AARHUS UNIVERSITY

Water Supply – Project Spring

Estimation of Sabro Waterworks

Description and assessment of Sabro Waterworks nowadays and in the future – implementation of an additional residential area. Analysis of a potential influence of Ristrup Waterworks on a performance of the Waterworks in Sabro.

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PREFACE

This project is a part of the international environmental engineering course at Aarhus University School of Engineering. This report was prepared considering myself an engineer who was hired by the waterworks company in Sabro, in order to analyse the characteristics of the three wells where the raw water is abstracted from, the current treatment facilities and the supply network.

Being supervised by Peder Maribo, with the extra help of Kristian Vestergaard and Michael R. Petersen and using the knowledge obtained on the Water Supply course this report was produced as the final project of the bachelor.

I would express thanks to Peder Maribo, the main supervisor, for his time and help in preparing the report, as well as to Kristian Vestergaard and Michael R. Petersen for their help while working on the project.

ABSTRACT

The town of Sabro is located in the western part of Aarhus Municipally, with a population of 2807. There is approximately 150.000 m³ water supplied per year to all of the consumers. As the new residential area is planned, an increase of population is expected, which will result in a bigger consumption. It may have a significant impact on the performance of Sabro Waterworks and the conditions present in aquifers, from which the water is abstracted.

Using the Jupiter program, available on the Internet, the recharge area was analysed, potentiometric map was drawn and values, such as hydraulic gradient, velocity and flow, were calculated. Furthermore some calculations concerning the water quality and quantity, in order to check the conditions of water and aquifers, were carried out. Also a simplified model of the network was produced in Mike Urban & Epanet and described. As for the optional part a possible influence of Ristrup Waterworks on Sabro Waterworks was estimated.

The aim was to give an opinion about the current process – which gathers the abstraction of the water, the treatment and the distribution. The outcome of the analysis showed some potential problems, though they do not put a significant threat on the performance of the system nowadays. The detailed results, which appeared during creating the report, are included on the following pages.

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INTRODUCTION

The project consists of two parts: the mandatory part and the optional part. The mandatory part is divided into three parts. First of all a geological study about the wells where the groundwater is abstracted from was proceeded, describing the abstraction and recharge area of the aquifers related to the wells as well as an study of the geological layers of the area. Secondly there is a chemical study based on chemical analysis of the groundwater and its relation with the treatment facilities. Thirdly a capacity analysis of the supply network of the village of Sabro is carried out. The optional part is related to a big well field in the north of Sabro, in Ristrup, which may influence Sabro Waterworks - the chemical and hydrological analysis is made in order to find out about the influence on the abstraction wells of Sabro.

On one hand, the goal of the geological study was to describe the geological characteristics of the three wells of Sabro, drawing a profile of all the geological layers of each well. On the other hand, it was to describe the recharge and the abstraction area of the wells, in order to set the abstraction capacity of groundwater from them.

For the chemical part in the mandatory part, the most relevant data of chemical analysis was to be evaluated and the most important characteristics of the aquifer and the groundwater was described - such as vulnerability, age of the water and the water treatment needed. Moreover the current waterworks performance was assessed and the comparison between the capacity of the facility with the current drinking water consumption was made.

The network system was created using Mike Urban – EPANET and the data, concerning the water consumption, was provided by Sabro Waterworks. The system was checked in order to find any bottlenecks or critical points.

For the optional part, the influence of Ristrup well field on Sabro waterworks was checked, as it is possible that they obtain water from the same aquifers. For this purpose water pump tests and geological layers in each well in relation to others were compared and water quality was evaluated.

1. MANDATORY PART

1.1. GEOLOGY

1.1.1. Introduction

There are three abstraction wells located in Sabro area: 78.538, 88.1401 and 88.1102, which abstract 93160, 24038 and 36380 m3 water per year respectively. The water table in the well 88.1401 is situated above an aquifer and the water table in the well 78.538 and 88.1102 is lower than the top of an aquifer. This leads to the conclusion that the well 88.1401 is in the confined aquifer , whereas wells 78.538 and 88.1102 lie in the unconfined aquifer. There are six parts of the geological report, singled out above, which will be presented in the following pages:

- Description of geological layers
- Storativity calculation
- Transmisivity calculation
- Abstraction area calculation
- Recharge area estimation
- Vulnerability to contamination analysis

Figure 1: Abstraction wells in Sabro [Reference 1]

1.1.2. Description of geological layers

The figures showing the geological profiles around the boreholes, as well as a table presenting the characteristics of each well are attached in appendix A–Figure 36, Figure 37, Figure 38.

Present stratigraphy is the consequence of phenomenon which took place mainly in Pleistocene, which consisted of glacial and interglacial periods. Due to it the aquifer type is melted sand and gravel, which is actually said to be the one of the main importance in Denmark. Analyzing the layers moraine deposits (such as unsorted material of clay and sand), melt water deposits (sorted clay, sand, gravel), moraine deposits (well-sorted material) might be noticed. In each example the upper layer consists of clay, so that the aquifers which lay beneath are formed as, so called, buried outwash plains with a confining layer – taking this into consideration the screens cross the area were only gravel and sand is located, as these are the layers said to be the ones suitable for the abstraction of the water, whereas clay is not recommended (no proper hydraulic connectivity and permeability). From the geochemical point of view the water which derives from this structures is of a great quality, due to the fragments of chalk and limestone (created during Pre-Quaternary) being a part of beds. It has the neutralizing properties in relation to the groundwater. As the water analysis will be introduced in further chapters, it will be shown that the quality of abstracted water is satisfactory.

1.1.3. Storativity calculation

Well Number	Confined/unconfined	Q = Q_t (Consumption) (m^3/year)	b - Thick of aquifer (m)
88.1102	Unconfined	36,380.9	55
88.1401	Confined	24,038.7	56
78.538	Unconfined	93,160.3	31.5
Total		153,579.9	

Table 1: General data of three abstraction wells in Sabro (Consumption –[Reference 2])

The storativity S, represents the volume of water that a porous rock will absorb or expel per unit surface area per unit change in head. In other words, the aquifers ability or willingness to yield water is expressed by its storativity. [reference 3]

$$\mathbf{S=hS_s+S_y} \quad \text{(Equation 1)}$$

Where:

S: Storativity

S_S: The specific storage

S_y: The specific yield

b : The thickness of aquifer

The storativity formulas for a confined and an unconfined aquifer differ from each other:

- For a confined aquifer, storativity is the vertically integrated specific storage value

$$\mathbf{S=S_s \cdot b} \quad \text{(Equation 2)}$$

- For unconfined aquifer storativity is approximately equal to the specific yield (S_y) since the release from specific storage (S_s) is typically orders of magnitude less ($S_s << S_y$).

$$\mathbf{S=S_y} \quad \text{(Equation 3)}$$

The average value for S_y (specific yield) of medium-grained sand is 26% (aquifer material see appendix A–Figure 36, Figure 37, Figure 38).

TABLE 2.1
Statistics on Specific Yield from 17 Studies Compiled by Johnson (1967)

Texture	Average Specific Yield	Minimum Specific Yield	Maximum Specific Yield	Coefficient of Variation (%)	Number of Determinations
Clay	0.02	0.00	0.05	59	15
Silt	0.08	0.03	0.19	60	16
Sandy clay	0.07	0.03	0.12	44	12
Fine sand	0.21	0.10	0.28	32	17
Medium sand	0.26	0.15	0.32	18	17
Coarse sand	0.27	0.20	0.35	18	17
Gravelly sand	0.25	0.20	0.35	21	15
Fine gravel	0.25	0.21	0.35	18	17
Medium gravel	0.23	0.12	0.26	20	13

Source: Modified from Healy, R.W. and Cook, P.G., Using groundwater levels to estimate recharge, *Hydrogeol. J.*, 10(1), 91, 2002.

Table 2: Specific yield table [Reference 4]

The final Storativity is calculated below:

Well No.	Confined/unconfined	S_s (%)	S_y (%)	b (m)	S (%)
88.1102	Unconfined	0	26	55	26
88.1401	Confined	0.0005	0	56	2.8
78.538	Unconfined	0	26	31.5	26

Table 3: Storativity table with S_S (specific storage), S_Y (specific yield), b (thickness of the aquifer) and S (storativity) [Reference 5]

1.1.3.1. Transmissivity calculation

The transmissivity T is the ability of an (unit) aquifer to transmit water (showing how permeable it is); for a confined and an unconfined aquifer, the formula to calculate the T is different, as shown below:

- Confined Aquifer:

$$T = \frac{0{,}183Q}{s_W} \log \frac{135Tt}{r_W^2 S} \qquad \text{(Equation 4)}$$

T: Transmissivity

r: Radius

S: Storativity

t: Time

$$T = \frac{0{,}183}{3600} \frac{Q}{s} \log \frac{135 \cdot 0{,}008 \cdot 1440}{0{,}15^2 \cdot 0{,}0004} = 0{,}00042 \frac{Q}{s}$$

- Unconfined Aquifer

$$T = \frac{0{,}183}{3600} \frac{Q}{s} \log \frac{135 \cdot 0{,}008 \cdot 1440}{0{,}15^2 \cdot 0{,}1} = 0{,}0003 \frac{Q}{s}$$

While calculating T, it was assumed as 0.008 at first, and then Q and S (data got from the PDF file from JUPITER, see (appendix A-PDF files “78.538”, “88.1102” and “88.1401”) were taken into calculation. In order to obtain a proper result transmissivity was calculated in a couple of iterations. The first and second steps of the calculation are shown in (appendix-A Table 27, Table 28), the third (final result) is shown in the table below:

Well No.	Confined Unconfined	Formula	Abstraction from the well Q (m3/h)	Depression of the water in the well S(m)	T (m^2/s)
88.1102	**Unconfined**	**0.0002628·Q/S**	17.4	2.7	0.001693
		0.0002628·Q/S	13.2	2.1	0.001693
		0.0002628·Q/S	24.6	3.7	0.001684
					Average 0.001635
88.1401	**Confined**	**No data**	**No data**	**No data**	Assume 0.003
78.538	**Unconfined**	**0.0002864·Q/S**	40	2.3	0.004981

Tabla 4: Transmissivity calculation 3

After the third round circulation calculation, the T tends towards stability. The well 88.1401 is provided with no data, so transmissivity was assumed as 0.003 (between 0.00163 and 0.00498).

1.1.4. Abstraction area calculation

The abstraction area is an area on the land surface, below which the flow of the water goes in the direction towards a well, for which the calculation is proceeded. The flow is defined as a three-dimensional value in this case and that is why a three-dimensional flow pattern is reflected on the land surface. [Reference 6]

1.1.4.1. Infiltration calculation:

a. precipitation assumption:

In order to calculate the abstraction area at first the precipitation in area of Sabro should be known. Depending on a source of the data values are slightly different - from 600 to 900mm/year.

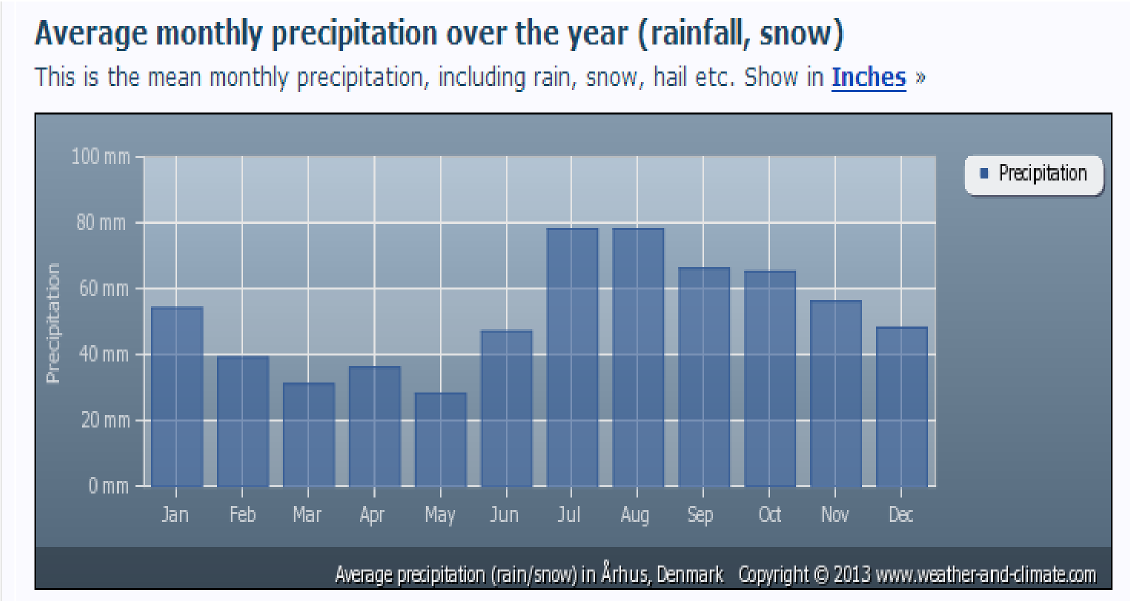


Figure 2: Precipitation map in Aarhus [Reference 7]

Summing the 12 month's precipitation, the annual precipitation gets a value of 700 mm/year. Comparing the value taken form the Internet, precipitation and evaporation reach up to 700 mm and 450 mm in Aarhus respectively. [Reference 6]. This data was used in the next calculations.

b. Water balance calculation:

Water balance equation:

$$\mathbf{P=E+I+ Rs+ Ru+\Delta S} \qquad \text{(Equation 5)}$$

P : The precipitation in the area in question (mm/year per unit area).

