Final Report: Brilliant Marine Research Idea 2018

1. General information

Title of the idea	Delineating the area where submarine groundwater discharge occurs in the Belgian coastal area
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2. Brilliant Marine Research Idea – Report about the activities

Abstract

In this research idea, we use a combination of surface geophysical methods [frequency domain electromagnetics (FDEM), electrical resistivity tomography (ERT), and marine ERT] to assess submarine groundwater discharge (SGD) in front of 'De Westhoek' and the dunes East of Wenduine. Both sites give us two extremities seen at the Belgian coast: we find a wide dune belt at the former, while the latter contains only a narrow belt. SGD contains fresh groundwater flowing from the land towards the sea on one hand and seawater which recirculates in the seabed, this results in a brackish quality of the discharge. SGD can be visualized by imaging the salt and freshwater distribution through geophysical investigation of the area, since freshwater (high resistivity, low conductivity) can be distinguished from salt water (low resistivity, high conductivity).

Intro

Coastal areas around the world are vulnerable and densely populated. The proximity of salt water can lead to saltwater intrusion in coastal aquifers. While groundwater – sometimes contaminated – can directly discharge into near-shore environments as submarine groundwater discharge (SGD). This phenomenon probably plays a more important role in the contribution of nutrients, carbon, and metals to oceans and seas than rivers (Moore, 2010). It is, therefore, important to study the quantity and quality of the discharge and to assess the processes affecting SGD.

In the Belgian coastal area, tourism puts enormous pressure on drinking water supplies, especially during July and August. In the dunes, the phreatic aquifer consists of a freshwater lens, formed by infiltration of rainwater. This shallow potable water is, however, surrounded by more saline or brackish water (which we find at a relatively shallow depth on the beach and in the polder area), risking salinization if badly managed. Also, part of this valuable freshwater flows towards the sea. Van Camp and Walraevens (2004) estimate that around 60% of the recharging freshwater in the Belgian dunes flows to the North Sea as submarine fresh groundwater discharge (SFGD), when no groundwater extraction sites are present in the dunes.

The Belgian dune belt is not continuous, it is fragmented by many urbanized zones. Also the width of the dunes varies, we find the widest dunes at 'De Westhoek' (West of De Panne). While, the dunes East of Wenduine are very narrow. The wider the dune belt, the bigger the freshwater lens underneath, probably leading to a larger discharge. Previously, SGD has only been described at 'De Westhoek' (West of De Panne) by using well logging (Lebbe, 1981), heat transport studies (Vandenbohede &

Lebbe, 2011), and hydrogeological modelling (e.g. Lebbe & Walraevens, 1988; Vandenbohede & Lebbe, 2006a, 2006b; Vandenbohede et al., 2008).

The "*Brilliant Marine Research Idea*" was used to expand the geophysical survey, needed in the preliminary step of my PhD (assessment of SGD and saltwater intrusion at the Belgian coast). Fieldwork started in February 2018. First, the beach was investigated (from the low water line towards the dunes) using frequency domain electromagnetics (FDEM) and electrical resistivity tomography (ERT). Both techniques are used to determine the conductivity (FDEM) or resistivity [= conductivity^{-1}] (ERT). SGD also occurs below the low water, so a marine ERT device was rented (made possible thanks to the "*BMRI*") to investigate the resistivity of the seabed sediments.

Material & Methods

The zone of investigation is at the limit between the terrestrial and marine realms, which makes it difficult. The semi-diurnal tides limit the measuring time at the lower beach. And for the data collection at Wenduine, we were limited by the presence of breakwaters on the beach.

Electromagnetics

Two different FDEM devices were used to map the conductivity. This technique uses a primary EM field, induced by a transmitting coil. The latter induces currents within the Earth, causing the creation of a secondary magnetic field. A receiver coil then measures both primary and secondary EM fields and deduces the conductivity.

