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Meeting the future demands for borehole data and hydraulic heads

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Abstract Borehole data and hydraulic heads are some of the most important data in groundwater modelling, and they are often treated as if they were 100% correct. They may not be, and the problems arising from that are often neglected or not fully recognized. The result may be that comprehensive and time consuming modelling is built on erroneous data which in the end may lead to uncertain or wrong conclusions. Therefore, it is important to recognize the errors attributed to both the primary borehole data and to the hydraulic heads before using the data, both for simple assessments and for more complex modelling. Since a number of different participants are involved in the data sampling, it is important to have precise and generally accepted guidelines for the collection and storing of data in order to meet the future demands for reliable data for geological models, groundwater models, etc. The present work describes a methodology to evaluate the quality of borehole and sounding data. It focuses on the importance of checking reference levels and time series, and it offers a way to select the best data for water table maps and for future monitoring programmes. We believe that this methodology can also be applied to selecting the best data for groundwater modelling, etc.

Key words borehole data; hydraulic head; water table maps; data quality; time series; GIS application

INTRODUCTION

This paper describes an approach to analysing borehole and sounding data of different quality and origin evaluated during a comprehensive mapping of hydraulic heads on the island of Funen, Denmark. The work was based on existing data. It was carried out by the former County of Funen and was comprised of the mapping of the water table and the planning of future monitoring programmes within a large number of specific aquifers.

During the past 10 years the water authorities in Denmark have carried out a comprehensive mapping campaign using new geophysical methods (Thomsen *et al.*, 2004), in combination with classic mapping techniques such as survey drilling, pumping tests, etc. On Funen this has led to the recognition of around 130 separate or partly separate aquifers, most of which consist of glacially deposited sand and gravel beds. The sandy aquifers range in size from smaller water bodies to regional aquifers. To the east, a geological complex of limestone and marls from the Danien form another regional aquifer. The geophysical mapping has made it possible to establish detailed geological models of a number of water protection areas on Funen, e.g. Fig. 1. These geological models have been used to select wells for water table maps for specific aquifers and for establishing groundwater models for water protection areas. However, both water table maps and groundwater models rely on the quality of borehole data and soundings. Uncertainties related to hydrogeological modelling have in recent years been recognized and thoroughly analysed, e.g. Nilsson *et al.* (2007). Guidelines to ensure the quality of new data are also being applied, e.g. Lapham *et al.* (2006) and Geological Survey of Denmark and Greenland (2006). However, we believe that the quality of basic historical data has often been neglected.

ORIGIN AND QUALITY OF BOREHOLE DATA

In Denmark all well contractors must by law report the construction of a new well to the geological survey (GEUS). The borehole report must include information about location and drill depth and must also include a preliminary description of borehole samples. The well construction (i.e. number and position of screens, etc.) must also be specified. However, the quality especially of older borehole reports vary somewhat.