E : The actual evaporation (mm/year per unit area).

I: Infiltration in the area (mm/year per unit area).

Rs: The runoff from the area via surface streams and drainage systems.

Ru: The subsurface drainage, the net amount of groundwater flowing out of the area.

ΔS: The change in total groundwater storage in the area during the period in question (normally one year). ΔS can normally be regarded as zero if averaged over a number of years.

The assumptions taken for every parameter of the water balance equation are shown below:

P = 700 mm/year

E = 450 mm/year

Rs+ Ru = 50mm/year. It cannot be found exactly how much runoff water via sewer system and surface streams can get in the aquifer, but using the Google Maps Application it could be seen that Sabro is located in the countryside, among green areas, and the imprevious area percentage seems to be very low, so it has been assumed that only 5% of the precipitation is the sum of Rs+ Ru.

ΔS = 0 (explanation given above)

So if the data are substituted in the water balance equation, the infiltration value calculated is 200 mm/year.

1.1.4.2. Abstraction area calculation

The abstracion area calculation follows the equation below:

A = Q/I (Equation 6)

Where:

A = Abstraction area

Q = Volume of each well

I = 200 mm/year (calculation in section b of 1.1.4.1)

Based on the equation 6, abstraction areas of each well were calculated and the results are shown in the table below:

Well No.	Q (real volume m^3/year)	A (abstraction area m^2)
88.1102	36,380.9	181,904.5
88.1401	24,038.7	120,193.5
78.538	93,160.3	465,801.5
Total	153,579.9	767,899.5

Table 5: Abstraction areas for each well

The population in Sabro will increase soon, due to a new resdiential area planned in the east of the coty. It will consist of 220 households [Reference 8]. It is assumed that one houshold consists of 2.5 people and the average water consumption in Denmark is around 0.14 m^3/person/day [Reference 9], so the future water consumption should increase up to 28.105 m^3/year.

The total water consumption in the future (with the new area included) will be around 181.684 m^3/year (nearly 20% of increase).

The new abstraction area in the future (using the equation 6), knowing that the Q will be 181,684 m^3/year and the I of 0.2 m/year, will be equal to 980,525 m^2.

1.1.4.3. Abstraction area outline calculation

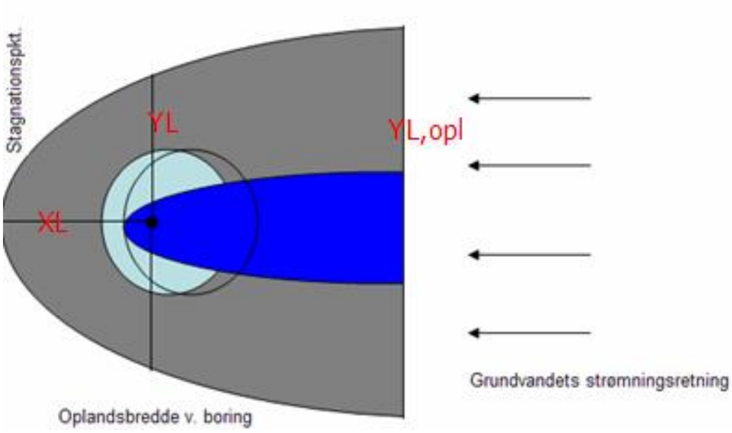


Figure 3: Abstraction area outline

The equations for the calculation of the three key parameters describing the shape of the abstraction area are shown below:

- **Point of stagnation**

$X_L = \frac{Q_{max}}{2 \cdot \pi \cdot I_w \cdot T}$ (Equation 7)

Where:

$$Q_{max} = f_d \cdot \frac{Q_t}{1.25}$$

Fd: The value for a country side village is considered 2.5 [Reference 9]

Q_t: Consumption in m^3/year.

I_w: Gradient closed to the abstraction well (near to the point a, see figure 4).

T: Transmissivity in m^2/year.

- **Width of abstraction area by the well**

$Y_L = \frac{Q_{max}}{2 \cdot I_w \cdot T}$ (Equation 8)

The meaning of the parameters is the same as for the equation 7.

- **Width of the abstraction area up stream**

$Y_{L,opl} = \frac{Q_t}{I_a \cdot T}$ (Equation 9)

Where:

Ia: Gradient in the whole abstraction area

The meaning of the other two parameters can be taken from equation 8.

a. Gradient calculation:

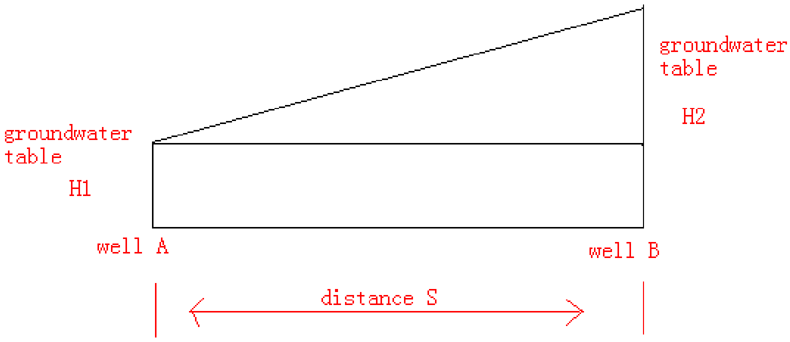


Figure 4: gradient calculation scheme between two wells (A and B)

$I = \frac{H_2 - H_1}{S}$ (Equation 10)

I: Gradient between well A and well B
H2: Groundwater table in well B
H1: Groundwater table in well A
S: Distance between well A and well B

The gradient for each well should be a constant value, but while calculating the gradient, the value varied a lot due to different comparative wells chosen (well of reference – Well A in figure 4), in other words, there are some different wells around a well chosen as a main one to calculate the gradient (78.538 for example) and the gradient changes depending on which well around the choden well was picked up. The gradient which value is not that big was chosen (see in table 6 below), because otherwise (calculated taking another well as a reference) the shape of the abstraction area would be too big, and it would not make sense with the movement of water shown in the potentiometric map (figure 6).

Well number	I_w (-)	I_a (-)
88.1102	0.02	0.005
88.1401	0.01	0.005
78.538	0.001	0.005

Table 6: Gradient results for each well

b. height of abstraction area calculation:

In the theory to calculate the h, the abstraction area is assumed to be a ladder-shaped one. Meaning of YL, YL, opl and XL (see figure 5).

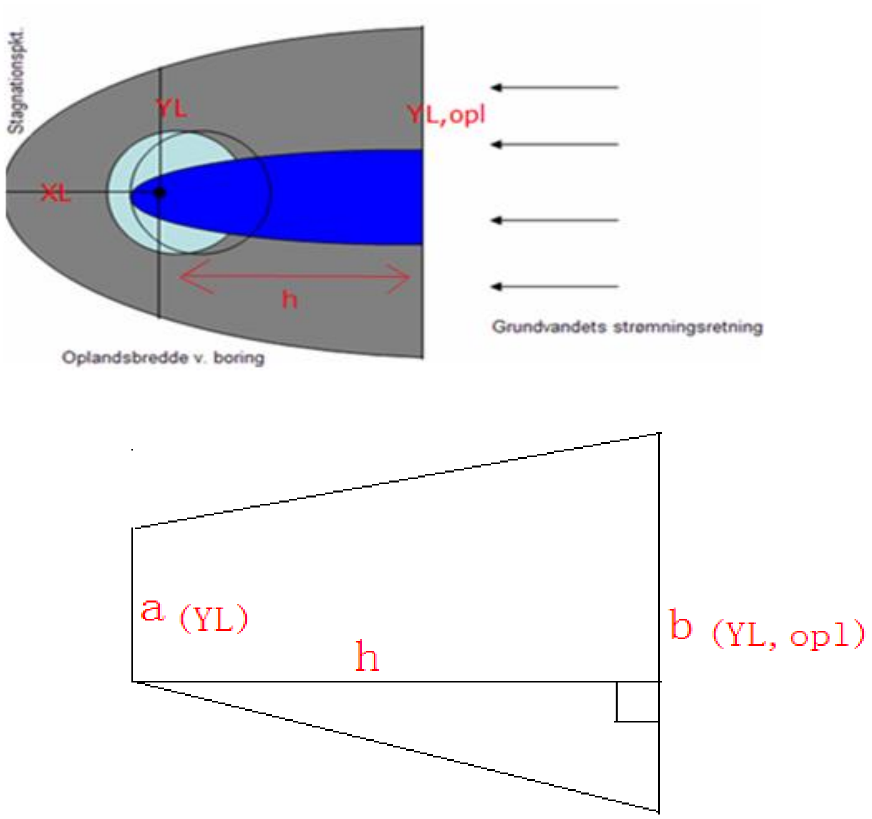


Figure 5: generic abstraction area, with the well located in point "a"

So taking this shape as the abstraction area, the value of the area is calculated by the equation 11 and the "h" by the equation 12:

$$A = \frac{(a+b)\cdot h}{2} \quad \text{(Equation 11)}$$

$$h = \frac{2\cdot A}{(a+b)} \quad \text{(Equation 12)}$$

The final result for all the parameters of the abstraction area are shown in the tables below (table 7 and table 8):

Well No.	Abstraction Area (m^2)	Q_{max} (m^3/s)	T (m^2/s)	I_w	I_a
88.1102	181904.5	0.002365591	0.00163529	0.02	0.005
88.1401	120193.5	0.001563066	0.003	0.01	0.005
78.538	465801.5	0.006057552	0.004981326	0.001	0.005

Table 7: Data for the calculation of XL, YL, YL,opl (see equations 7, 8 and 9)

Well No.	XL m	YL m	Yl,opl m	H m
88.1102	11.12	34.93	139.75	2082.53
88.1401	8.29	26.051	52.10	3075.84
78.538	193.63	608.02	121.60	1276.81

Table 8: XL, YL, YL,opl calculation (see equations 7, 8 and 9)

c. Groundwater flow direction:

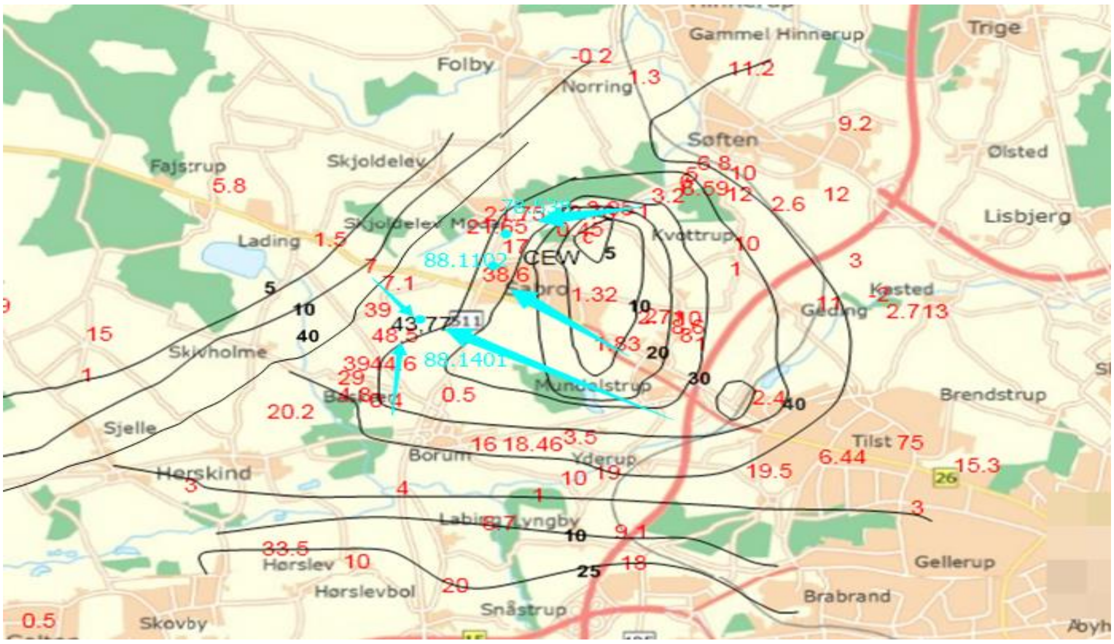


Figure 5: Potentiometric map of Sabro area with light blue arrows showing the direction of water displacement

The red lines [Reference 10] show the locations (in meters) of water table in relation to the terrain. The higher the numerical value, the lower the groundwater table is, and water flows from higher groundwater table level to lower groundwater table level. It can be seen looking at wells 78.538 and 88.1401 that the tendency of the flow is in the direction from the east. For the well 88.1401 the groundwater could flow from 3 different directions but finally it was assumed to be only from east direction (for the gradient in the east area which close to well

88.1401 is steeper).The groundwater flow direction map is the fundamental for the drawing of the abstraction area map. The light blue arrows represent the movement of water.

d. Abstraction area map:

Figure 6: Abstraction area map in Sabro. Dark area: currents abstraction area. Red line: future abstraction area

Using the data provided in Table 8 (1.1.4.3) and ground water flow direction map (figure 6) , abstraction area map was drawn (figure 7). But as it was said in section 1.1.4.2, the water consumption in the future may increase around 20%. So the area enclosed in red lines indicates the potential abstraction area in the future.

