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FRESH-SALT WATER DISTRIBUTION IN THE CENTRAL BELGIAN COASTAL PLAIN: AN UPDATE

Alexander VANDENBOHEDE[1], Carolien COURTENS[1], Luc LEBBE[1] & William DE BREUCK[2]

(5 figures)

1 Research Unit Groundwater Modelling, Dept. Geology and Soil Sciences, Ghent University, Krijgslaan 281 (S8) 9000 Ghent, Belgium. E-mail: alexander.vandenbohede@ugent.be
2 Faculty of Sciences, Ghent University, K. L. Ledeganckstraat 35, 9000 Ghent, Belgium

ABSTRACT The 1974 map showing the depth of the fresh-salt water interface (defined by 1500 mg/l total dissolved solids concentration) in the Belgian coastal plain is a vital document for hydrogeologists. Since its publication, new data have been collected. These comprise water quality analyses and borehole measurements ordered by the Flemish Environmental Agency, the Flemish Land Use Agency or from dissertations and new lithological data synthesised by the HCOV (Hydrogeological Code Flemish Subsurface) mapping. The aim of this paper is to compare the new information with the 1974 map and provide an update for the central part of the Belgian coastal plain. This resulted in only minor differences. The main adjustments are the identification of a number of additional areas where the phreatic aquifer is completely filled with fresh water, incorporation of insights of the groundwater flow system in the dunes, shore and sea and, some small changes in the position of transition zones between fresh-water lenses and adjacent areas where salt water occurs at very shallow depth. The general conclusion is that comparison with new field data obtained in the more than 30 years after its publication, confirms and strengthens the validity of the map.

KEYWORDS: fresh-salt water interface, water quality data, water quality map.

1. Introduction

A complex fresh-salt water distribution occurs in the phreatic Quaternary aquifer of the Belgian coastal plain. This distribution is the result of the recent geological evolution and human intervention in the area. Examples of the former are sea level rise, palaeomorphological changes, sediment supply and creation of accommodation space (Baeteman, 1985, Baeteman et al., 1999). Examples of human interferences are historic land reclamation, evolution of drainage patterns, presence of large canals and groundwater extractions.

Knowledge of the fresh-salt water distribution is for obvious reasons (agriculture, ecohydrology, water extraction etc.) of the utmost importance. In the late 1960s/early 1970s a systematic geo-electrical survey was undertaken (De Breuck & De Moor, 1969, 1972) to map this fresh-salt water distribution. More than 1700 resistivity soundings were performed. This survey was supplemented by water analyses of samples taken at different depths in boreholes throughout the coastal plain. The result was the well-known map, covering the complete Belgian coastal plain, depicting the depth of the fresh-salt water interface (defined as the depth of the 1500 mg/l TDS or total dissolved solids concentration) in the phreatic aquifer (De Breuck et al., 1974). Fresh water is found above this interface, brackish and salt water below it. The map remains to this day a basic document consulted by researchers as well as policy-making officials or groundwater consultancies for numerous reasons.

Besides its descriptive qualities, it also provides an input for groundwater flow and solute transport modelling. Such models need an initial groundwater quality distribution to start the simulations. This initial distribution corresponds in many cases with the current fresh-salt water distribution. The map provides for instance the initial fresh-salt water distribution in SWIFLEC3D (Salt Water Intrusion Flemish Environment Agency 3D) which is used by the Flemish Environment Agency to model the impact of extractions on the fresh-salt water distribution (Lebbe et al., 2008).

Since the compilation and publication of the original map, new data have been collected in the framework of different studies and dissertations. New data comprise mainly water sample analyses and borehole measurements, this in contrast with the original data which consisted of mainly surface geophysical data (vertical electrical soundings in Wenner arrangement), although also supplemented with water quality analyses from boreholes.

The Flemish Environment Agency (VMM, Vlaamse Milieu Maatschappij) ordered a compilation of these available data (Vandevelde, 2002). Recently this agency has developed a network of observation wells (phreatic groundwater network), spread over Flanders for the collection of water samples on a regular basis. The Flemish Land Use Agency (VLM, Vlaamse Land Maatschappij) has a number of ongoing studies in the coastal plain where water quality data are available.