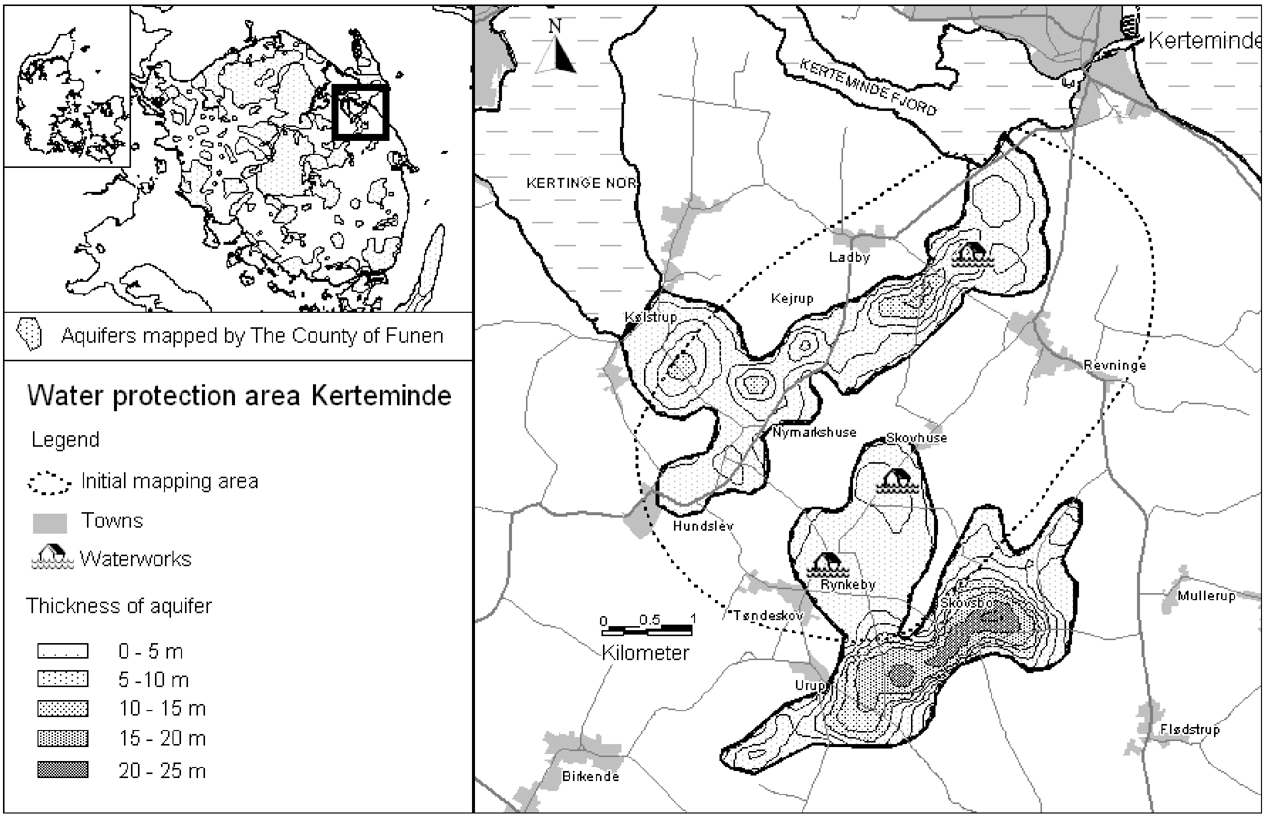

Fig. 1 Aquifer thickness in water protection area Kerteminde, Funen, Denmark. The aquifer thickness has been mapped through a combination of extensive geophysical soundings and borehole information. Notice that the aquifer exceeds the initial mapping area.

Sometimes the position and number of screens and intakes are lacking or are reported ambiguously. Location, reference level and description of borehole samples are also occasionally found to be reported ambiguously. A training programme to certify staff from well contractors initiated by the Ministry of the Environment, was started a few years ago, and generally new borehole reports are more precise.

We have found three parameters of the borehole data to be of crucial importance for the production of water table maps:

– the position of screens in the well;
– the description of borehole samples;
– the precision and description of the reference level.

Rating and visualizing the quality of borehole data

The boreholes (approx. 20 000) were far from uniformly distributed, and the data were far from being of the same quality. In order to analyse data and select the best data, a method for rating the quality of the borehole data has been elaborated. The data were divided into five classes (A–E), in accordance with Table 1.

The rating was performed automatically from data stored in the borehole database using a GIS-application and was afterwards illustrated on thematic maps, Fig. 2. For each aquifer a detailed selection of the wells for the water table maps was performed in the GIS taking into account both the areal distribution and the quality of the well data. A GIS-tool that enabled documentation of each selection was used. A similar approach was used for selecting wells for monitoring programmes and is believed to be suitable for selecting boreholes for calibrating and validating groundwater models as well.

Table 1 Rating of borehole data. In the rating, knowledge about the position of screens is regarded as the most important parameter and is required for quality A, B and in most cases for quality C.

Known position(s) of screen(s)	Samples are described by geologist	Samples are described by contractor	Precise reference level (+- 1cm)	Data rating
Yes	Yes		Yes	A
Yes	No	Yes	Yes	B
Yes	Yes		No	B
Yes	No	Yes	No	C
Yes	No	No	Yes	C
No	Yes or No	Yes	Yes	C
Yes	No	No	No	D
No	Yes or No	Yes	No	D
No	No	No	Yes or No	E