It can be seen from the map that the abstraction area for well 78.538 is the biggest one (which fits the abstrac volume for well 78.538 is the biggest). As the groundwater flow goes rather from the east, it is possible that in the future, the stream located nearby, might be influenced by the abstraction, but what is more, it also means that the stream water quality should not influce the groundwater quality of Sabro area.

1.1.5. Recharge area estimation

The groundwater recharge area is defined as that part of the land surface area from which rain water leaks down to the aquifer and further on towards the well. Unfortunately it was not possible to find the exact geological condition in the whole Sabro area, so it is assumed that the abstraction area is enclosed in blue circle. For in the future there will be around 20% increase of water consumption, so the area enclosed by the red line represents the recharge area in the future.

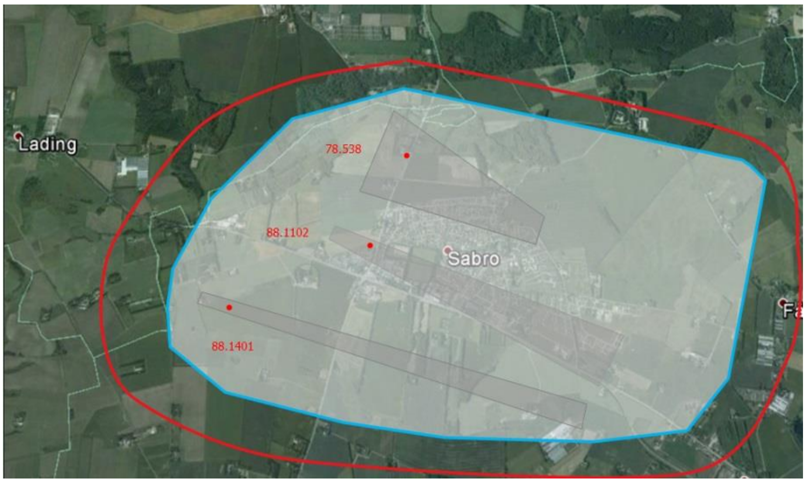


Figure 7: Abstraction area around Sabro. Light blue: current abstraction area. Red line: future abstraction area

1.1.6. Vulnerability to contamination

Looking at a map below, wqhich shows the contamination in Sabro, and also at the one attached to appendix A-Figure 38, which presents contamination intensity in the whole Aarhus Municipally, it can be seen that the situation in Sabro, concerning this issue, poses no big threat. As it will be introduced, in one of the following chapters, water quality in Sabro is satisfactory. Though some polluted areas can be observed within the city, which means there is always a risk of its expansion towards the wells in the future.

Figure 8: Sabro contamination map

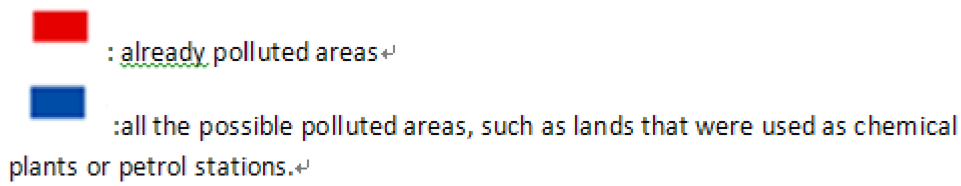


Figure 9: Meaning of colors for figure 9

In the recharge area map (figure 7) it can be seen that there are some farm land located in the recharge area, so if pesticides are widely used in this area, it may also influence the groundwater quality in Sabro (once the groundwater were polluted by pesticide, it would be so tricky to deal with).

1.2. CHEMICAL ANALYSIS

1.2.1. Introduction

The chemical analysis of the groundwater is like the fingerprint of the aquifer and all the soil which is inside the aquifer. The chemical analysis helps in gaining the knowledge about chemical processes to which the groundwater has been exposed while filtering through the soil until reaching the aquifer. As well give us an information about a path that the groundwater followed and what kind of relevant solids exist inside the soil - their properties in relation to the processes (acid/base properties, redox properties) and if they are menace to the water, in other words, if they are contaminants.

The structure of this part of the report will present, step by step, carried out water analysis of the three wells where Sabro Waterworks abstract water from (see their location in figure 11). First of all, the main compounds present in the groundwater are to be found in the latest chemical concentration measurements [Reference 10]. All the data collected are given in (appendix B – tables 29 to 34], however these compounds which do not fit the criteria will be singled out and these which are considered as the main ones, or at least most common, will appear here as well (see table 9, table 10 and table 11). Secondly, the main parameters, related to the chemical processes the groundwater is exposed to while filtering through the soil, will be calculated. Knowing their values conclusions related to the aquifer protection, age of the water or any potential danger will be presented. All the equations used in order to calculate the parameters are given in the [Appendix B]. Finally, an analysis of any changes concerning the concentration of the most relevant chemicals present in the groundwater will be made. It can be changed during the last ten years or less, depending on how many measurements were made and saved in Jupiter Database.

After the analysis of each well, a general conclusion and sum up will be written to remember and compare the highlights of the analysis.

Figure 10: Location of the three wells 78.538, 88.1102 and 88.1401

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,01	0,05
Ca^{2+}	67	-
Fe^{2+}	0,01	0,1
Mn^{2+}	0,023	0,02
NO_3^-	25	50
O_2	2,7	-

Table 9: Main compounds in well 78.538 (whole table in appendix B)

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,01	0,05
Ca^{2+}	91	-
Fe^{2+}	0,055	0,1
Mn^{2+}	0,011	0,02
NO_3^-	17	50
O_2	6,4	-

Table 10: Main compounds in well 88.1102 (whole table in appendix B)

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,02	0,05
Ca^{2+}	71,9	-
CO_2	< 5mg/L	2
Fe^{2+}	0,19	0,1
Mn^{2+}	0,14	0,02
NO_3^-	0,5	50
O_2	0,1	-

Table 11: Main compounds in well 88.1401 (whole table in appendix B)

1.2.2. Well number 78.538 (Adress: Sabro Vandværk, Stillingvej 7 - 8471 Sabro, see figure 1) and Well number 88.1102 (Adress: Sabro Vandværk, Stillingvej 74- 8471 Sabro, see figure 1)

1.2.2.1. Comparison with the criteria

As it can be seen in the table 9 and table 10, both wells (78.538 and 88.1102) have a quite similar concentration of the main chemical compounds. The second well seems to be very clean - no compound has a concentration higher than the Danish water criteria - but in the first one the concentration of manganese is a bit too high. Because of these similarities, the redox type, for the water taken from both wells, will be the same: **type A**, which means strongly oxidised (procedure to know the redox type in (appendix B – figure 43).

1.2.2.2. Analysis of the main parameters and conclusions

Parameters		
I	1,08	Little ion exchange
F	1,31	Existing pyrite oxidation
dH	10	Middle water
logSI	0.16	Not aggresive sample

Table 12: Main parameters of well 78.538

Parameters		
I	0,63	Little ion exchange
F	1,69	Existing pyrite oxidation
dH	13,32	Middle water
logSI	0.30	Not aggresive sample

Table 13: Main parameters of well 88.1102

In the tables above (table 12 and table 13) the main parameters calculated by taking the current concentration of the chemical compounds are singled out. General data and equations used are included in (appendix B – table 30, 32 and 34).

a. Ion exchange

First of all, based on the **ion exchange** parameter of the well 78.538 (1.08, in table 12), it is shown that this process almost did not take place while filtering until the water arrives the aquifer. In the geological layers, it is noticeable that at the top there is some clay (appendix A - figure 36). However, the water was not filtered through that layer, probably it followed another path, or it came from another zone near the well where there is no such barrier. It fits with the fact that the aquifer is not well protected and the water is quite young, but it also means that the groundwater flow is very high and the retention capacity of the soil has reached the equilibrium and is quite low. The low retention capacity explains the reason for the low protection. If contaminants get in with the groundwater flow, they will not make a connection with the soil and they will reach the aquifer.

For the well 88.1102, the argumentation and the conclusion are exactly the same. As it can be seen in the geological layers (appendix A - figure 37), the profiles are quite the same between both wells. However, in this case the iron exchange process did not take place (ion exchange parameter 0.63, in table 13). The criteria for the ion exchange parameter can be seen in (appendix B – figure 40).

b. Degree of weathering

Secondly, the **degree of weathering** (1.31, in table 12), so a pyrite oxidation took place in the well 78.538. The calculation and criteria of the parameter is shown in the (appendix B – figure 41). Due to the pyrite oxidation and other chemical processes such as biodegradation of organic matter and nitrification, acidic compounds are formed and these compounds dissolve calcite, so the concentration of calcium and hardness increase. The value of hardness in this well is shown in table 13. The acid/base condition of the water in the aquifer is buffered, which means that pH value is of 7.5 (Appendix B – figure 44). That pH value means that the water is neutralized, so every kind of acid that was releases, due to any process mentioned at the beginning of the paragraph, was neutralized with limestone while filtering. The neutralization process releases dissolved calcium and more hydrocarbonate to the water. The released calcium is the one that can be changed by sodium in the ion exchange process.

Again these ideas can be applied for the well 88.1102 (whose degree of weathering value is 1.69, in table 13).

c. Calcite Saturation Index

Calcite Saturation Index (logSI) can tell if the sample is aggressive or if it is in equilibrium. In the case of well 78.538, the parameter is higher than zero (0.16, table 12), which means that the sample is not aggressive and the concentration of carbon dioxide follows this conclusion (see appendix B – table 27). It is considered that the measured concentration is more reliable than the value of this parameter because the concentrations taken for the formula of the logSI (shown in appendix B) are not the real concentrations that participate in the reaction. The real concentration of the substance that takes part in a reaction is the activity, which is always lower than the net concentration. Summing up, the sample is not aggressive, and the same can be applied for the well 88.1102 (value of calcite saturation index 0.30, table 13 can be compared to concentration of CO_2 in appendix B – table 31).

d. Conductivity

The **conductivity** in well 78.538 (45, appendix B – table 30) tells how salty the water is. If the conductivity is extremely high (higher than 130 mS/m)this is a signal for the intrusion of salt water. However in this case 45 mS/m is considered a typical value.
As far as well 88.1102 is concerned, the value of the conductivity can be seen in appendix B – table 32. Its value is also inside the typical range.

e. Ion balance

Finally, **the ion balance** is a parameter which only goal is to approved if the chemical analysis is well measured, and if the correct compounds have been taken. In the case of well 78.538, the ion balance has a value of -5.66 % (see appendix B – table 30). The value must be inside the range [-5,5] (%) to be acceptable. However, the difference from -5.665 to -5 is not very big, so it is considered to be acceptable.
In the case of the well 88.1102, the conclusion is more clear because the ion balance value is -3.71 % (see appendix B – table 32), which is clearly inside the range of acceptance.

1.2.2.3. Evolution of the concentration of relevant chemicals

It is important to know how the different chemicals have changed along the last years. The last chemical analysis can be assumed to explain the treatment process in waterworks and the quality of the water, however the waterworks might have been ready to treat some other components that currently have a low concentration (below the criteria) comparing to the past, though it can increase because of the movement of water from other zones with a different quality and characteristics.

By the analysis made in the second step (section 1.2.2.2), for both wells, it can be noticed which compounds are the most relevant and which of them probably will not appear. On one hand, that selection shows the fact that the redox type of water is strongly oxidised and buffered, and that the aquifer is not very well protected. On the other hand, it is shown that the area of Sabro is vulnerable to nitrate and pesticides [reference 11]. These facts mean that for example H_2S will not be a relevant chemical because it appears in very reduced mediums, sodium is not important because the ion exchange is relatively low and that the nitrate is an important chemical to analyse because Sabro is vulnerable to this chemical.

The chemicals that will be studied are: iron and manganese (both treated at waterworks by normal treatment) and nitrate (it needs special treatment).

a. Iron

As it is said, the **iron** needs the normal treatment at the waterworks, and its concentration in the last chemical measurement is quite low for both wells, however it will be interesting to know if its concentration follows always the same pattern. The graph is shown in the figure below (figure 12).