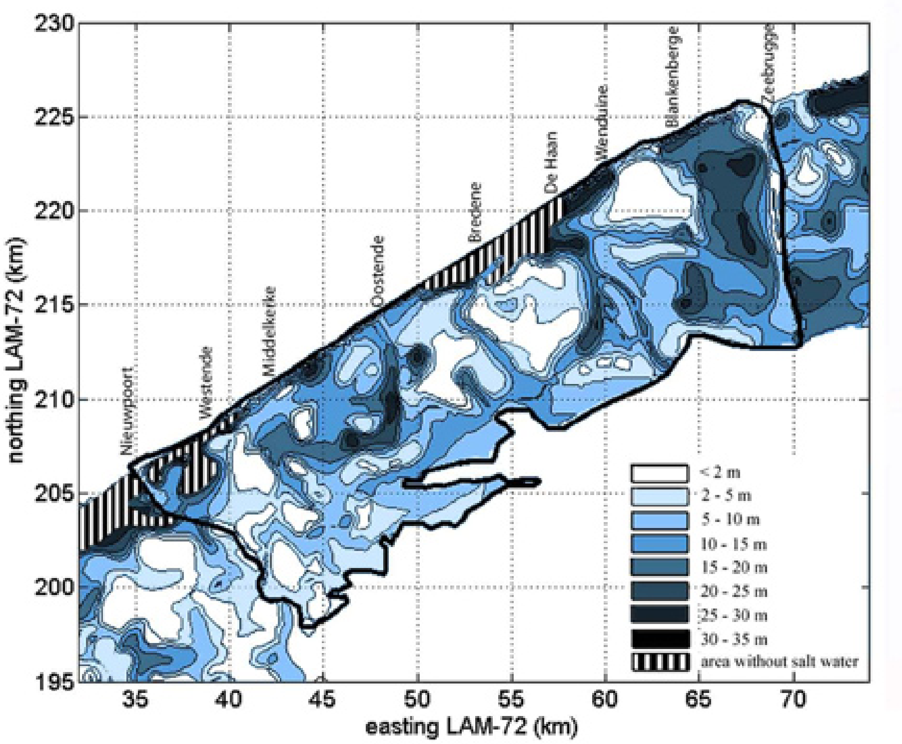

Figure 1. Depth of the fresh-salt water interface in the central Belgian coastal plain as mapped by De Breuck et al. (1974). The study area is outlined in black.

These data sets are combined here and compared with the original map of 1974. The central part of the Belgian coastal plain is chosen as study area since the mentioned data were collected and work done in the framework of an Interreg IVb project, CliWat (Adaptive and sustainable water management and protection of society and nature in an extreme climate), focusing on this area. The central part of the Belgian coastal plain is defined here as the area between the ports of Nieuwpoort and Zeebrugge. Wherever required the fresh-salt water distribution in the study area is adapted resulting in an updated map of the central part of the Belgian coastal plain.

2. Original map (De Breuck et al., 1974)

Fig. 1 shows the original map of the De Breuck et al. (1974). The depth of the fresh-salt water interface in the Quaternary phreatic aquifer, defined as the 1500 mg/l TDS concentration, is given using 8 discrete depth intervals. Additionally, the area where no salt water in the phreatic aquifer is found, is indicated. The major influences determining this complex distribution can be seen on Fig. 2. Fig. 2A shows the distribution of dune, peat and clayey sand, and Quaternary cover deposits. The latter are also mainly sandy deposits. Fig. 2A is based on the HCOV mapping (Hydrologische Codering Ondergrond Vlaanderen, Hydrogeological Code Flemish Subsurface) (Meyus et al., 2000) which was elaborated by Lebbe et al. (2006) for the coastal Quaternary deposits. Figure 2B shows the topography of the study area where the surface levels between 0 and 6 m are stressed to indicate the subtle differences in the polder. The thickness of the phreatic aquifer increases towards the coast and shows a maximum of 45 to 50 m at Oostende.

