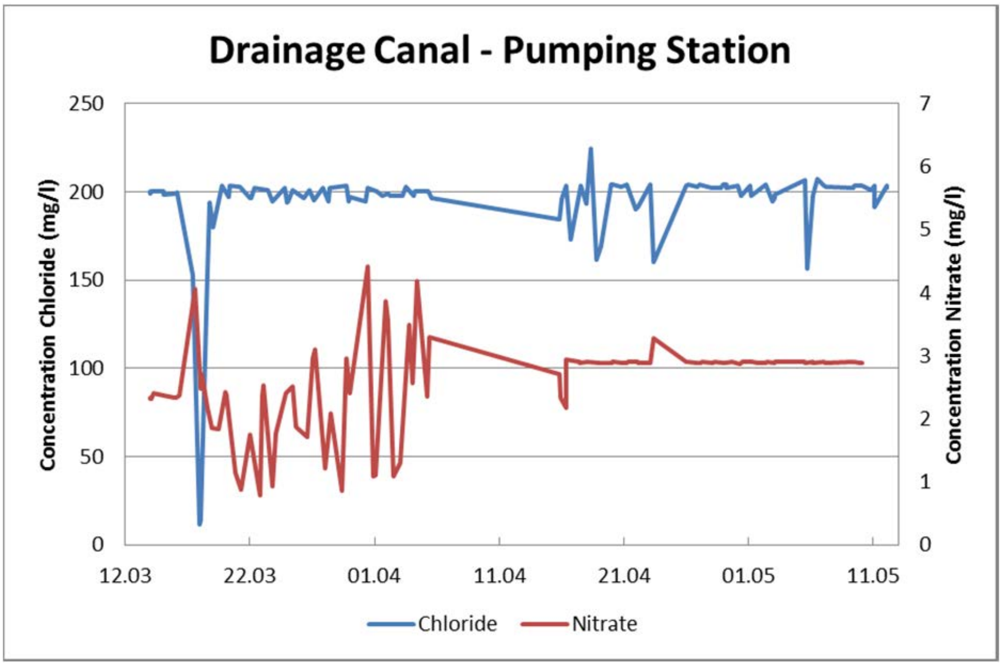

Figure 5. Chloride and nitrate measured with the sensor array and data-logger, as measured at the drainage canal near the pumping station between 12 March, 2014 and 11 May, 2014. Note that there is a 10-day period in the middle of the monitoring period where power to the data-logger was lost with the battery needing to be repaired.

In both tests, the chloride sensors had a more stable signal than the nitrate when applied in the surface waters. However, in both tests, as the monitoring progressed the chloride sensor became more unstable. This is illustrated in Figure 5, where the sensor was relatively stable before April 11, whereas afterwards it became much more unstable. Although it is impossible to determine, this could be the point when fouling made the chloride sensor unstable an unresponsive to the actual chloride concentrations in the surface water.

In summary for the surface water tests, it is clear that fouling is a problem. In all tests, both the chloride and nitrate became unresponsive to changes in concentrations. This is likely due to biological fouling of the sensing surfaces. It is not possible to determine how long the sensors remained responsive, but it is likely that the lifespan of the sensors in the surface waters is under two weeks (under the testing conditions of this study).

Field Application – Groundwater Monitoring Well:

The chloride sensor was applied in a monitoring well at Marielyst Waterworks. In this set-up there was a 15m cable between the sensor array and data-logger, with the sensors deployed at 14 m under the water table – close to the screen interval in the well. The sensors were deployed from the 26 September, 2014 to the 22 November, 2014. The sensors were calibrated both before and after the study, with very little difference between the two calibration curves (Figure 6). Thus it is clear that, unlike in the surface water, the chloride sensor remained responsive through the entire deployment period.