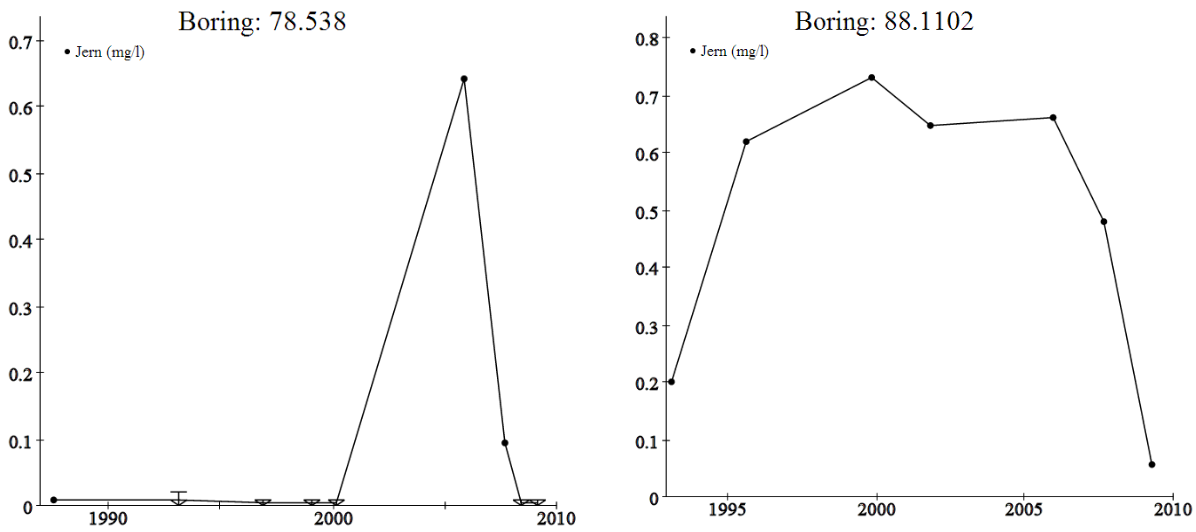


Figure 11: Fe concentration evolution in the last 20 years for wells 78.538 and 88.1102

As it is seen in this figure above, the level of iron in well 78.538 is very low every year except from years 2006 and 2007, when suddenly the level increased a lot. It reached a level of about 0.65 mg/L where the given limit is 0.2 mg/L. It was probably caused by the movement of water from the recharge area. The treatment of iron is necessary. In the case of well 88.1102 (figure 12 right), the iron levels in space of the same time period look completely different. The concentration has kept quite high in the last years and it started to decrease 7 years ago, reaching a very low level in the last analysis. It seems to be a strange phenomenon, knowing that the redox type of water is strongly oxidised.

b. Manganese

In the case of manganese, its concentration in the last analysis is higher than the criteria given for the well 78.538, so it will need treatment anyway, but as in the case of the iron, it is interesting to know how it changed during the last years. However in the case of the well 88.1102 the concentration of manganese is very low in the last analysis and fits the criteria given. The graph of the evolution of the concentration can be seen in the figure below (figure 13):

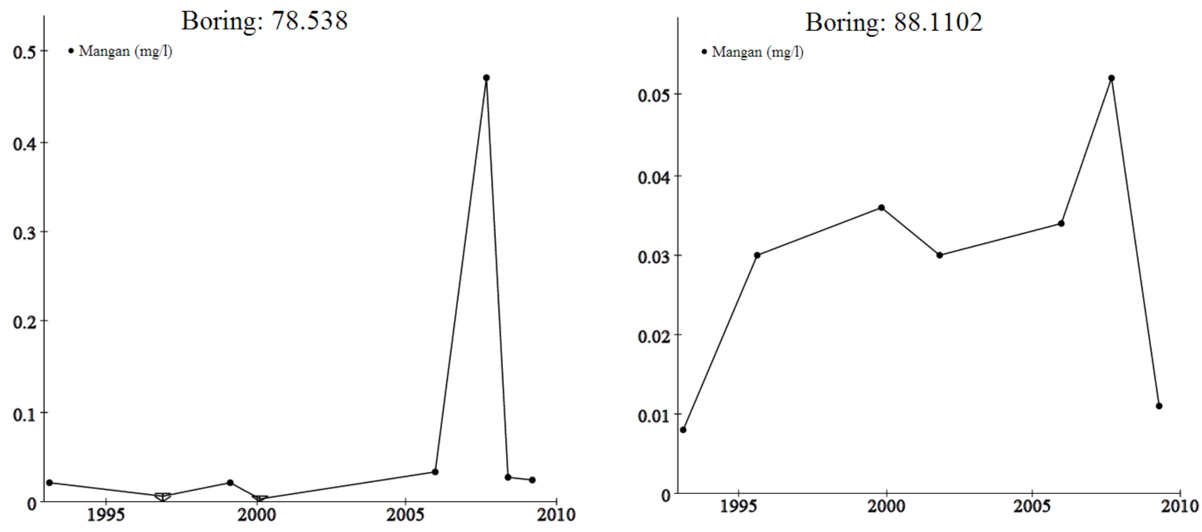


Figure 12: Mn concentration evolution in the last 20 years for wells 78.538 and 88.1102

As it can be seen in the figure above, in the well 78.538 the Mn behaves likely the Fe. It keeps the level of low values, maybe above the criteria, but only for a low distance. Though it reaches suddenly a very high level around 2007 and 2008 (almost 0.5 mg/L). The conclusion is that the Mn must be removed constantly from the water. In the well 88.1102, the manganese acts also like the iron in this well, and the causes and conclusions are the same – there are strongly oxidised conditions.

c. Nitrate

In these wells, the nitrate is the most important compound to study because of the low protection of the aquifer and the high vulnerability of the Sabro area against pesticides and nitrates. The nitrate probably comes from agriculture and farms of the area.

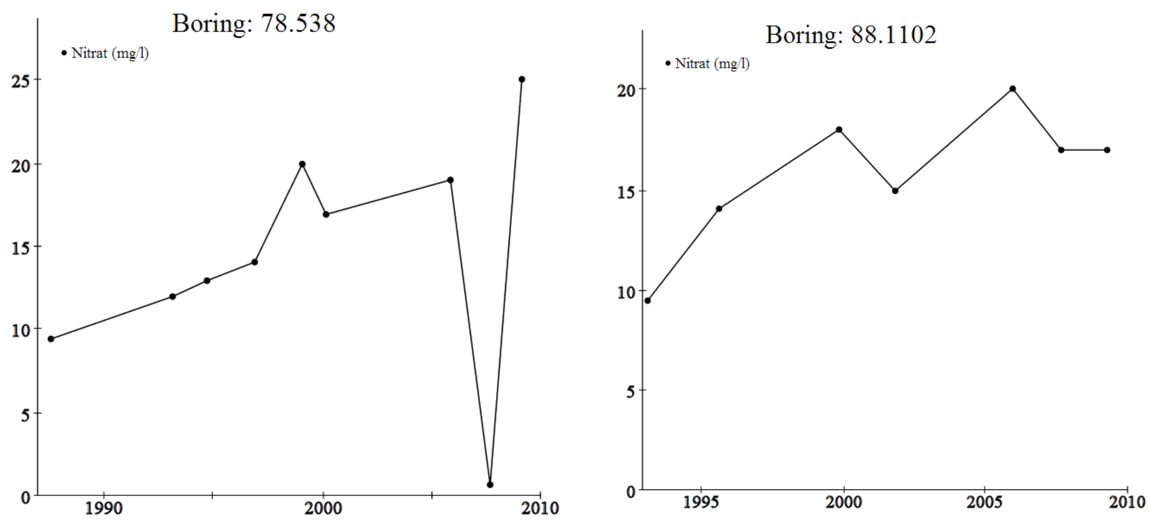


Figure 13: NO_3^- concentration evolution in the last 20 years for the wells 78.538 and 88.1102

From the graph of the well 78.538 (figure 14), it can be seen that the evolution of the nitrate shows a constant increase of the concentration. The maximum showed does not reach the criteria yet, but it can be considered that in some years it will. That is very dangerous because the removal of nitrate needs a special treatment, and high amounts of nitrate are very harmful for the consumers. The best idea is to prevent it by encouraging the consumers who own farms to use less pesticides. The fall down of this graph produced around 2008 is not very relevant, however it was caused probably due to a movement of water in the aquifer from the nitrate front (from a deeper zone of the well). In the case of the well 88.1102, the concentration of nitrate is always lower than in the well 78.538, however it also follows an increase of nitrate concentration in the well. This similar behaviour seems similar because probably both wells belong to the same aquifer.

1.2.3. Well nº 88.1401 (Adress: Eshøjvej 73 - 8471 Sabro)

1.2.3.1. Comparison with the criteria

As it can be seen in table 11, in this well there are three components which concentration does not fit the given criteria: the carbon dioxide, manganese and iron. It is also important to know that the concentrations of some other relevant chemicals (oxygen and nitrate) are quite different from the wells 78.538 and 88.1102. This is the reason why this well is analysed in a different section. These differences make the water of this well having a redox conditions different, however, with the current data it is impossible to know the exact redox type, in other words, there is a redox conflict. But the extremely low concentration of oxygen and nitrate, gives some indications to think that the conditions could be reduced.

1.2.3.2. Analysis of the main parameters and conclusions

Parameters		
I	0,96	Little ion exchange
F	1,25	Typical
dH	10,59	Middle water
logSI	0.13	Not aggresive sample

Table 14: Main parameters of well 88.1401

In the table above (table 14) are the main parameters calculated -by taking the current concentration of the chemical compounds. General data and equations used in appendix B.

a. Ion exchange

The ion exchange value in this well (0.96, in table 14), shows that this process almost did not take place while filtering until the water arrives the aquifer, so the argumentation and conclusions used for last wells are valid. The criteria for the ion exchange parameter can be seen in (appendix B – figure 40).

b. Degree of weathering

The value of the degree of weathering (1.25, in table 14) shows that this process took place. In this process the iron is released, so this could be the origin of the high concentration of iron in the water sample. Here is the difference with the other two wells, which is caused by the low concentration of oxygen and nitrate.

c. Calcite Saturation Index

Calcite Saturation Index (logSI) presents that the sample is not aggressive because its value is higher than zero (0.13, table 14), but comparing to the concentration of carbon dioxide, it indicates that it is aggressive (see appendix B – table 33).

d. Conductivity

The conductivity value can be found in appendix B – table 34. The analysis for this parameter is the same as the shown for the other wells.

e. Ion balance

Finally, **the ion balance** has a value of 0.22 %, so comparing to the range shown in the ion exchange of wells 78.538 and 88.1102, the analysis is quite accurate.

1.2.3.3. Evolution of the concentration of relevant chemicals

a. Carbon dioxide

For this well, the important chemicals to study are the same as before: iron, manganese and nitrate, but in this case, the carbon dioxide will also be studied, just to know if its high concentration was only an isolated case or if the carbon dioxide is high every time.

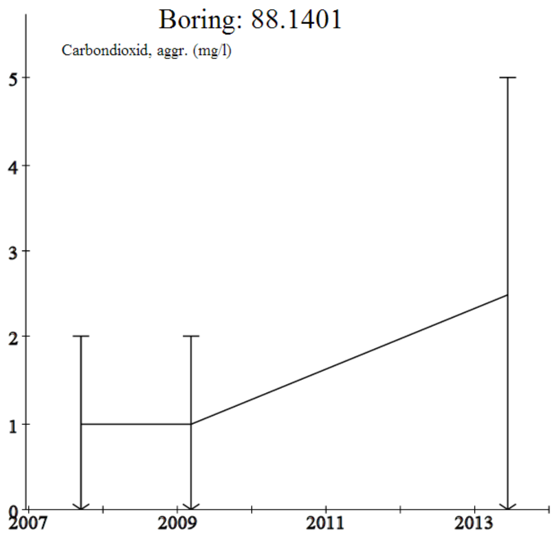


Figure 14: CO_2 concentration evolution in the last 10 years

As it can be seen (figure 15), the carbon dioxide increases during the last years until the last analysis. It is seen that the last two years, the concentration is above the criteria, but not too higher. It means that in the waterworks gases stripping will be needed to remove the carbon dioxide. However, the concentration increases constantly with time, but in this case it is not very dangerous because the removal of carbon dioxide is by standard treatment.

b. Iron

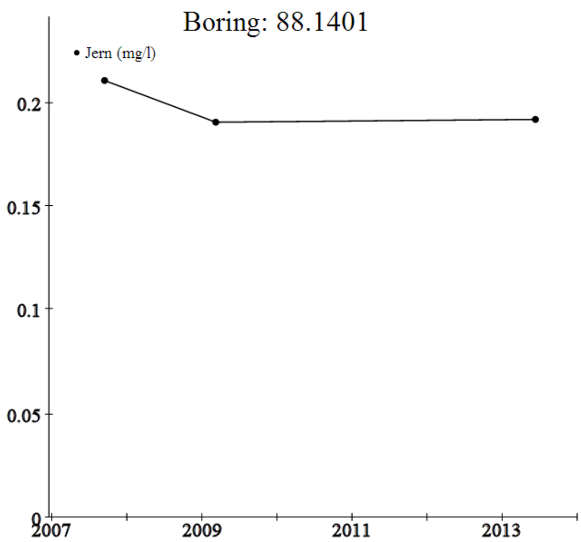


Figure 15: Fe concentration evolution in the last 7 years

In the case of the iron (figure 16), it is seen that seven years ago, the concentration was a bit above the criteria and it has been constant and above the criteria during the last 5 years. It means that the iron must be treated in the waterworks.