Both FDEM devices are relatively easy to use and can quickly measure data. This is necessary in the intertidal zone, since the tides allow us only a short time span for data collection. First, the CMD-MiniExplorer (GF Instruments) was used (at 'De Westhoek' and Wenduine), a small device, operated by one person. It gives us information on the upper 2 m of the subsurface. Also, the DUALEM-421S (Dualem Inc.) was used at 'De Westhoek', which obtains a larger investigation depth (up to 6 m). But it does have to be pulled by a quad.

Electrical resistivity on land

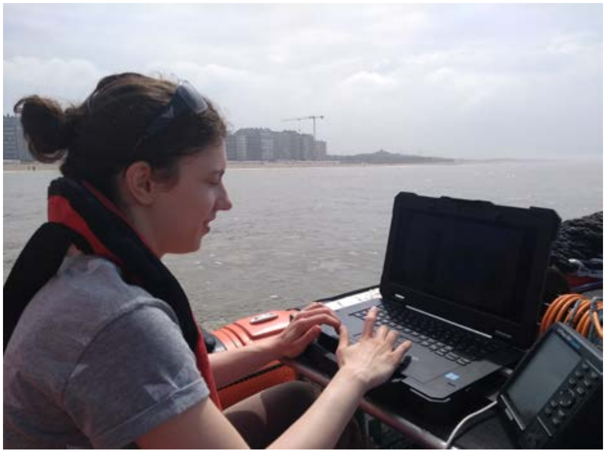
For ERT, we inject electrical current in the soil using 2 current electrodes, while we measure the resulting potential difference between 2 other electrodes. We then deduce the resistance by using the formula $R = \Delta V/I$ (Ohm's law); where R is the resistance, ΔV the potential difference, and I the current intensity. By using different electrode locations, we obtain many resistance measurements which make it possible to compute the resistivity distribution of the subsurface. Resistivity gives us information on how easily the electrical current can flow through the subsurface. For example: salt water contains many ions which will transmit the current more easily, leading to a low resistivity (or high conductivity).

The Terrameter LS (ABEM) was used for the ERT survey on land. We could obtain very long profiles (over 600 m) by using a roll-along technique with this instrument. A spacing of 5 m between the different electrodes gave enough depth in which the current could penetrate (up to 40 m). And the resolution is good enough to clearly visualize the salt and freshwater distribution from the low water line up the dunes. Resistivity profiles were measured both perpendicular (illustrated by figures 1 and 3) and parallel to the sea. We used a multiple-gradient arrangement of the current and potential electrodes, since it allows a relatively fast data acquisition speed (e.g. Dahlin & Zhou, 2006), which is needed on the lower beach.

Marine electrical resistivity

For the marine ERT survey, we hired the Syscal Pro Deep Marine from IRIS Instruments (Orléans). This is a continuous resistivity profiling (CRP) device, which allows us to collect data continuously and relatively fast. The instrument works similar to the land ERT system, but uses a 195 m long floating cable with 2 fixed current electrodes and 11 potential electrodes. They are spaced at an interval of 15m, because we need deeper penetration compared to land ERT, since part of the injected current is lost in the seawater (due to its conductive nature). We used a reciprocal Wenner-Schlumberger configuration (a certain fixed arrangement of the electrodes), allowing a simultaneous collection of 10 data points for each current transmission. The injected currents were between 35 to 37 A, which might seem high, but is needed to have enough current penetrating into the seabed.

"De Zeekat" – a small rigid inflatable boat of the Flanders Marine Institute (VLIZ) – was used to tow the cable, this was done with a relatively constant speed of around 3.5 km/h. While moving, data was collected continuously for as long as the streamer lay in a relatively straight line. The highly conductive seawater layer does have a large influence on the signal, so a correction is needed. Therefore, bathymetric data was gathered using a Garmin GPSMAP 188 Sounder system that was directly connected to the Syscal unit. And, also, seawater conductivity was separately recorded with a CTD-diver (Eijkelkamp).