The signal received from the sensors was also stable (Figure 7). The chloride concentrations as measured from the sensors was seen to decrease from 272 mg/l on September 26 to 263 mg/l on October 15; a decrease of 9 mg/l. Noise in the signal was also low, less than the equivalent of 2 mg/l chloride concentration. Samples taken from the well at the start of the deployment and on October 17 showed a chloride concentration of 272 mg/l and 275 mg/l respectively. A third sample taken on November 22 had a concentration of 266 mg/l showing that there was very little change in chloride concentration in the monitoring well. Assuming a stable chloride concentration throughout the test, the sensors had a drift of 12 mg/l over the period between September 26 and October 15, with an average drift of -0,6 mg/l per day.

It should be noted that after October 15, there were technical problems with the data-logger. The power and signal from the logger became unstable, even after repairs were made. The signal was received sporadically after October 15, with the data-logger ceasing to function at all after November 17. Therefore, there is no logging data for the sensors after October 15 which could be used to assess the drift and stability of the sensors after October 15, 2014.

In summary, the chloride sensor deployed in the groundwater well performed very well. The signal received when the data-logger was working (over 20-days) was stable, with drift a relatively steady -0.6 mg/l per day. Calibration tests showed that sensors were just as responsive after the 2-month deployment as they were before deployment.

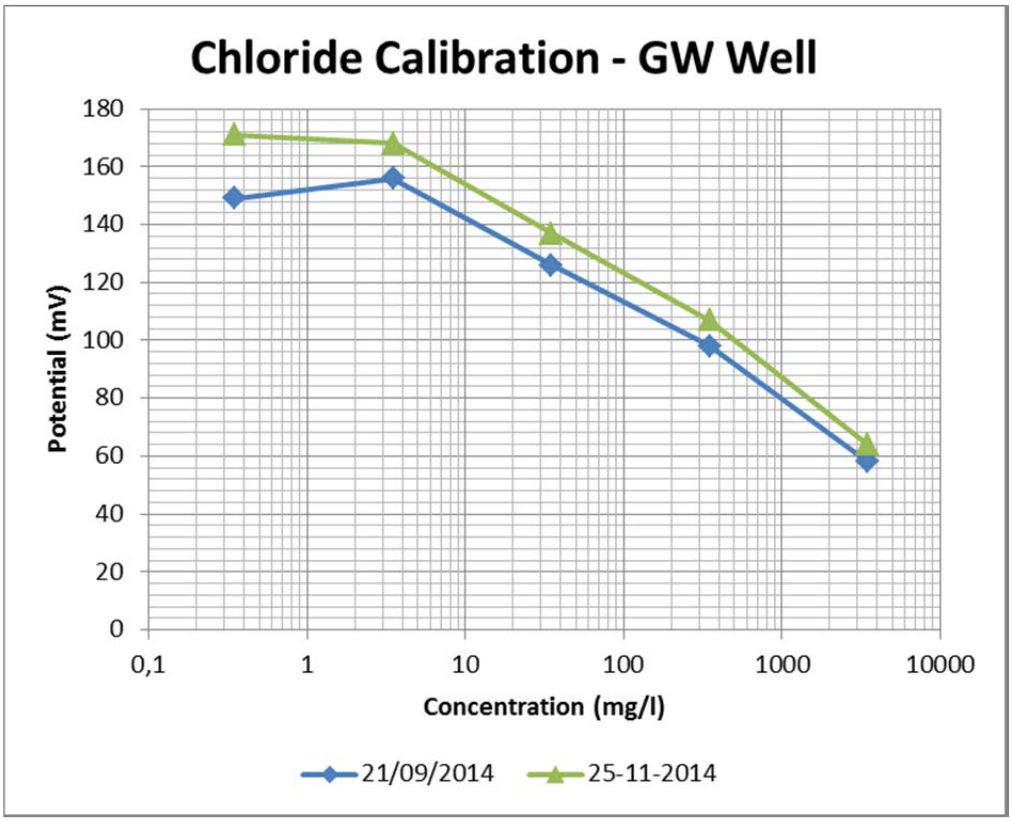

Figure 6. Calibration of the chloride sensor before and after deployment in the groundwater monitoring well at Marielyst Waterworks.