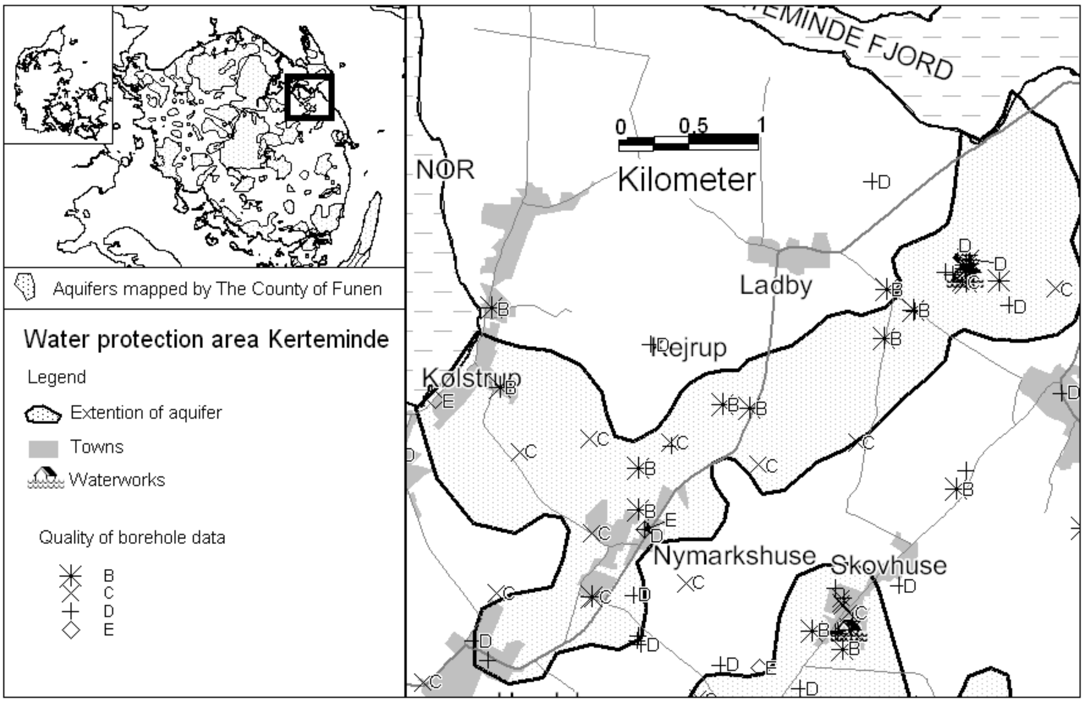

Fig. 2 Map showing distribution of boreholes and quality of borehole data.

ORIGIN AND QUALITY OF THE HYDRAULIC HEADS

Soundings of the water table from the past approx. 100 years are available from the national borehole database run by the geological survey in Denmark (GEUS). However, the quality of these soundings varies a lot because they typically have been carried out by a number of different participants:

The well contractor usually makes the first sounding of the water table as the well is completed.

The waterworks often make soundings on a regular basis. However, these soundings are sometimes made during production or shortly after the pumps have been stopped, so only a limited and varied restoration of the hydraulic head has taken place.

In some few selected wells throughout the country the geological survey (GEUS) has for a number of decades been measuring the hydraulic head four times a year, and for these wells long, informative time series usually exist.

As part of the mapping of the groundwater resources the water authorities and consulting companies have performed synchronous sounding campaigns within specific aquifers or water protection areas.

While the above mentioned soundings primarily have been carried out manually, the water authorities also have automated data loggers in selected wells.

Because of the very mixed origin and quality of the available soundings, it is essential to check these data for errors before they are used for groundwater modelling, etc. The sounding (i.e. the measurement of the distance from the reference level to the water table) is in itself regarded as fairly accurate and usually free of errors. Data errors are primarily related to the lowering of the water table due to pumping from neighboring wells or due to the use of erroneous reference levels when calculating the hydraulic head.

In order to locate hydraulic heads, influenced by extraction of water, from a database containing some 250 000 soundings, a computer routine was developed. This routine was designed to select wells with shifts in water levels of more the 0.5 m within one year and overall variations of more than 2 m. Time series that showed such shifts were inspected manually and soundings, that were found to be erroneous, were rated as poor and omitted from succeeding data analyses. Inspection of time series has previously also been applied by others to omit erroneous data, e.g. Kinney & McDonald (2006).

When more reference levels have been used at the same well site by different participants, there is a greater risk of mixing them up when storing data. To check that this was not the case, we have found it necessary to plot time series of water levels and corresponding reference levels, see Fig. 3. When shifts in water level and reference level take place simultaneously and are of the same order of magnitude, clear indications of reference errors exist. Sometimes the reason is obvious and data can be corrected, but often one is left with more choices and time consuming work to reveal what went wrong.