The Syscal was rented for 2 full weeks, but was only used on 2 days (30 and 31 May 2018), due to bad weather conditions (fog, high waves,...). Even though this was a setback, we were able to gather a lot of data. On the 30th, 5 different profiles were collected at 'De Westhoek'. Three parallel to the coast and 2 perpendicular (of which 1 at the French-Belgian border and another 1 km East of the border). The 31st, we sailed to Wenduine, obtaining 2 parallel and 2 perpendicular profiles (in front of the city and the dunes East of Wenduine).

Afterwards, inverse modeling of the data was done in the RES2DINV software of Loke (2011). For this we had to include the bathymetric data and seawater resistivity. However, we encountered some problems with the bathymetry. First of all, there was a lot of noise (due to the rocking of the boat) which had to be filtered. Then, there turned out to be a systematic error in the bathymetric data (probably caused by some default in the echosounder). By comparing the overlapping land and marine data, the bathymetry was estimated to be 5 m too deep. Therefore, all profiles where corrected with this factor.

All marine data was acquired during high tide, to ensure a good overlap with the profiles on land. The overlap is good at 'De Westhoek', but was not obtained in Wenduine. Mostly due to the difficulty of sailing between breakwaters with a 195 m long cable behind the boat, which hindered us from nearing the beach even further. The plan was to also obtain measurements during low tide. At that moment, the salt water column is less thick, decreasing its influence on the signal, and increasing the resolution of the data. But there was no time for this (due to above mentioned reasons).

Results/Conclusions

'De Westhoek'

Land ERT data show that a freshwater lens (blue) is present in the dunes of 'De Westhoek' nature reserve (figure 1). Also, a tongue – of fresh/brackish water (blue/green/yellow) – arises from this lens and reaches towards the sea. On the beach, there is a large saltwater lens (red) on top of the tongue, which is formed by infiltration of seawater during high tides. The thickness of the saltwater lens decreases from the middle to the lower part of the beach.

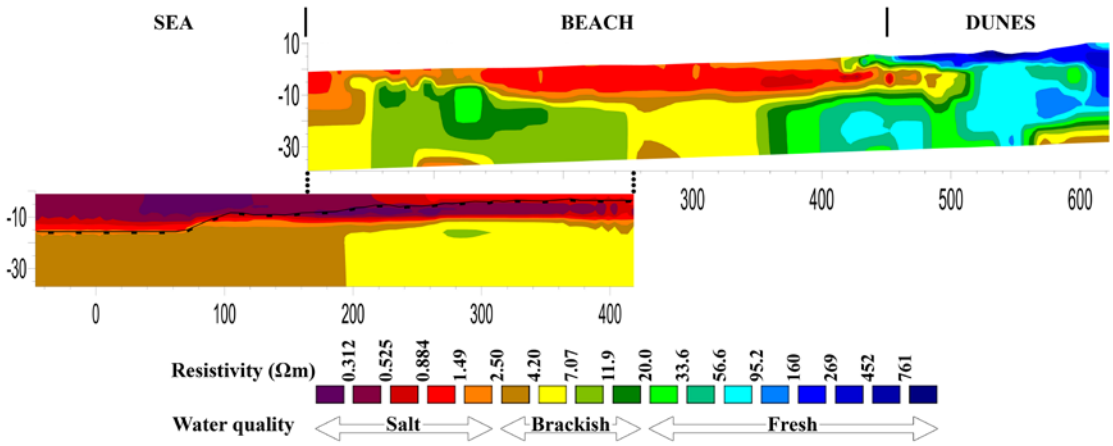


Figure 1: Marine (bottom) and land ERT (top) profiles at K1, located 1 km East from the French-Belgian border. The black line shows the seabed on the marine profile.