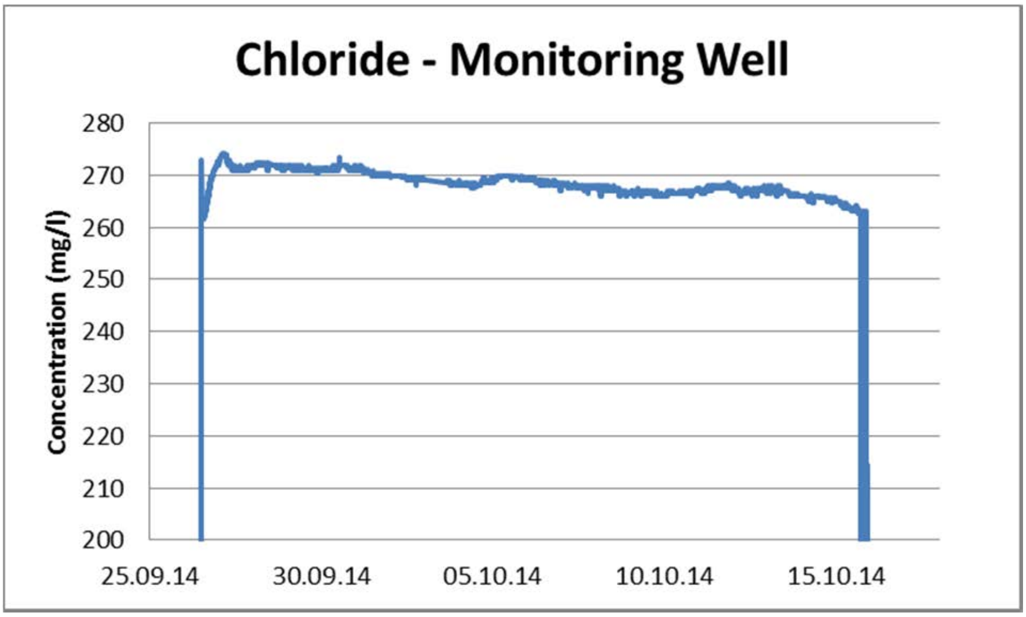

Figure 7. Signal response from the chloride sensor. Note the low measurement in the beginning shows when the sensors were deployed and turned on. The low measurements just after 15 October shows the time when the data-logger started to malfunction.

4.4 Data collection and transfer

Data was gathered and transferred with the data-logger from Comsystem (www.comsystem.dk) with GPRS capabilities. The data transfer is relatively simple. The data-logger registers the measurements from the sensors, being both temperature and potential in mV. The measurements are digitized and stored in the data-logger memory. At one-hour intervals, the data logger connects to a GSM network and sends the data to a specific IP address which receives the data and processes the data (the data processing is presented in chapter 5).

For the study, mobile internet capabilities were provided by Telenor, which had very good GSM coverage at all three test sites. There was maintained a strong mobile signal, providing stable data transfer and connection with the data-logger, when it was in operation.

The study is a field-based study, and the data-logger was located next to the stream/well which was being monitored. The data-logger was not connected to an electrical net, with batteries supplying the needed power to run the system. The data-logger and batteries were sealed in tight aluminium casing allowing the electronic equipment to withstand the differing weather conditions, including rain and low temperatures – according to the manufacturer, the logger should be able to continue operation at temperatures below -10° C.

The operation of the data-logger at the test sites turned out to be less stable than advertised. The longest period of continuous data transfer was just under one month. Difficulties with the data-logger included failure of the battery and shorting out of the electronics in the system. Particularly sensitive was the system measuring potential from the sensors. The battery supporting the sensors proved to be extremely sensitive to the humidity, often shorting out in spite of efforts to remove humidity from the casing. The electronic system also shorted out twice, prompting the need for repairs of the data-logger. The reasons for this are unknown, but likely due to sensitivity to changing atmospheric conditions (cold and humid conditions). In the end, the data-logger proved to be unstable in the Danish test site, causing only sporadic data collection and monitoring over shorter periods than what was originally planned. Further work in future projects are needed in order to sort out the problems, and develop systems, which does not require maintenance for a period of at least one month.