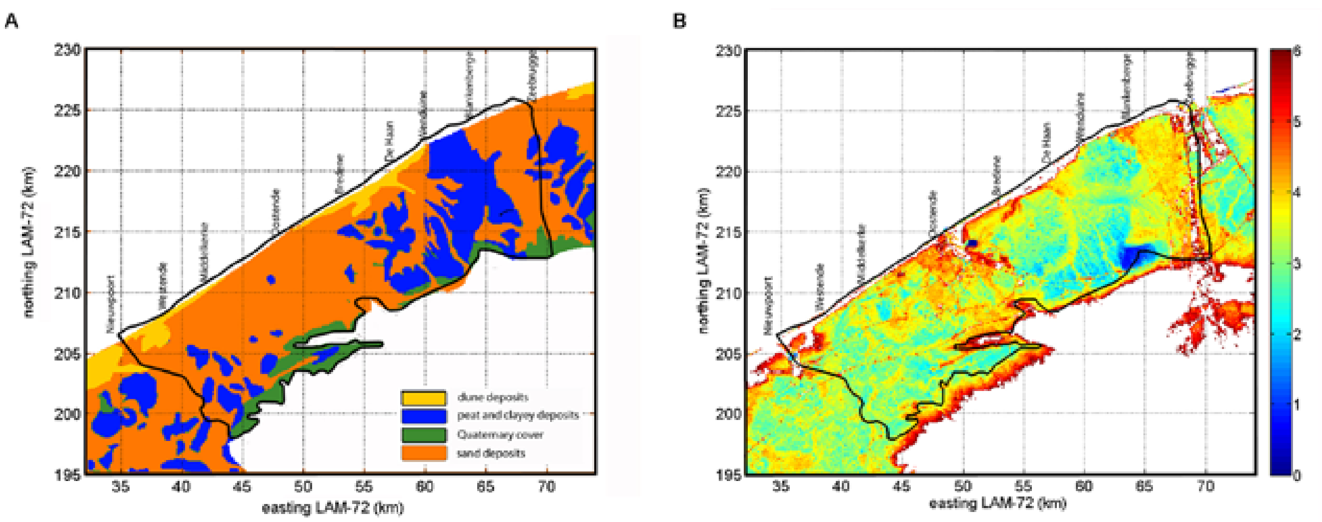

Figure 2. Distribution of different deposits according to the HCOV mapping (A) and the topography of the central part of the Belgian coast (B).

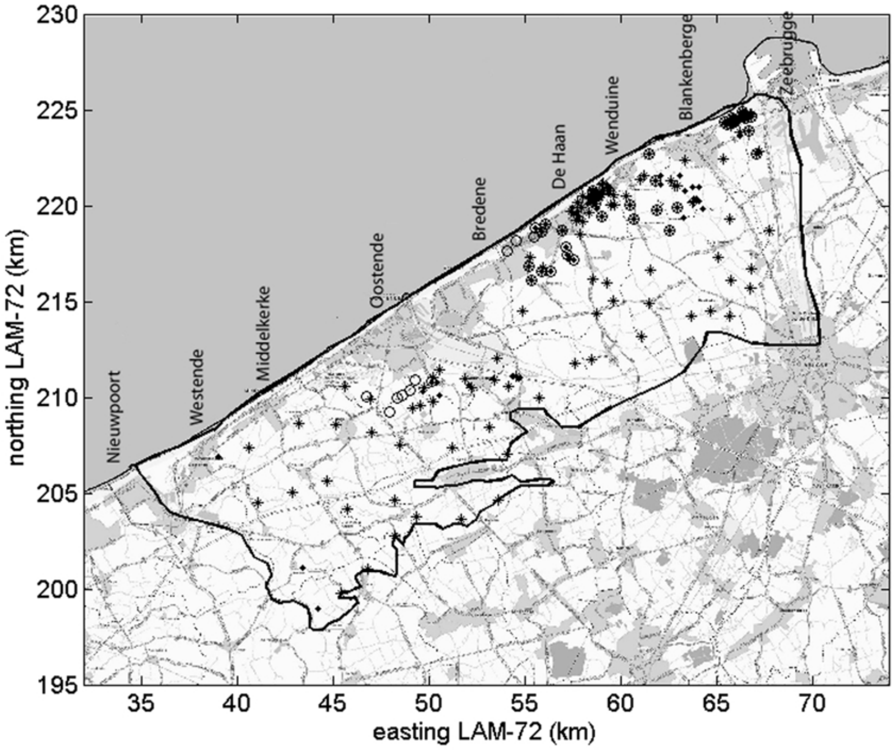

Figure 3. Location of the available measurements: location of borehole measurements (o), location water quality analyses from wells with a single screen (•), location water quality analyses from wells with multiple screens (*).