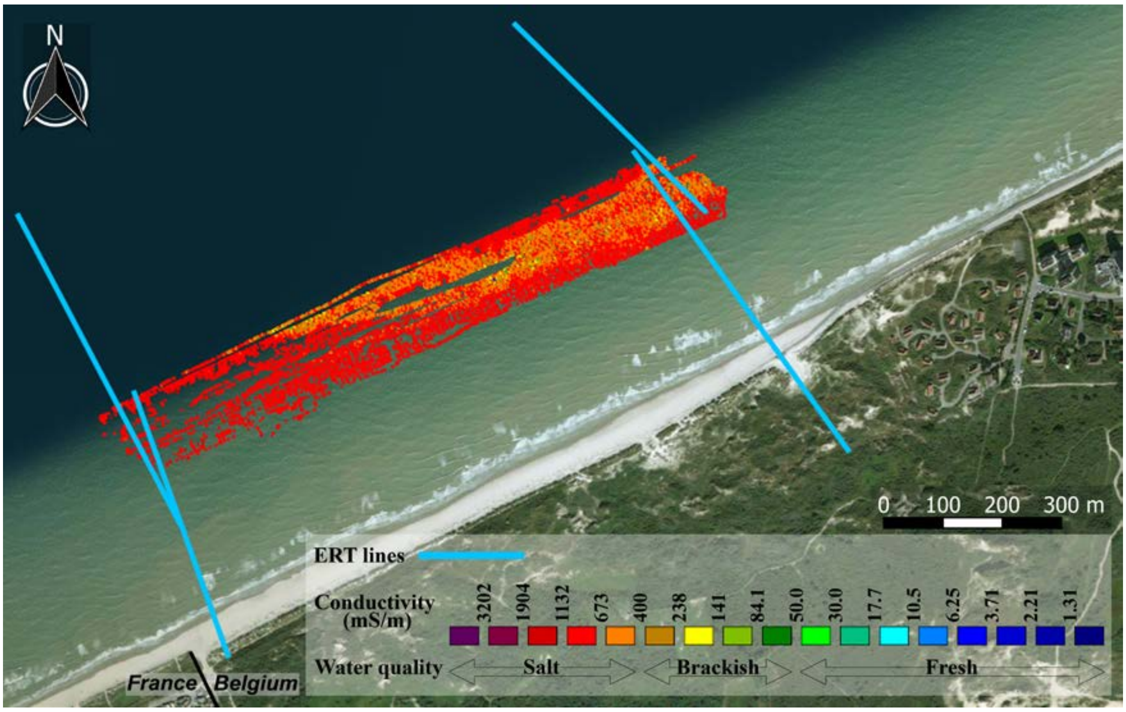


Figure 2: FDEM data at a pseudodepth of 6 m, obtained with the DUALEM-421S, displaying outflow of groundwater (orange/yellow) between the French-Belgian border and 1 km East (towards De Panne). The locations of the ERT lines on figures 1 and 3 are shown in blue.

At 1 km from the French-Belgian border (K1, figure 1) and in front of the city of De Panne, we see the outflow of SGD close to the low water line. The location is visible on both land and marine ERT profiles. The former shows a rise of the brackish/freshwater tongue at the low water line, with outflow of weak salty to brackish water. While the latter displays brackish water (yellow) (figure 1) on exactly the same location. At the border (K0), the zone of discharge is not visible on the beach. Here, SGD can only be seen on the marine data, since it is below sea level.

The FDEM data (figure 2) clearly displays the shift of the zone of discharge towards the North at a pseudodepth of 6 m, from K1 (figure 1) to K0 (at the border). The measurements, taken in September, do not show the presence of discharge above this depth very well. Whereas SGD is visible at the surface on the K1 land ERT profile (obtained in March), while all measurements where started at the lowest tide. This comparison proofs that there is a seasonal variation in the quantity of fresh groundwater discharge, being stronger in winter/spring than summer/autumn.

<u>Wenduine</u>

The dunes of Wenduine are narrower, leading to a much smaller freshwater lens underneath, compared to 'De Westhoek'. There is no SGD on the lower beach of Wenduine, but freshwater might discharges at the foot of the dunes, on the highest part of the beach. In front of the dunes, a salt water lens is clearly visible on the beach. At 40 m depth, a brackish water flow (brown) can be seen underneath, originating in the dunes. And on the marine profiles (perpendicular to the coastline), outflow of brackish water is visible in front of the dunes and the city of Wenduine.