5. Data handling and data information technology

5.1 Data upload and handling

The data loggers send data via GPRS to a server. The server is identified with an IP-number and a port-number, which has to be programmed into the data logger. Data are send using the TCP-protocol and ComSystem A/S (www.comsystem.dk) delivers a client program that can listen for data and write them to a text-file when they are received. If this program is not running on the server, the data is lost. The program has to be started manually and cannot run as a service, which is not optimal. Whenever the server reboots due to automatic updates the programme needs to be restarted.

We developed a small service that parsed the text-files whenever new data arrived and forwarded the data to a cloud database (SQL Azure). On top of the database we had a service layer (HydroInform.CloudApp.Net) through which data could be accessed from web-clients. Thus, there is no direct access from outside to the database. Furthermore we have developed a small service that can get data via the service layer and transfer it to a SiteFx database (see section 6.1). The data flow is illustrated on figure 8 below.

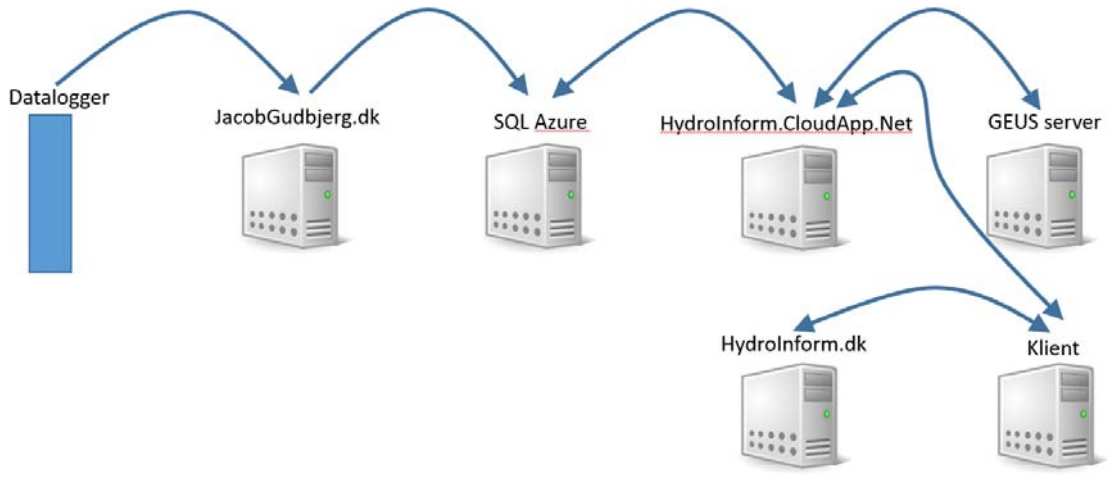

Figure 8. The data flow from logger to web clients.

The data flow Figure 5.1 may seem overly complicated; however, with this architecture the individual components are not interdependent. This means that we can for instance make changes to the database without changing the rest of the system. Adding new types of data from other dataloggers would also just require that a parser was made that could send data into the underlying database.

Note also that there is no significant time delay in this system. Within the same minute data are send from the logger it is available on the web page.

5.2 Data information technology

We have developed a website where all measured sensor data are available, and can be visualised. A screen dump is shown on Figure 9 below. In the graphs it is possible to zoom in on selected time intervals. When zooming in more data is displayed. Data are only send from the server when necessary. This advanced technology is necessary because the loggers may run for several years collecting data every minute. Downloading all data every time the web page is accessed would make the system increasingly slow. Thus, we have developed a system that can display huge amount of data very fast. From the graph it is possible to download the data directly. Examples can be seen on www.hydroinform.dk.