The major fresh water lenses are related to old tidal channels whose relicts can clearly be seen on the HCOV mapping and/or on the current topography. Vandenbohede & Lebbe (2002) illustrated with a field example how during the recent geological history, fresh water lenses formed under these old tidal channels. After of land reclamation (impoldering) fresh water recharged the aquifer instead of salt sea water. Because of the higher topographical level of the former tidal channels (which evolved to channel ridges) and the permeable sediments, fresh water could recharge the aquifer, replacing the older salt water. This was not the case in the adjacent well-drained areas where only a limited amount of fresh water could infiltrate. The most distinct example is the 'Houtave channel ridge', south of De Haan. It corresponds with sandy deposits surrounded by silt to clay and peat deposits. The level of the ridge is markedly higher than the surroundings because of the drainage and the resulting compaction in the adjacent clay and peat area. A similar example is to be seen in the area south of the coast between Zeebrugge and Blankenberge. A less deep fresh water lens occurs south of Bredene. Another example is present in the polder area south of Oostende. In contrast with the other lenses, there is no noticeable difference between sediments in the old tidal channel and the adjacent areas. In both cases, sandy deposits are encountered. The map of Michel Van Langren (Langrenius) of 1627, however, clearly shows a tidal channel at the location of the current fresh water lens. On this map, one can see that the tidal channel is already surrounded by dykes. Figure 2B shows a distinctly higher elevation of the location of this old tidal channel system and a denser drainage system in the adjacent areas. Consequently, fresh water could recharge the aquifer at the location of the old channel system and replace the older salt water, resulting in the present-day fresh-water lens.

3. Available data and methodology

As indicated before, new data have been collected since the compilation of the original map. These are mostly water sample analyses and borehole measurements (long normal resistivity and electromagnetic induction measurements). Vandevelde (2002) summarised these

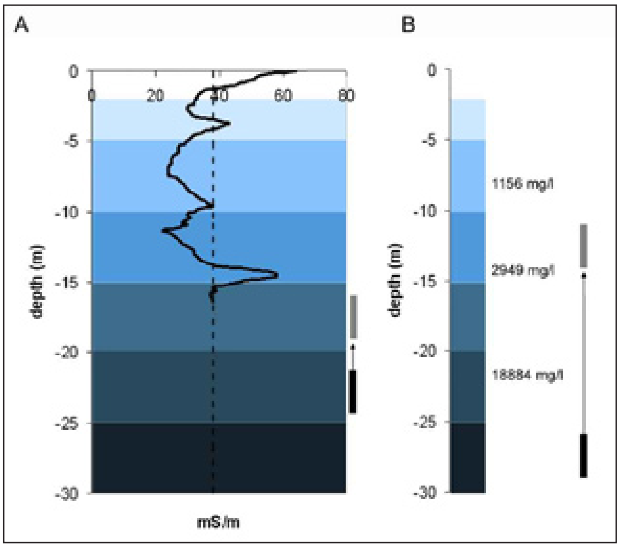

Figure 4. Illustration of the update procedure in case of a borehole measurement (A) and water quality data (B). The intervals according to the original map are indicated as well the classification in the old interval (black bar) and the reclassification (grey bar). The dotted line (A) gives the threshold value of 37.5 mS/m.

data in a data base which served as a starting point to optimise the VMM monitoring network (for head and water quality data) in the coastal plain. This data base comprises 34 locations within the study area where borehole measurements are available and 67 locations with water samples. Most of these locations have screens at different depths. The current groundwater phreatic groundwater network of the VMM forms a second data set. Groundwater is sampled twice a year since 2004 on most of the 53 locations within the study area. Also, two or three screens are available at each location. The database of the VLM comprises 47 observations wells in the study area and in most cases two or three screens are here also available at each location. These data are provided mainly from studies in the Uitkerke polders near Blankenberge and the Oostends Krekengebied. In 7 wells, borehole measurements were made. Drillings were made at seven new locations on a transect over the fresh water lens south of Oostende in the framework of the CliWat project. Borehole measurements (magnetic induction measurements) in these wells were performed and used here.