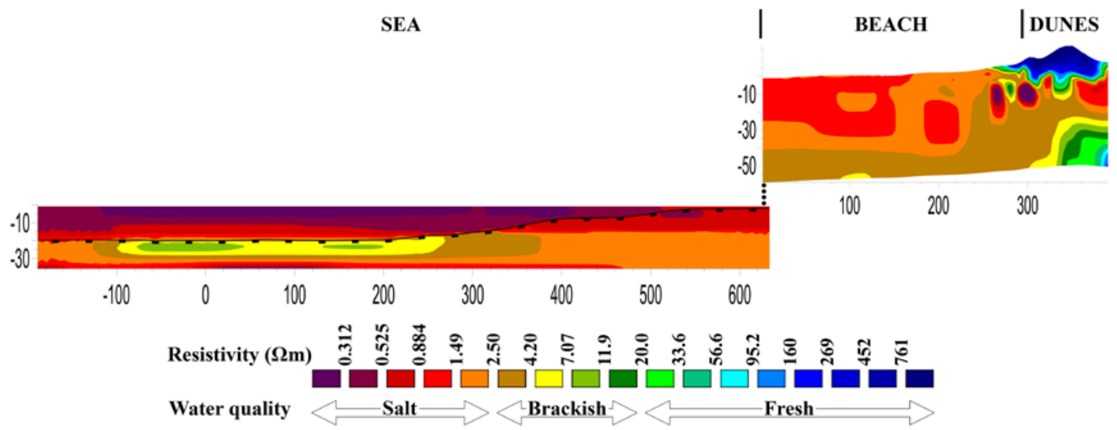


Figure 3: Marine (bottom) and land ERT (top) profiles, located in front of the dunes between Wenduine and Blankenberge. The black line shows the seabed on the marine profile.

These first results show that geophysics can be used to locate SGD. By combining (marine) ERT and FDEM, we can visualize the salt and freshwater distribution from the near-shore up to the dunes. These geophysical methods are very easy to use, which is perfect in this difficult environment. They provide us 3D visualization of the subsurface's resistivity/conductivity. By knowing exactly where to find SGD at 'De Westhoek', we can focus on this zone for future evaluation of the discharge by using other techniques (e.g. analysis of water samples, natural isotopes,…). And at Wenduine, additional marine ERT data (measured at low tide) is needed to better understand the brackish lens underneath the sea bottom.

This work could not have been possible without the help of many people. We would like to thank the *Research Group Soil Spatial Inventory Techniques* of Ghent University, and in particular Daan Hanssens, Philippe De Smedt, Valentijn Van Parys, and Anja Derycke. We also would like to acknowledge the *Applied Geophysics* research unit of the University of Liège for loaning us the Terrameter and MiniExplorer. And finally, special thanks to Jan Vermaut and Tim Deckmyn, and the entire VLIZ for providing logistical support in the marine survey.

If you want more information look out for Paepen et al. (in progress).

References
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3. Overview of the expenditures

Describe in detail how the requested fund was spent within the implementation period (1 March 2018 and 28 February 2019). Be as specific as possible.
The money was spent on: 1) The rental of the Syscal Pro Marine (IRIS Instruments) during 2 weeks; including a marine cable (13 outputs and 15m spacing), a Garmin GPS with echo sounder, the Sysmar software, and transportation costs from Orléans towards Ghent. **€ 3,312.98** 2) The purchase of 4 car batteries, which supply the power for the marine resistivity measurements. **€ 707.77** 3) Reshipment of the marine system to Orléans. **€ 574.75** 4) Transportation costs (to and from the Ostend; on 29, 30 May, 1, and 6 June). **€ 286** 5) Transportation costs (to and from the Nieuwpoort; on 30 May). **€ 88** Total amount = **€4,969.50**