c. Manganese

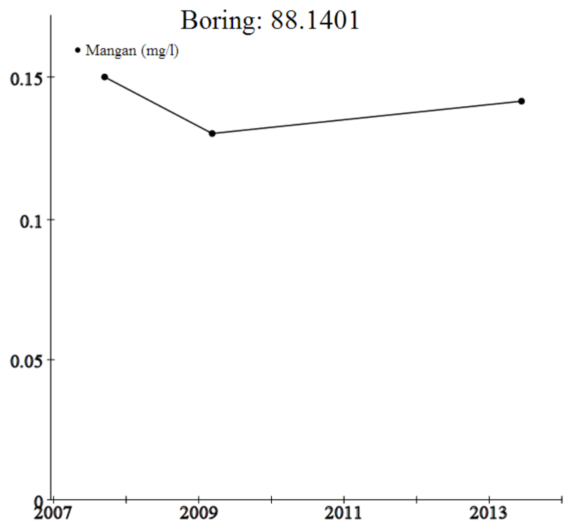


Figure 16: Mn concentration evolution in the last 7 years

The concentration of manganese (figure 17) is all the time above the criteria given, as it happens in the last chemical analysis. It only means that the waterworks will have to treat manganese as well. In this case the concentration of manganese looks like it has increased the last five years, but the tendency is very slow.

d. Nitrate

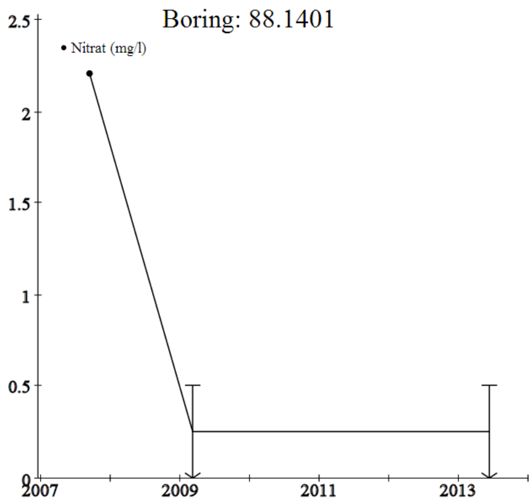


Figure 17: NO_3^- concentration evolution in the last 7 years

In this case, the removal of nitrate is not necessary, and the prevention neither. The concentration of nitrate in this well is always very low (figure 18).

1.2.4. Conclusion

1.2.4.1. Well 78.538

It can be said that the well 78.538 belongs to an aquifer which is not well protected, probably with relatively young water but of a good quality. However it is very vulnerable to contaminants that the groundwater can wash out. The groundwater in this aquifer is in a strongly oxidised conditions and buffered pH, which means that there is not presence of acids. Probably the weak hardness of the water comes from the buffering process and some processes cannot take place (like sulphate reduction) due to the oxidised conditions. Fortunately, the chemical history of this well proves that the water that comes from this aquifer only needs some standard treatment for the iron and manganese.

1.2.4.2. Well 88.1102

The treatment needed for the groundwater taken from the well 88.1102 is the same as the required for the well 78.538. Besides, both wells have the same characteristics and the screen separated by a low distance (50 and 67 respectively – appendix A – figure 36 and 37). It means that probably both wells belong to the same aquifer. It is also important for both wells that the prevention of nitrate increase, overall because of the low protection of the aquifer. If the increase of nitrate is not prevented, there will be a risk of a necessity of the nitrate treatment, which is special and different from the treatment available nowadays in the waterworks - as it will be oulined in the next part of the report. The presence of high level of nitrate usually results in closing the well, something that has already happened in this area with two wells.

1.2.4.3. Well 88.1401

The treatment needed for the water abstracted from this well is the standard one, and there is no risk of appearance of other dangerous chemicals such as nitrate. As it can be seen in the geological profile (appendix A – figure 38), the chemical composition and the redox conditions, this well probably belongs to a different aquifer than the 78.538 and 88.1102.

1.3. WATERWORKS ANALYSIS

1.3.1. Introduction

In this part of the report a thorough description of Sabro waterworks will be given. All the data was provided from on-line sources. The waterworks consists of elements such as pumps, storage tanks, compressors, pipes and measuring equipment (flow meter, pressure gauges). In the followings chapters some calculations concerning filter design, velocity and as well operation and backwash time, wash water consumption, efficiency of water treatment and afterwards its quality are shown. Also information about a hygiene inside the waterworks will be mentioned. The aim of this kind of facility is to produce a decent drinking water, so that is why, checking the condition of filters seems to be one of the most crucial tasks. After caring out the analysis conclusions and some suggestions concerning any possible changes in the future will be introduced – as it was mentioned before, Sabro is about to be expanded, so an increase of populations is forecasted. Sabro waterworks uses air compressor, air blower, 2 pressure filters TFB25 maximum flow 25m^3/h, dehumidifier, pumps, 2 fresh water tanks which capacity is 425 m^3, backwash water tank which capacity is 425 m^3.

1.3.2. Filters design, filters velocity

Water conducted to waterworks derives from three wells, which were described before. As well, as it was mentioned in previous chapters, it call for treatment, it cannot be distributed to consumers without this process. The whole equipment should be chosen based on the results obtained from measurements – which will be presented beneath, in order to check the condition of the waterworks and if it is suitable for Sabro.

The waterworks uses two pressure filters TFB25, of the maximum flow equal to 25m^3/h. Below can be seen values of velocities, consumptions. Estimated time for waterworks is 14 hours. Filter area is 1,77 m^2, high of the filter bed is 2,29m, filter volume approximately is 4,04 m^3 and the porosity is 0,4. (appendix C–Table 36)

Figure 19: TFB25 filters filters in Sabro waterworks for cleaning water

Velocity filter m/h	True velocity filter m/h	Year consumption m^3/year	Day consumption m^3/day 1(filter)	1 filter flow m^3/h
7.95	19.87	143,474.2	196.54	14.04

Table 15: Key characteristics of filter TFB 25 based on 2013 consumption of street, yearly average calculated values

The main element which needs to be removed in Sabro waterworks is iron, manganese and aggressive CO_2. The concentration of iron is about 0.192 mg/l whereas the criteria is 0.1. Manganese is 0.142 mg/l, but criteria is 0.02 mg/l. Iron and manganese concentrations are taken in the worst case. (appendix C–Table 35) (appendix B–Table 29, Table 31, Table 33).

The city has still an increasing number of populations around 220 new households are planned. Each household will gather approximately 2,5 person per house and each person use about 150 litres per day. The calculations data can be seen in appendix C–Table 37, Table 38, Table 39, Table 40.

Velocity filter m/h	True velocity filter m/h	Year consumption m^3/year	Day consumption m^3/day 1(filter)	1 filter flow m^3/h
9.62	24.04	176,586.7	237.79	16.99

Table 16: Key characteristics of filter TFB 25 based on 2013 consumption of street, yearly average calculated values

As it can be seen, consumption raises about 30,000 m^3/year. The flow of filters changes approximately to 2.5 m^3/h. Of course, the backwash consumption and times of it will increase, because more water will go through the filters and the iron concentration will be increased in filters as well. Maximum filter velocity is 25 m^3/h, so the filters can properly do their job. In addition, filters design is a very important issue. Filters layers and (their thickness is of a great importance) are used to clean raw water from elements which value is higher than criteria. For removal of aggressive CO_2 air in pressure filters is needed. After the raw water is pumped to pressure filters there is a signal for the air compressor to blow air to the filter to reduce aggressive CO_2 concentration in raw water appendix C–Table 37, Table 38, Table 39, Table 40.

Number Nummer	Description Beskrivelse	thickness of layer [cm] Lagtykkelse i cm.	thicknes [%] Lagtykkelse i %
327538-001	NEVTRACO I 20LT/25KG	59,77	46,85
327534-101	HYDROLIT MN I - 15,5 liter	12,47	9,78
327510-104	KIS 3 0,8-1,4MM. 17,61LT/25KG.	36,43	28,53
327510-103	KIS C 1,6-2,5MM 17,36LT/25KG	9,48	7,42
327510-101	KIS A 3-5MM 16,67LT/25KG	9,48	7,42

Bund ---------->Top

Figure 20: Model of filter filling for TFB25 pressure filter [Reference 13]

Each filter uses a single filtration and has two media. All the information about the filter can be seen above in the figure 20.

1.3.3. Wash water consumption

Wash water is used to clean filters. During this process air is blown to the filters. There are two criteria concerning the moment when backwash should be made, so it depends on which one will be achieved first. One claims that the backwash should be implemented after 5 days and the other one, that when the amount of water which goes through the filter oversteps 440m³.

Figure 21: Air compressor for mechanical aeration in filters and for valves

	Filter 2	Filter 1
Total flow	329192 m^3	329143 m^3
Yesterdays flow	70 m^3	68 m^3
Another wash	194 m^3	191 m^3
Number of washes	655	643
Next wash	401 m^3	189 m^3
In advance	440 m^3	440 m^3
Next wash in time	119t	94t
Days in advance	5	5
Rinse step	20	0

Table 17: Display example of filters [Reference 13]

Despite the criteria, in Sabro waterworks the backwash is carried out more often, every second day. Calculated cleaning was 23.4 days (iron). The consumption of wash water for the first filter is 4.026 m^3 and for the second filter is 4.392 m^3 – provided by the head of Sabro waterworks. Calculated value is 4,045m^3. The easiest way to measure filters wash water consumption in order to calculate it, is to take a ruler and make measurements before and after backwash, to see the difference in the water level. (Appendix C– Backwash calculations)

1.3.4. Treated water quality and efficiency of waterworks

In Sabro, the main element witch needs to be treated is iron. Iron criteria is 0.1 mg/l, and the information from the Jupiter database from one of wells in that area shows 0.192mg/l, so the concentration is close to the criteria value. To clean the raw water, as it can be seen in chapter "filter design, filter velocity", waterworks uses pressure filters. Iron concentration, after the treatment, drops to 0.002 mg/l.

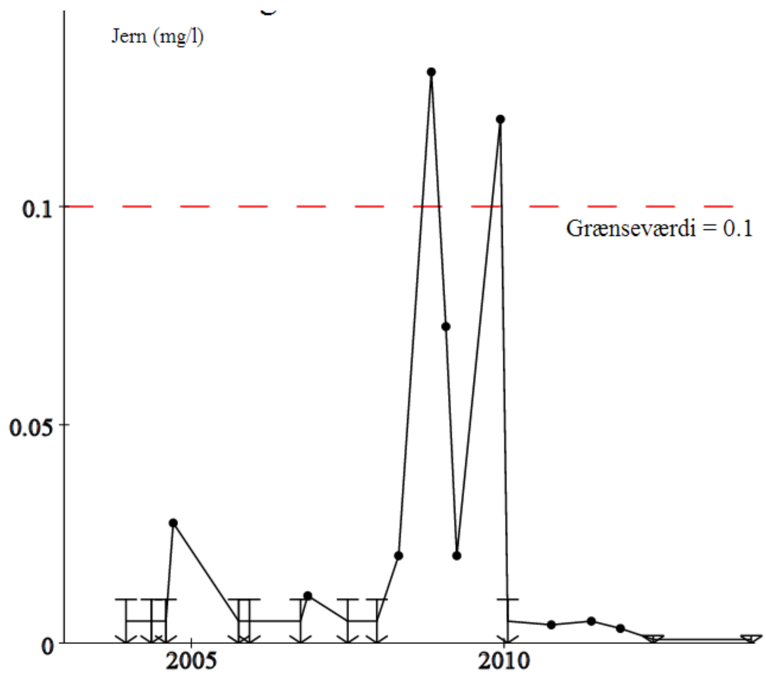


Figure 22: Iron concentration in water since 2005 till 2014 from the one of the households

As it can be seen the concentration now it is very low, the water is clean and drinkable. In 2008 concentration was a bit higher than the limit which is 0,1 mg/l. Now Sabro waterworks filters improved and the capacity of iron is insignificant.

Sabro Vandværk - Analyser

ANALYSEPARAMETER	RESULTAT	ENHED	MIN	MAX	D.L.	METODE/REFERENCE	+/-	
Arsen	**1.3**	µg/L		5	0.02	M-0140 RefM018/ICP-MS	10%	✓
Benzen	**<0.1**	µg/L		1	0.1	M-0131 GC-MS	20%	✓
Bor	**0.02**	mg/L		1	0.01	M-0139 RefM018/ICP	10%	✓
C10-C25	**15**	µg/L		10	5	M-0153 DS 9377-2 Mod.	20%	✗
C25-C40	**<10**	µg/L		10	10	M-0153 DS 9377-2 Mod.	20%	✓
C6-C10	**<2.5**	µg/L		10	2.5	M-0153 DS 9377-2 Mod.	20%	✓
Cobalt	**<0.05**	µg/L		5	0.05	M-0140 RefM018/ICP-MS	10%	✓
Coliforme bakterier	**<1**	pr. 100mL		0	1	M-0032 Colilert	lg0.3	✓
E. Coli	**<1**	pr. 100mL		0	1	M-0032 Colilert	lg0.3	✓
Ethylbenzen	**<0.1**	µg/L			0.1	M-0131 GC-MS	20%	
Ilt	**9.6**	mg/L	5		0.1	M-0064 DS/EN 25814	5.0%	✓
Jern	**<0.002**	mg/L		0.2	0.002	M-0139 RefM018/ICP	5.0%	✓
Kimtal 22°C	**27**	pr. mL		200	1	M-0031 DS/EN ISO6222	lg0.3	✓
Ledningsevne	**47.0**	mS/m	30		1	M-0009 DS 288	5.0%	✓
Lugt drikkevand	**Ingen**					Organoleptisk	-	
m+p-xylen	**<0.1**	µg/L			0.1	M-0131 GC-MS	20%	
Mangan	**<0.001**	mg/L		0.05	0.001	M-0139 RefM018/ICP	10%	✓
Napthalen	**<0.1**	µg/L		2	0.1	M-0131 GC-MS	20%	✓
Nikkel	**0.15**	µg/L		20	0.03	M-0140 RefM018/ICP-MS	10%	✓
o-xylen	**<0.1**	µg/L			0.1	M-0131 GC-MS	20%	
pH	**7.7**	pH	7	8.5	0.05	M-0010 DS 287	5.0%	✓
Smag	**Normal**					Organoleptisk	-	
Temperatur	**8.4**	°C			0.1	TERMOMETER	1.0%	
Toluen	**<0.1**	µg/L			0.1	M-0131 GC-MS	20%	
Total CH	**15**	µg/L		10	2.5	M-0153 GC-FID	20%	✗
Udseende	**Klar**					Organoleptisk	-	

Table 18: Sabro waterworks water analysis on 28 of April 2014 [Reference 12]

The table above presents the newest information of the water after the cleaning process. The waterworks clean all the elements which have higher concentration than it needs to be, so their performance is satisfactory.