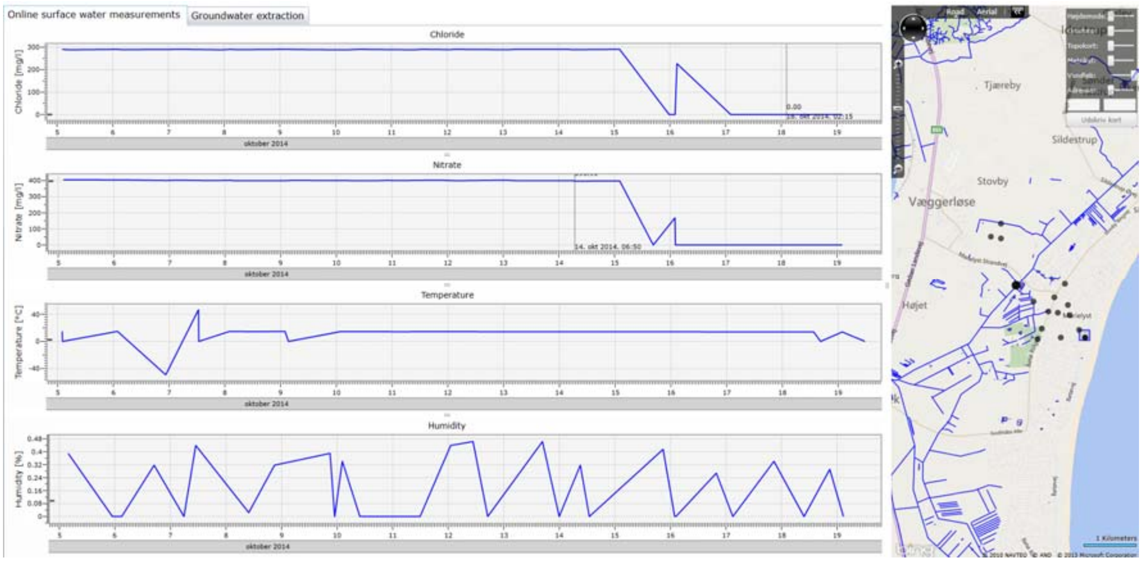

Figure 9. Screen dump from webpage displaying online data from sensors and selected datalogger.

6. Data integration and interaktive webserver

6.1 Data integration and databases

The final presentation of data relies on multiple data sources that are brought together for joint presentation. The source data are divided into regular relational databases and a few Web Map Services (WMS). The available databases are SiteFX (see section 5.1 for input instructions), Gerda and Jupiter.

SiteFX store all types of geological and environmental data, either static or time variant. A procedure for populating data from the sensors described in section 4 was developed as a part of this project (see section 5.1 for input instructions) and is fully operating when sensors upload data as described.

Jupiter is the Danish national well database storing information regarding well construction, geology, water levels, water chemistry and water quality from water works. The brand new tool, DBSync, for continuous update of the entire Jupiter database for external users (consulting companies, drillers, authorities etc.), has been applied in this project in order to keep the foundation continuously updated without manual interference.

Gerda is the Danish national geophysical database containing many types of geophysical data (airborne and surface em, wireline logs etc.) . The entire database serves as the source data foundation but only results of the down-hole logs are presented on-line for the end users in fixed pdf plots. Gerda is updated manually on a monthly basis.
Background maps using the WMS technology include, public maps from the Danish Cadastre (the Danish Geodata Agency), soil maps from GEUS (1:200´000) and Orthophotos (corrected aerial photographs) from COWI.