Availability of more borehole descriptions provided extra data points for the mapping of the base of the phreatic Quaternary aquifer. This depth as mapped by the HCOV (Meyus et al., 2000) is used in this paper.

As a result 167 locations with water samples and 48 locations with borehole measurements are available for the study area. These are indicated on Fig. 3. Screens at different depths at many locations result in the availability of 383 observation points. At the locations with borehole measurements, water samples are in most cases also available. In this case, the interface is based on the borehole measurements and checked with the results of the water samples. Borehole measurements give a continuous log of the formation resistivity or conductivity in function of depth whereas water samples only provide point information. Based on a formation factor of 4 (Lebbe and Pede, 1988) a TDS of 1500 mg/l in these sediments corresponds with a formation resistivity 27 Ωm or a formation conductivity of 37.5 mS/m.

For most of the locations with water analyses, samples at different depths are available. Although water samples only provide point information about the depth of the fresh-salt water interface, samples at different depths at the same location can confirm the current indicated depth or give an indication in which of the 8 intervals the interface is to be found. In case when a time series of quality data is available (for instance for most of the VMM data base), a mean TDS is calculated.

To update the map with the new data, the following procedure was followed. In case of borehole measurements, direct observation of the position of the fresh-salt water interface is present. Fig. 4A gives an example of a log of the formation conductivity as function of depth measured in a well located in the central part of the fresh water lens south of Oostende. The threshold value of 37.5 mS/m is added on this figure. The borehole measurement indicates fresh water down to the base of the Quaternary aquifer. The slightly higher values measured on three levels coincide with three horizons with a slightly higher clay content. The 1974 map indicates a depth of the fresh-salt water interface between 25 and 30 m. This is updated in first instance to a depth between 15 and 20 m and, because the complete phreatic aquifer is filled with fresh water, that indication is assigned. Fig. 4B shows an example in the vicinity of De Haan, using water quality data. Three water samples are available, locating the depth of the fresh-salt water interface between 10 and 15 m. This is changed in the updated map from the depth given on the original map (25 to 30 m).

Finally, the depth of the fresh-salt water interface is compared with the depth of the phreatic Quaternary aquifer given in the HCOV mapping. Wherever the latter is shallower than the former, this is indicated as "area without salt water".

In this procedure, the original data of the map on locations where no new data are available are maintained.

4. Update and conclusions

Figure 5 shows a comparison between the 1974 map and the new data. In general, the new data sets are in very good agreement with the original map. The new data endorse the general fresh-salt water distribution already mapped by De Breuck et al. (1974). Only 16% of the recent data differ from the original map. Most of the differences occcur in transition zones between fresh water lenses and the adjacent polders with a shallow interface. Obviously, unless direct observation of the depth of the interface is available, it is difficult to estimate the exact depth in these transition zones.

Plate 1 shows the updated map. The main differences are as follows:

- A number of extra zones where the aquifer is completely filled with fresh water are identified. The most important one is the fresh water lens south of Oostende. In the original map, the depth to the fresh-salt water interface is indicated between 25 and 30 m. HCOV mapping shows the base of the aquifer to be at 19 m as confirmed with the drillings and borehole measurements made for the CliWat project. Consequently, this new information is added to the map.
- Some changes are made in the vicinity of the coastline. In the early 1980s, it became known that the interaction between recharge water flowing towards the sea and the flow under a wide sloping shore and sea is more complex than previously assumed (Lebbe, 1983). In general there is a salt water lens under the shore above fresh water flowing from the dunes towards the sea. Vandenbohede & Lebbe. (2006) established that the flux of fresh water towards the sea, shore morphology and aquifer lithology determine the geometry of the fresh water distribution. At the time of the original publication of the map of De Breuck et al. (1974) this was not known and consequently not incorporated in the map. In the original map the depth to the fresh-salt water interface decreases from the centre of the fresh water lens in the dunes towards the high water line. In the updated map, the depth of the fresh-salt water