1.3.5. Filter operation time and backwash time

Step 1	Delay before backwash start	60 sec.
Step 2	Valve change	60 sec.
Step 3	Air alone	360 sec.
Step 4	Pause	120 sec.
Step 5	Backwash water (alone)	360 sec.
Step 6	Delay after backwash	120 sec.
Step 7	Valvechange	60 sec.
	Time from filling of backwash tank before pumping of water to recipient.	20 hrs

Table 19: Procedure for filter backwash

Backwash process has 7 steps. All of these steps are singled out in Table 4. Sabro waterworks uses compressor for valves, start/stop function, automatized alarm for low pressure , level transmitter for low/high water level, level switch for low level indication to prevent pumps from getting dry, flow meter. Backwash starts after 2 days or after 420m^3 consumption. As it can be seen in the Table 4, backwash takes 6 minutes , the water after backwash goes to sediment tank where stays for 20 hours. After 20 hours the water is pumped back to wells. Also, it was necessary to calculate Empty Bed Contact Time (EBCT) and residence time (T_{res}).EBCT is the length of time which water could be in filter bed if it is empty and it is 17,29minutes. T_{res} is the length of time that water is actually in filter bed and it is 6,91minutes. The T_{res} is similar which was given. (appendix C–Table 41, Table 42)

1.3.6. Hygiene inside the waterworks and protection

Hygiene and protection in waterworks are important factors. Water tanks with treated water should be protected from the environment, animals, bacteria, viruses. Waterworks should be clean all the time, fresh water tanks need to be tightly closed.

Figure 23: Fresh water tanks, their tightness and cleanness

In waterworks there is a need to sustain the same temperature and humidity. Furthermore proper ventilation is required. The temperature and humidity differences can destroy engineering equipment. In the picture below a ventilator can be seen. It blows dry air on non-stop basis, so that the waterworks is protected from freezing. Dry air also protects equipment from humidity.

Figure 24: Drainage pump

Figure 25: Dehumidifier in Sabro waterworks

In the Figure 24 drainage pump for the accidents is shown. If the pump is broken, the water is poured out – on a floor.

1.3.7. Conclusion

After checking the elements and the process in the waterworks a fair assessment can be made. The waterworks are working properly, both filters are pretty new and show no problems while treating the water. In addition to this citizens of Sabro get clean, drinkable water. As far as the conditions in the waterworks itself are concerned, the level of hygiene and protection are satisfactory and no changes are needed. There should be no influence, requiring any serious modification, in the time where new will be added to the system on the waterworks. The only thing which may be changed is the frequency of backwash. It is suggested to check the filters material before connecting the new area and for now it is possible to limit the number of backwash. Some calculations were carried out showing that 23 days is a period which might be suitable for the backwash.

1.4. NETWORK ANASYSIS

1.4.1. Introduction

Sabro, being one of the smaller cities united with Aarhus Municipally, situated in the west, is planned to expand its boarders in the east soon. The aim is to obtain a new public-oriented green area and as well create new housing facilities (such as small family houses and apartment buildings). 13,5 ha is destined to be rendered habitable. This new area, as planned by now, is subdivided into 6 regions and the number of households is claimed to reach 220. As a water supply system must be provided in this upcoming part of the city, the aim of this chapter is to estimate the existing system, and further on, suggest the suitable solution for connecting the new area and detecting potential future problems (e.g. the system cannot operate properly, due to increase of the consumption or the values of pressure or flow are not sufficient).

Below the current system is presented. The red sign stands for the waterworks.

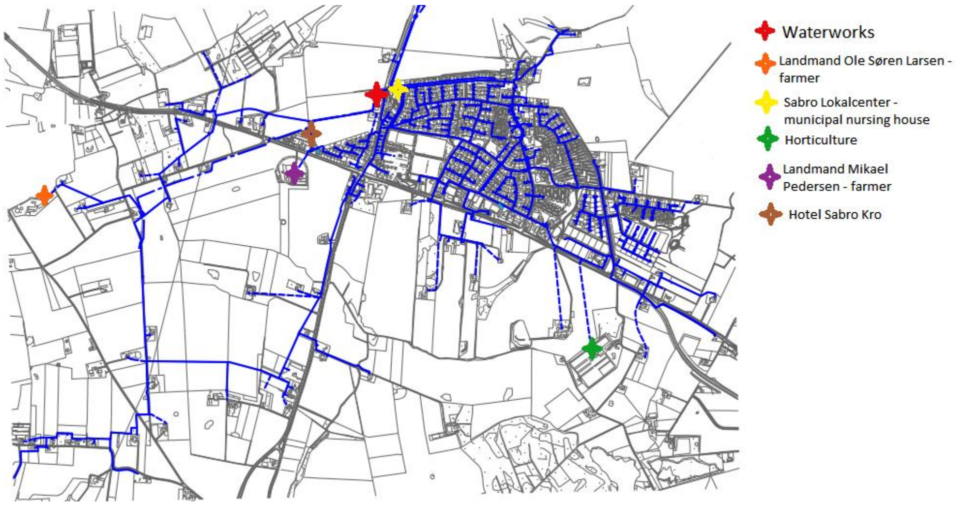


Figure 26: Existing water supply system in Sabro with the waterworks and the biggest consumers marked [Reference 12]

While checking the efficiency of the system a simplified model was produced. Knowing the overall amount of households, businesses, institutions (etc.), the consumption in almost every street was estimated. As a given data for the consumers were introduced in cubic meters per year, and while creating models in Mike Urban & Epanet the unit should be liters per second, it was essential to pursue some calculations. Values chosen in carried out equations are shown beneath.

	fd	fd max	fh	fh max	days/year
households	1,7	2	2	2	365
farms	2	2	2	2,5	365
gardens	2	2	2,5	2,5	250
bussiness	1,7	2	2	2	300
institutions	1,7	2	2	2	200
nursering.house	1,7	2	2	2	365
hotels	1,7	2	2	2	365

Table 20: The coefficients chosen in a calculation procedure

There is a significant outtake of water by the five biggest consumers – nursing house, two farms (one located on the Bakkevej street and the other on Viborgvej), horticulture facility and hotel [reference 13] – in the constructed model these consumers are ascribed to detached nodes. As mentioned before values implemented to Mike Urban, while creating the network, are introduced in liters per seconds – according to the flow, in meter – according to the elevation and pipes length and in millimeters – as far as pipes' diameters are concerned.

1.4.2. Simplified model for existing system

For this stage of analysis two models were constructed – one for the mean flow and the other for the maximum flow (respectively using mean and maximum factors presented in Table 20). Whilst designing the network the maximum flow is taken into consideration, so that it can be proved, that in the time of the highest demand, in every point of the network, every consumer has an access to water. In the Figure 27. and Figure 28. the simplified model of the network is presented.

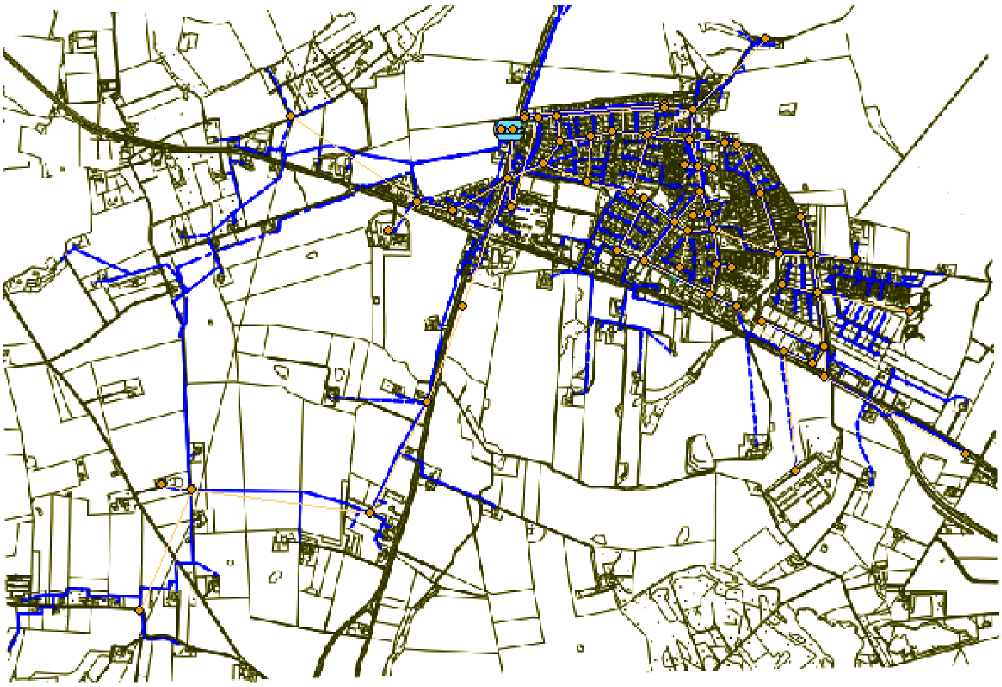


Figure 27: The produced simplified model on the original layout –blue lines represent the existing network, whereas thinner, yellow ones the simplified network produced for the need of the report

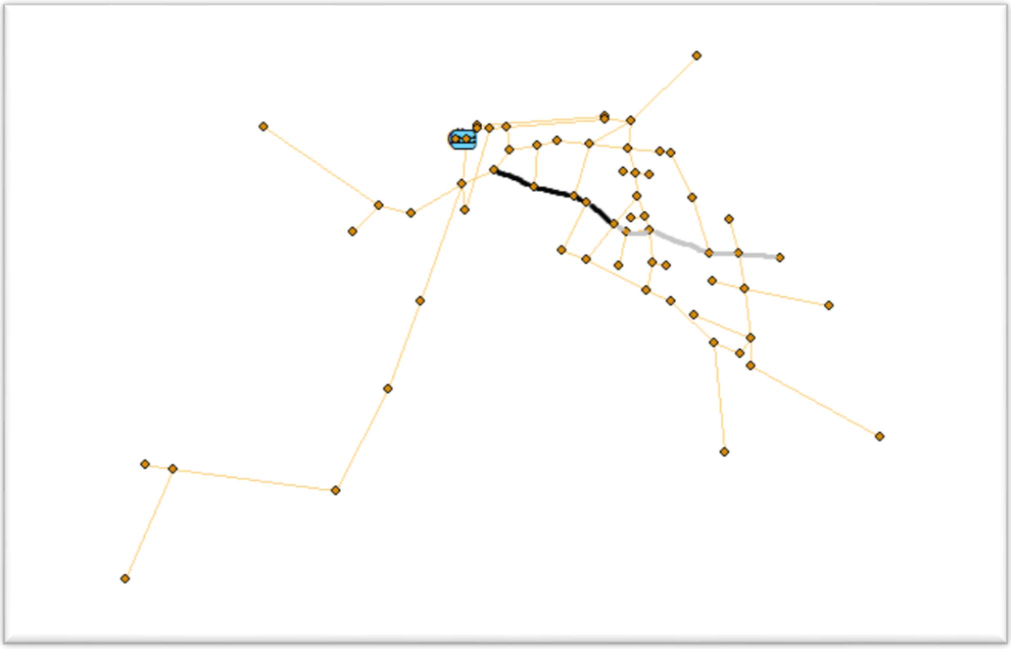


Figure 28: The produced simplified model with the main pipe distinguished

Using Google Earth program all the elevation data was ascribed to each node, whereas the lengths of pipes were obtained throughout the measuring tool available on the website - http://sabro.vandforsyning.net/mainpage.aspx. It was also required to describe the performance and significant values for a reservoir, as it is crucial to provide enough pressure, so water can be distributed in the whole system satisfactory. According to this the elevation of the reservoir was set as 123 meters above the sea level – where 83 meters above the sea level represent its location and 40 meters are the additional ones, it equals to 40mWC, so to 4bars, which is an outgoing pressure measured in the waterworks [Reference 13].