6.2 Data visualization on interactive webserver

Once the source data foundation is secured (section 6.1), read application tools (Figure 10) can be used to access the relevant data from different databases and organisations in various ways. The interactive web based tool EacoWeb developed by EarthFX Inc. (www.earthfx.com) is used to present relevant data defined by the user from within the project area. A homepage has been developed and can be accessed from:

https://eacoweb.cowi.com/water4coasts/
UN: water4coasts
PW: w4c-14

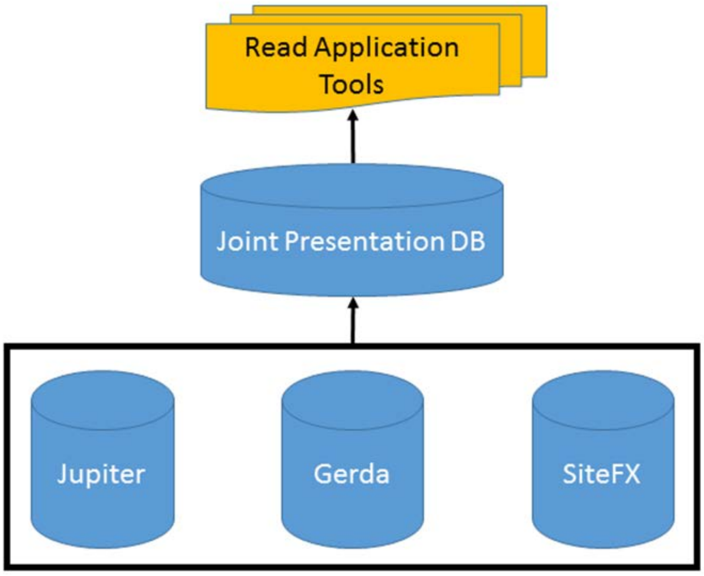

Figure 10. Illustration of source data integration from different databases.

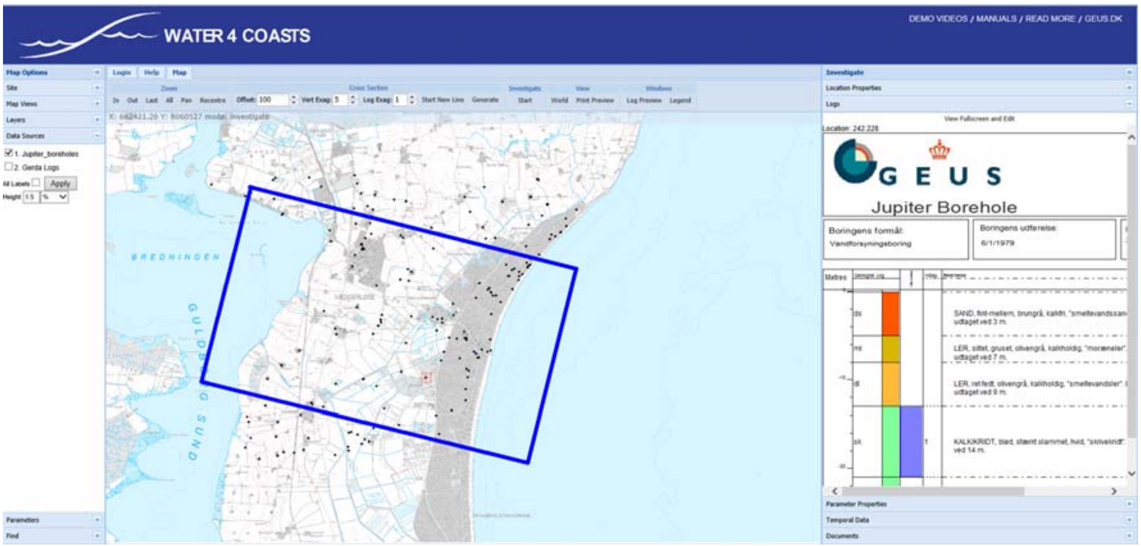

Figure 11. Screen dump from Water4Coasts interactive webserver displaying the project area as well as a geological log from a selected well in the Jupiter database.

It is a project specific homepage for the Water4Coasts project only and can contain multiple sites even though only the Falster (Denmark) case is available at this time.
Data outside the project area is available but merely filtered out. All data presented through EacoWeb are always up-to-date because it is extracting data from a data foundation that is continuously updated.