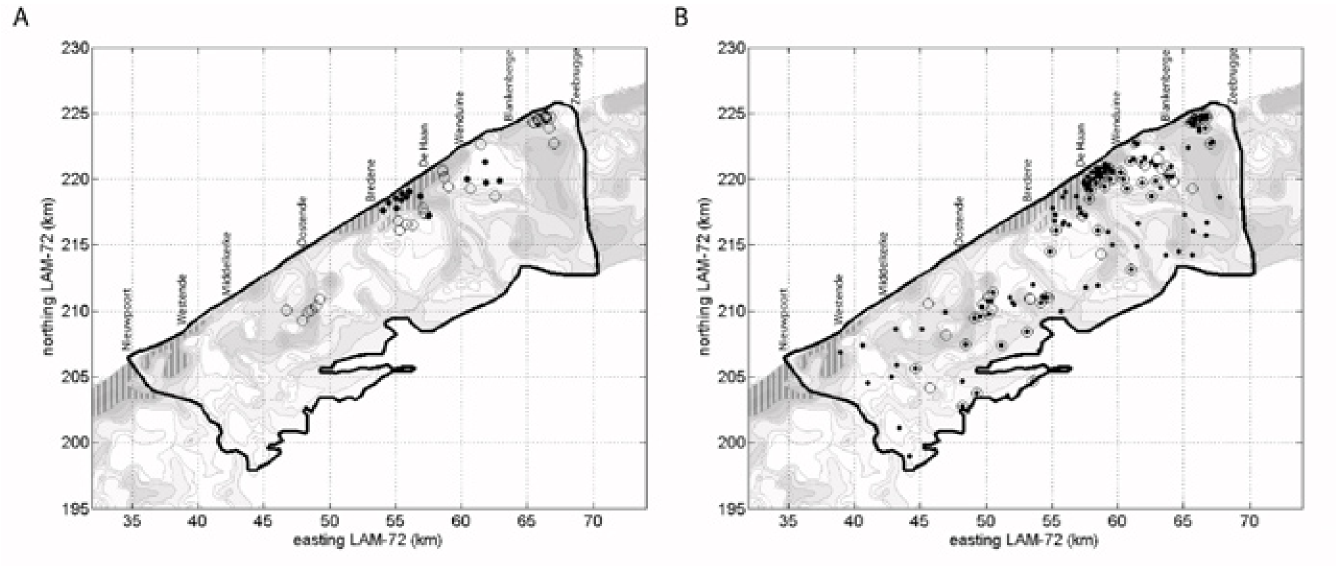

Figure 5. Comparison between the new data and the 1974 map in case of borehole logs (A) and water quality data (B). (•) indicates where the observation corresponds with the 1974 map, (o) where the new data do not confirm the map information.

interface at the high water line is more or less equal as the depth in the centre of the dune area. This represents the flow of fresh water, under the salt water lens on the shore, towards the sea. Additionally, the seaward boundary of the map is situated at the high water line.

- Other changes are very small and, as indicated before, are situated in the transition zones between fresh water lenses and adjacent areas with shallow salt water. In these cases, the transition zone is shifted laterally or the depth of the fresh-salt water interface is changed with respect to the original map. This may point to the fact that, although the map gives a very good overview of the fresh-salt water distribution, the detailed positions of transition zones need to be checked when used for very local studies.

The general conclusion from Fig. 5 is that the information of the original map is in good agreement with the data gathered during the 30 years since its publication. The water quality data and borehole measurements collected in the study area after its publication confirm and strengthen the validity of the 1974 map.

Secondly, the finding of only small differences between the updated and 1974 map illustrates that the evolution of the large scale fresh-salt water distribution is extremely small, if existent at all. This is in agreement with modelling results of the evolution of fresh water lenses (e.g. Vandenbohede & Lebbe, 2002).

Although only the central part of the Belgian coastal plain was studied, these conclusions can almost certainly be extrapolated to the remainder of the coastal plain.

5. Acknowledgements

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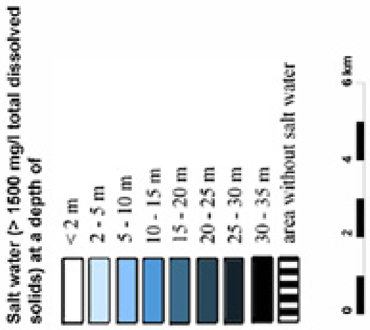

Plate 1. Updated depth of the fresh-salt water interface in the central Belgian coastal plain.