Pipes' outer diameters in the system (all are of PE kind with roughness 0,01) vary from 63mm to 225mm (75mm, 90mm, 110mm, 160mm), so that the main pipe has the biggest one in the beginning and then changes it into 160mm, going from west to east.

Running the simulation the extreme values were checked and shown in the table below.

	MEAN FLOW – MIN.Values	MEAN FLOW – MAX.Values	MAX FLOW – MIN.Values	MAX FLOW – MAX.Values
PRESSURE [mWC]	25,85 (area of Kiresbaervej)	69,43 (the middle of the pipe on the Stillingvej)	25,75 (area of Kiresbaervej)	68,95 (the middle of the pipe on the Stillingsvej)
FLOW [l/s]	0,01 (Urebjergvej)	3,43 (the outlet of the waterworks)	0,02 (Urebjergvej)	4,60 (the outlet of the waterworks)
VELOCITY [m/s]	0,00 (Sabrovej, Gronvej)	0,25 (the outlet of the waterworks)	0 (Urbjergvej, Sabrovej, Gronvej)	0,34 (the outlet of the waterworks)

Table 21: The extreme values in the network in mean and maximum situations

In every case the pressure does not drop below 20mWC, which, according to thumb rule, means that its value is sufficient and the consumers should not face the problem while using water. At some points in the network it reaches quite big values, almost 70mWC. The reason for it is the terrain on which Sabro is located – it goes down from north to south. The high pressure may cause a reduction of pipes 'life', making them more prone to cracks and etc. The velocity and flow, closely related, seem to be characterized sometimes by really low numbers, however the pressure guarantee that water is provided everywhere in the system. Values of this two parameters might be low due to pretty big pipes' diameters, it indicates that there might be as well too long retention time in some points of the system. Nevertheless calculations, carried out in order to check if there is a significant negative aspect like this mentioned above, showed that the period during which water stays in pipes should not have any impact on its quality. It is worth-mentioning that big diameters give a possibility for the future to expand the network, in case new areas will be built.

1.4.3. Estimation of the network performance in case of any excluding of different parts of the network

In order to test the network more thoroughly four pipe paths were closed, one by one (Figure29.). Pipes located at the beginning of the network, one which goes south and the other one which goes north, the part of the main pipe with a bigger diameter and, as the last one, a long pipe line just close to Viborgvej. In each situation simulations were run and obtained values for each and every node were analyzed. Proceeding these tests provide an important information concerning any potential problems in case of some damages, which may happen to the system. In all of the cases, carried out under conditions of the maximum flow, no worrying phenomenon was noticed, the values for pressure presented more or less the same range of values, though at some points they differentiate slightly, which actually didn't put any threat to the performance of the network. As far as velocity and flow was concerned the range was characterized similar as for the non-fault piping layout, nevertheless some more places with a low measurements were observed – hence the retention time sometimes was increased, yet not that significant to plan any changes.

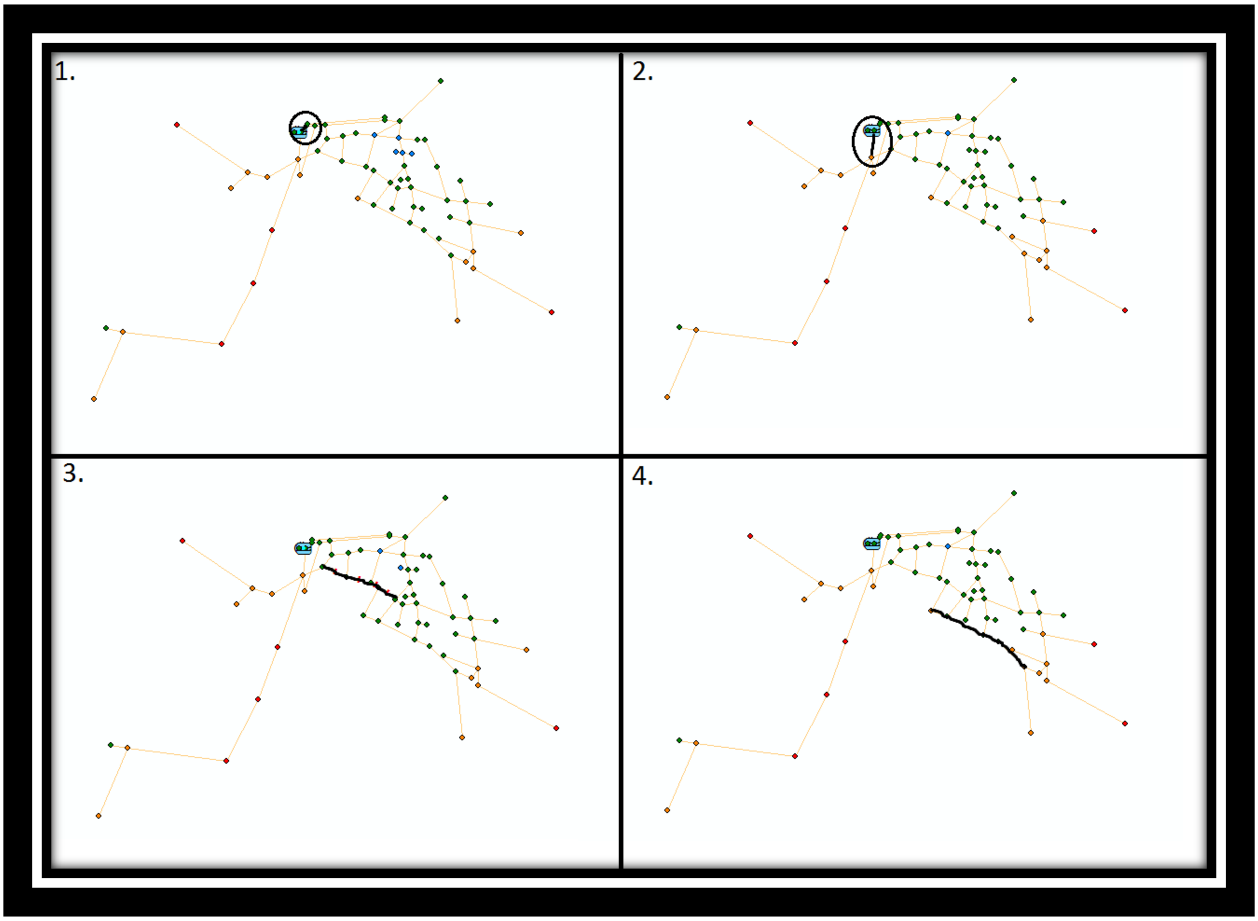


Figure 29: Closed parts of the network

The performance of the existing network is sufficient and pose no problems while distributing water in Sabro. Moreover it seems to be designed with a possible intention of expanding the system in the future, as the diameters are bigger than the ones which might be suitable, meaning that more money was destined for the project than necessary, if the network was not believed to be larger. This believe is justified in the following sections of this chapter, while the new area is connected to the model.

1.4.4. Analysis of the model with an additional consumers' area

Mentioned in the introduction, the new area is about to be implemented in the Sabro city, and what is bound to it, the extra distribution area need to be added to the existing network. To estimate the demand the average amount of water used per one person in Denmark in the space of a second, which is equal to 0,00162 liters (www.hykredit.dk , 11/04/14), was multiplied by the predicted number of the new citizens (as the average number of people in one house in Denmark is 2,1 - www.hykredit.dk , 11/04/14 - it was multiplied by the number of the new households, equal to 220). The consumption in this area was estimated to be equal to 1,2716 l/s (as the average and maximum factor is the same, the number was the same while proceeding the simulations under mean and maximum conditions). The new node was placed at the corner of the new planned area and two pipes connected it to the system. One of them was conducted to the nodes located on Astervej and Sabrovej. The layout of the system is presented on the Figure30.

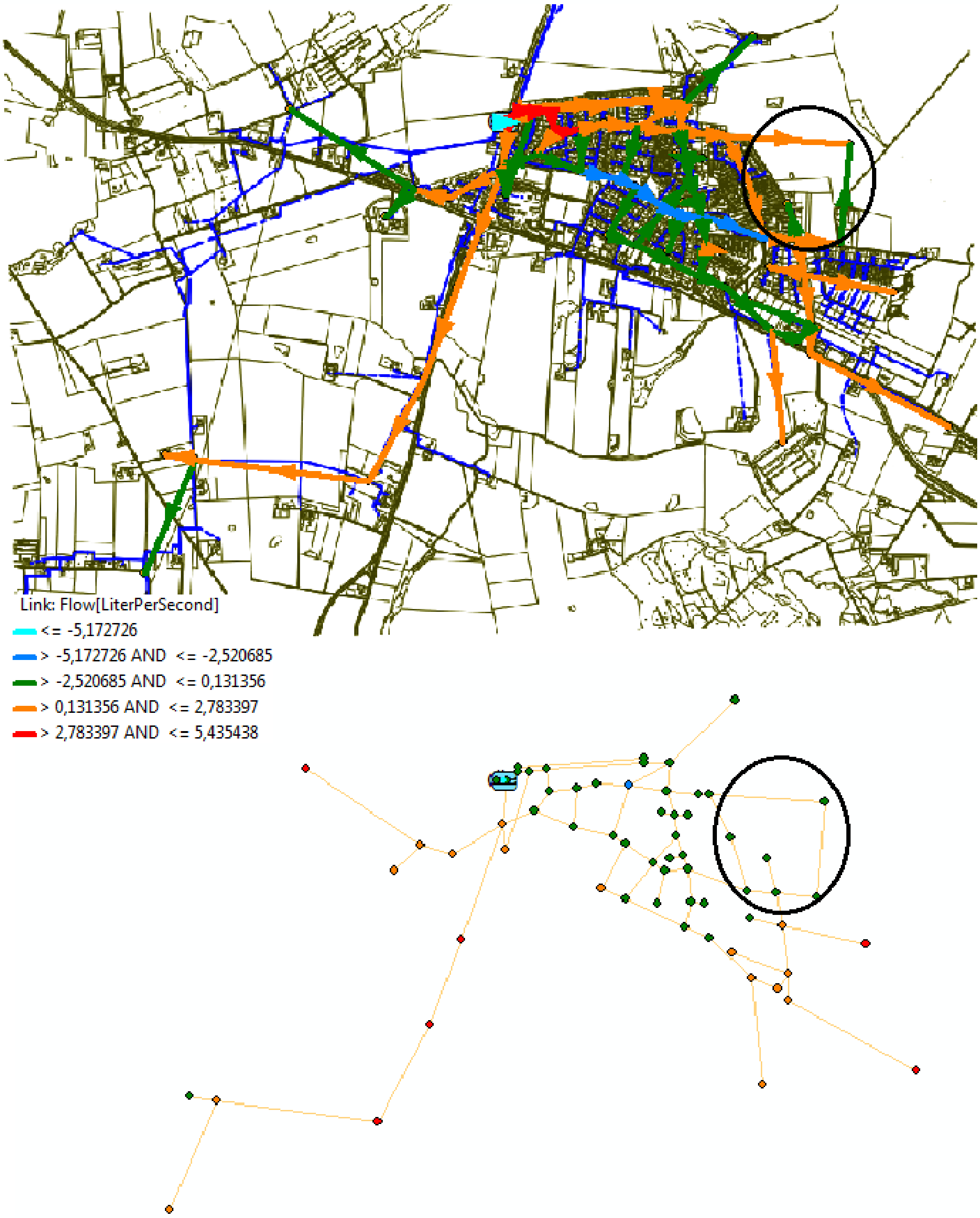


Figure 30: The layout with the inserted extra area enclosed in the black circle

New pipes' outer diameter is 110 mm, the lengths are 97,37 meters (from Astervej node) and 81,72 meter (to Sabrovej node).Pressure in the new node is equal to 35,53 mWC, whereas flow and velocity are respectively 0,65 l/s and 0,07 m/s in the first pipe and 0,36 l/s and 0,04 m/s in the second one. Values for the flow and velocities seem to be pretty low, that is why, to make sure if suggested diameter is suitable, the retention time was checked. The range of the retention time was obtained between 7 and 10 hours, which is an acceptable outcome.

As before, in the existing network, the same pipe paths were closed to see the performance of the future network. In each situation no problems were detected, not only in the new area, but as well in the whole system. These may be a decent proof that the system was constructed with a thought of expanding it and what is more the solution for the new area is given. After running the simulations there is a certainty that the system is capable of being attached to the extra consumers' area and can perform satisfactory, which was the aim of the following part of the report. There are not critical points to be outlined which also is promising for the future changes.

1.4.5. Conclusion

The existing system is operating properly, as the water is provided to every point of the network, no complaints from citizens were filed according its performance and no critical values during the analyze were detected. After connecting the new, planned area, the system was still able to keep the sufficient level of operation. As it was mentioned before a lot of pipes were designed with a bigger diameter than necessary one, but in case of implementing other new areas, it makes it more convenient, as no changes to the older parts will be probably needed (the capacity of big pipes in the system is still not fully used).