6.2.1 Functionality

At the left site under Map Options, it is possible to browse and enable different data.
Site and *Map view* is given, as there is only one.
Layers contain three different background maps, Orthophoto, soil map and a colour scale presentation of wells having water level and chemical sampling.
Data sources contain Jupiter boreholes and Gerda Logs. It is possible to enable a label for active Data sources from the tick mark box and manually scale the size of the label.

From the top bar at the left, it is possible to zoom and pan in various ways

In the centre of the top bar, it is possible to draw cross-sections through wells for further inspection of the geological logs.

For further investigation of a desired borehole (Location) use the Investigate→Start button from the top menu that will activate the Location properties Investigation menu at the very right of the homepage.

Investigate Functionality:
Location Properties display some selection information regarding the selected borehole.
Logs Display a log of the borehole together with screen position. For Gerda logs, it will display the selected parameters Gamma, Conductivity, Resistivity and Caliper. By pressing *View Fullscreen and Edit*, a new window opens where it is possible to adjust the scale of the parameters in order to get a better view of the data.
Temporal data is of specific importance to this project because it is possible to display temporal data as groundwater chemistry and water levels as graphs or tables. When data are plotted on graphs it is furthermore possible to include different parameters from the same or different boreholes on the same graph. More help is available on-line at the eacoweb website: https://eacoweb.cowi.com/water4coasts/.

Figure 12. Graphing capabilities in EacoWeb, where data sets from different parameters and even different boreholes can be investigated online on the same graph.

7. Discussion and perspectives

One primary obstacle encountered in the monitoring of chloride and nitrate with the ion selective electrodes was fouling of the electrodes when monitoring in the surface waters. Analysing the data, it is not possible to see how long the sensors remained responsive in the surface waters. However, it seems apparent that they were responsive for less than two weeks. This is not a satisfactory length of time if the objective is to monitor concentrations over longer periods. It is also apparent that fouling affected all three electrodes – the nitrate, chloride and the reference electrode. The fact that fouling affected all three electrodes in less than two weeks was disappointing. The prevention of fouling of the sensing surfaces will need to be improved upon in order to establish a more effective monitoring system.

On the other hand, the sensors when applied in the monitoring well seem to be more robust and not affected by fouling. By measuring down in the monitoring well, the system is isolated from biological activity, and thus the sensing surfaces on the sensors were not degraded at nearly the same rate as in the surface waters. Thus the potential for long-term monitoring down in wells is very promising. However, when measuring for changes in monitoring wells, the sensors should be located as close to the screen as possible to be sure that the water being monitored is representative of the aquifer. There should also be assured that water is flowing through the well, and not just stagnant. If possible, it would be ideal to apply the sensors in a well that is being pumped from – this will provide the most representative monitoring. However, if pumping from the wells, it will need to be certain that the wires and sensor array do not get caught up in the pumps themselves.

Because of the simple silver surface of the chloride electrode and the glass membrane of the reference electrode, it was possible to recondition both electrodes after fouling allowing them to be reused. This, of course is important with regards to overall life-span of the electrodes, making it more economical in the long run. However, the membrane on the nitrate electrode was more susceptible to degradation and needed to be replaced. If the membranes of the electrodes need to be replaced often, this can become costly, both in terms of time and money, and make the sensors less attractive to use.

When the data logger was able to send the signal to the server, the system worked very well. The website established for the system was able to display the monitored concentrations in real-time. A simple formula using Nernst Law was able to convert the signal (in mV) being sent from the data logger to actual concentrations, and displayed directly on the website. Thus by simply accessing the website, you can have a complete overview of the monitoring as it is happening. Using the mouse to scroll in and out allowed for a quick and easy adjustment of the time-scale one is looking at the data from, allowing to see data from the entire monitoring period to the last day in just seconds. In addition, the downloading of data from the website to a text file was very simple, being just a right click with the mouse. This allowed for the data, as displayed on the website, to be downloaded over the wanted time frame and quickly loaded into programs such as Excel, where it can then be processed even further.