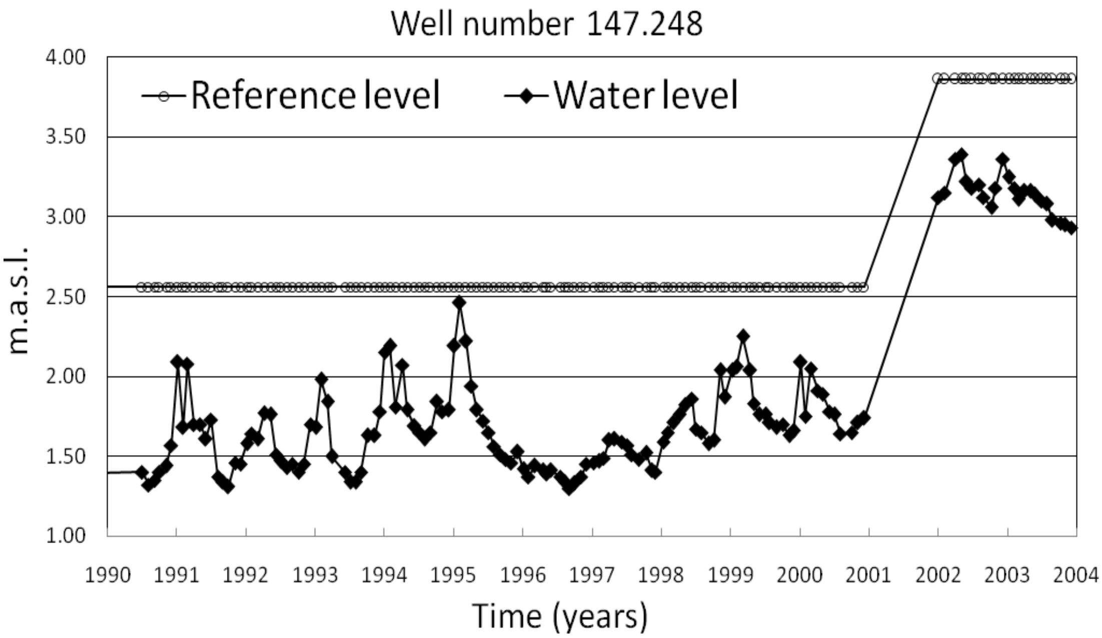

Fig. 3 Erroneous time series of water level and reference level for well 147.248. It is seen that the prominent shift in water level is related to a similar shift in reference level. To restore the present data, the reference level may have to be checked by field measurements.

Problems may also arise when a point of reference is removed or altered due to needs for a new well construction, as such changes are often not reported. To avoid these problems, a set of guidelines for reporting borehole data and soundings to the geological survey (GEUS) has recently been established, e.g. Geological Survey of Danmark and Greenland (2006). It is important that these guidelines become well-known and accepted amongst borehole contractors, geologists and other fieldworkers involved in data sampling. Furthermore, we believe that future use of the new digital PDA-technology (Personal Digital Assistant) could offer a way of online data sampling. This could make it possible *in situ* to check the point of reference and to compare a new sounding with former measurements stored in the database, etc.

Other steps to ensure a better collection and storage of data have already been initiated. These steps include the merging of data from the 12 former counties in one national database for borehole information including soundings (Jupiter).

Rating time series

In order to understand the hydrology of a specific aquifer, it is important to have representative time series of the hydraulic head to illustrate annual and historic variations. Furthermore, when producing water table maps or modelling groundwater hydraulics, it is important to incorporate data that represent these variations. In order to locate wells with soundings that show natural, yearly or historical fluctuations in the hydraulic head, a rating of the available time series was performed. In this rating, long time series and time series with information about the yearly fluctuations was given higher rates in accordance with Table 2.

Table 2 Rating extension and frequency of time series.

Total span of the time series	Sub score I	Sounding frequency *	Sub score II	Total score
>10 years	3 points	≥4 soundings per year	2 points	5 points
3–10 years	2 points	≥4 soundings per year	2 points	4 points
<3 years	1 point	≥4 soundings per year	2 points	3 points
>10 years	3 points	<4 soundings per year	0 points	3 points
3–10 years	2 points	<4 soundings per year	0 points	2 points
<3 years	1 point	<4 soundings per year	0 points	1 point

*The sounding frequency within the past two years was used in the rating in order to be able to compare contemporary annual variations throughout the aquifer.

The ratings of the time series were shown on thematic maps. This way, wells with long and informative time series could be found and interpreted. Since the inspection of the time series was carried out from within the GIS, effects of extraction of water from neighboring wells could be recognized more easily. From selected wells within each aquifer, a short description of the natural annual and historic variations in the water table was made. This was used as an element in the design of a future monitoring programme for each aquifer.

CONCLUSIONS

A methodology to evaluate the quality of borehole data and soundings has been developed. This has been applied to selecting data for water table maps and also applied to planning future monitoring programmes. However, we believe that a similar approach can be used for selecting the data for groundwater modelling.

Of the possible errors related to borehole data, we find that ambiguous or missing location of screens is the most crucial. Furthermore, a poor description of borehole samples may lead to erroneous data interpretation of the hydrogeological conditions. The use of different reference levels at the same well site may introduce great risks of corrupting the hydraulic head data. In the future, the sounding of hydraulic heads will still be performed by a number of different participants. Therefore it is essential that existing data quality guidelines become well known and accepted amongst borehole contractors, geologists and other fieldworkers involved in sampling.

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