Traditionally, when data loggers are used in the field, they have to be connected via cable to a computer in order to retrieve the data. This means having to physically go to the field to download the data at certain intervals. Therefore, even though data is being continuously collected, it cannot be seen until it is downloaded. In addition, if the system stops working, there is no way of knowing when it stops until the fields site visit occurs. Having the data transferred automatically from the data logger to a server via GPRS has the distinct advantage of not only being able to access the data being collected in real-time, but seeing straight away if the system starts to have problems. This advantage was illustrated very nicely in this study – it was known within less than 24 hours every time the data logger lost power or stopped operating properly. This allowed for the site to be visited and the logger to be fixed. Unfortunately in this case, the data logger proved to be very unstable and much of the monitoring time was lost anyway in the numerous attempts to fix the logger. In a fully operating system the real-time uploaded data can be used in the automatic control of pump yields etc. at water works in a fully automated SCADA (Supervisory Control And Data Acquisition) system. The project group will in collaboration with new Danish SMEs continue to develop such tools in an up-coming EU project on subsurface water solutions developed to control salt water intrusion in coastal aquifers.

8. Recommendations and conclusions

8.1 Sensor Development

More work still needs to be done in order to use the sensors in surface waters. The test showed that both nitrate and chloride sensors had a limited lifespan in the surface waters that were tested in this study – likely no more than two-weeks. Further studies need to be conducted looking at preventing fouling of the sensing surfaces and reference electrodes under different conditions when monitoring in surface waters.

The study shows that there is a good potential use for the sensors directly in groundwater monitoring wells. Even after two months in the wells, the chloride sensors remained sensitive to changes in chloride concentrations. Further development in the applications will be to test how long the cable between the sensors and data logger can be, so that it would be possible to monitor even deeper in the well. The sensors should also be tested in wells where there is a known change in concentrations to determine whether or not the sensors can pick up the concentration changes. Further tests in e.g. active water supply wells with monitoring of the specific electrical conductivity and frequent chloride analyses are recommended.

When applying the sensors directly in the field, the data logger which measured the potential differences from the sensors, proved to be more sensitive to the changing weather conditions than other applications such as monitoring of temperature, pressure and humidity, which the manufacturers of the data logger conduct successfully. Therefore further testing must be done in order to get a more stable data logging and data transmission capabilities for the more sensitive potential measurements from the ion selective electrodes. It should be noted that a data logger from only one manufacturer was tested, and that there may be other more stable options available.

The project group recommend to improve the collaboration between public and private partners within water research and innovation for continued research on improved sensor, data logging and transfer technologies to be used for the development of efficient supervisory control and data acquisition (SCADA) systems, as well as online and interactive data visualisation, for optimized assessment and control of salt water intrusion and sustainable management of coastal freshwater resources.

8.2 Enhanced use of data integration strategies and EacoWeb data presentation

International projects where data are used in between many organizations will benefit greatly from a centralized approach to structuring of their source data in order to ensure a single version of the data and one entry point for the data. EacoWeb possess great possibilities for presenting the source data in different ways and much functionality have not been explored as a part of this project. Mobile Sample Manager (MSM), a field access tool for the SiteFX database is one tool that was considered to be used but not applied due to the basic challenges with the loggers. MSM include field upload of data as well as access to the source from the field. Powerful visualization capabilities for geological models as well as any other gridded data could also further enhance the user experience and interpretation capabilities when using EacoWeb if such data were added to the project. Finally, EacoWeb is also used to store large document archives of georeferenced data such as reports, photos, drawings etc. that all can be geocoded and displayed on the map as well as downloaded for subsequent use at the will of the user. We recommend that the work on such tools is continued and the tools continuously improved for efficient and sustainable management of the quantity and quality of the global water resources (Scharling et al., 2014).

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