1.5. CONCLUSION

Within the recharge area of the Sabro well field some consumers that represent the most important nitrate producers of the area are found. Looking at the chemical analysis of the wells, the nitrate concentration increases and it will reach dangerous values in some years if its discharge is not reduced.

As it is seen in figure 31, the Horticulture and Farmer consumers (inside blue area) are the ones which mainly cause too big concentration of nitrate, so to prevent this negative phenomenon these consumers should be somehow encourage to use less of this compound.

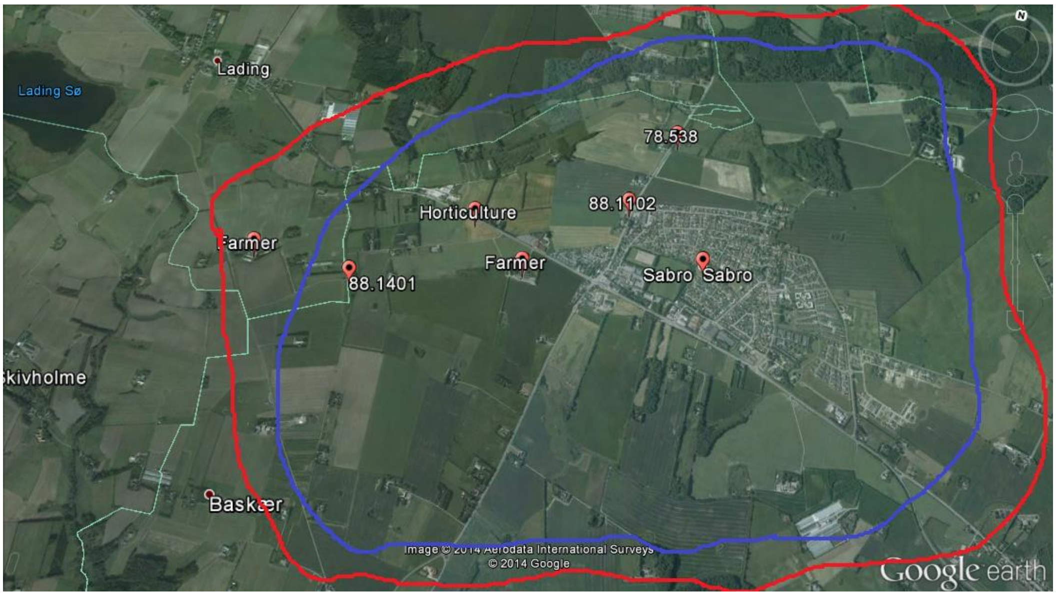


Figure 31: Sabro area with the current recharge area (blue) and the future recharge area (red)

In the red area (future recharge area (20 % bigger) a new farmer will be attached to the recharge area, which is a new source of nitrate. It means that this consumer should be included in the future in the prevention plan.

The waterworks, however, does not have problems to achieve its goal, which is nowadays, getting rid of iron, manganese and carbon dioxide. The installation can take care of the current demand and the future demand (with the new area added). Again a nitrate concentration might be problematic if nothing will be done soon. There might be a necessity of implementing the additional, extra treatment, which is pretty expensive. There are two ways of possible treatment: anaerobic treatment with organic matter to convert the nitrate in nitrogen, or treatment by membranes.

Finally, as it has been shown in the analysis of the network, the installation is ready to deal with the water demand in the current Sabro area and the future one. Its size is sufficient to deliver enough water for every consumer of Sabro. However, some problems can be caused because of the high pressure in some zones of the network system like cracks and leaks, but in general the networks system is considered to work properly.

2. OPTIONAL PART

2.1. INTRODUCTION

The second part of report – the optional part – is based on the analysis of potential influence of Ristrup Waterworks on Sabro Waterworks while abstracting water from wells. As it can be noticed, in the figure beneath, wells which belong to the Ristrup facility are lying in the relatively close distance to the once of Sabro.

Figure 32: The location of Sabro (red stars) and Ristrup (yellow stars) wells

In order to make a meaningful assessment, concerning this matter, it is essential to check if there is any geological connection between the aquifers from which each and every well abstract water, from these shown in the figure 32, carry out chemical analysis of the water quality, so that any similarities might be found between the water in the both facilities, describe the relation in the graphs, which derive from pumping tests of the wells, in order to check if there is an influence of the quantity of water acquired as well in Ristrup as in Sabro, while operating both waterworks at the same time. All of this aspects are thoroughly presented on the following pages and a credible conclusion is given to sum up the outcome of research resulting in solving the task.

2.2. GEOLOGICAL PROFILES

The first step of evaluating the potential influence of Ristrup waterworks on Sabro waterworks is to analyze existing geological layers within both areas. Throughout comparing the sediments and levels of water tables is it easy to make an assessment of the possible connection between aquifers, in different words, checking if water in both waterworks is abstracted from the same water-bearing sediment, which indicates that there is a fair chance of affecting the quality (meaning as well quantity of water released to the supply network) of one facility while the other is working. In order to achieve this goal a program called GeoScene 3D was used, and a data filed provided from Aarhus Vand Company was applied, so that the needed profile could be obtained. Figure1. shows a projection form above on the path along which the profile was constructed, whereas in the following Figure33., the profile itself is presented.

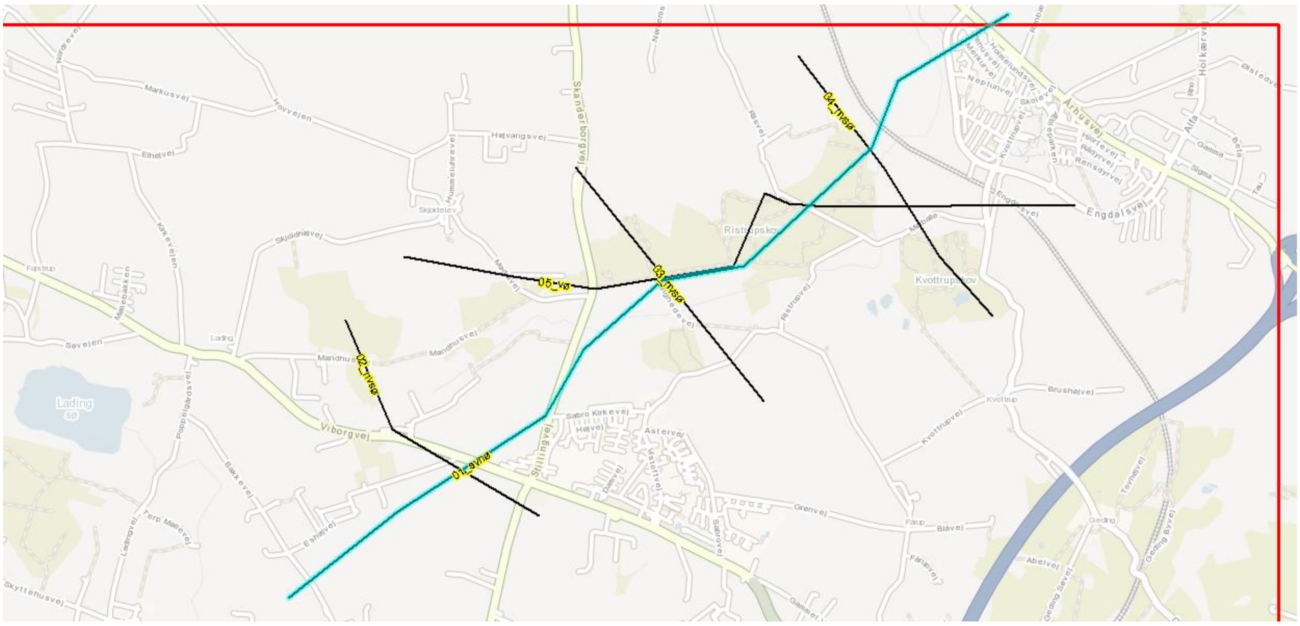


Figure 33: The projection of the path of the needed geological profile - shown as a blue line (number 01)

Profile of geological layers in (appendix D – Figure 46)

To make the profile more clear in the table22 the abbreviations are explained. As it can be noticed the profile is simplified – there are less layers in the pictures comparing to their amount singled out next to the wells. This is the result of a different interpretations of geologists who described the profiles, some of them decided to differentiate more sediments than others, who probably did not consider it as a crucial approach or did not do it precisely enough.

Lithological codes (GEUS)	Description	Hydrostratigraphical unit
g	gravel	aquifer
s	sand	aquifer
i	silt	aquitard
l	clay	aquitard
ms	sandy till	aquitard
ml	clayey till	aquitard
dg	glaciofluvial gravel	aquifer
ds	glaciofluvial sand	aquifer
di	glaciofluvial silt	aquitard
dl	glaciofluvial clay	aquitard
ks	miocene quarts sand	aquifer
gs	miocene mica sand	aquifer
gi	miocene mica silt	aquitard
gl	miocene mica clay	aquitard

Table 22: Description to abbreviation of sediments given in the profile

To give a better understanding of the profile it is necessary to explain for what stays each color. In GeoScene 3D yellow, pink and red refer to sand, brown to clay and blue to pre-Quaternary sediments. Being provided with this knowledge it is pretty easy to notice that there is connection between wells , meaning that they lie in the area of the same aquifer, which actually is located in, so called buried valley. That indicates that there should be an influence on one waterworks to another.

2.3. PUMPING TEST

2.3.1. Introduction

In order to estimate if the influence of Ristrup well field on Sabro well field exists, the wells 78.432 and 78.433 (of Ristrup – they are the closest to Sabro) are going to be checked by analysing the pumping test for each of them. As well wells 78.538 and 88.1102 of Sabro will be compared (because they are considered near Ristrup). The rest of wells from Ristrup and Sabro are not taken into consideration in this analysis due to their are location – the distance between two well fields is bigger.

First of all, the transmissivity was calculated using the data which concerns time and drawdown [Reference 14], then the distances between all wells was calculated by taking the coordinates of the wells from Jupiter. Furthermore the storativity was assumed for both wells of Ristrup. Then, the parameters (storativity and transmissivity) were used in the functions [Reference 14] designed to calculate the drawdown in confined and unconfined aquifers depending on time. The result of the well is compared with the results taken from the field study in Ristrup area [Reference 14].

Knowing if the wells are confined or unconfined, the influence of the water abstraction in Ristrup is checked in the two wells from Sabro waterworks.

The detailed calculations and the process are shown in appendix E.

2.3.2. Results

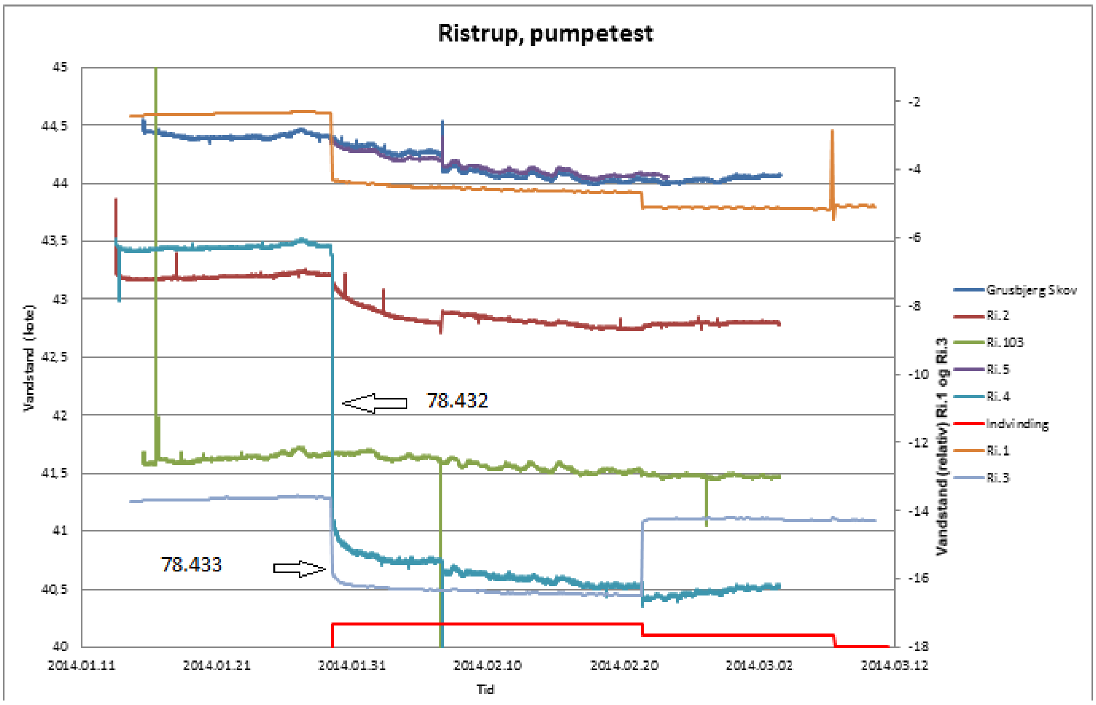


Figure 34: Pumping test in Ristrup, with the drawdown of every well

In well 78.432 the drawdown is 2,5 meters (see figure 34) and in the calculations for the confined aquifer it is 2,09 m (see appendix E – figure 48). For the unconfined aquifer the drawdown in well calculated is 1,59 meters (see appendix E – figure 49).

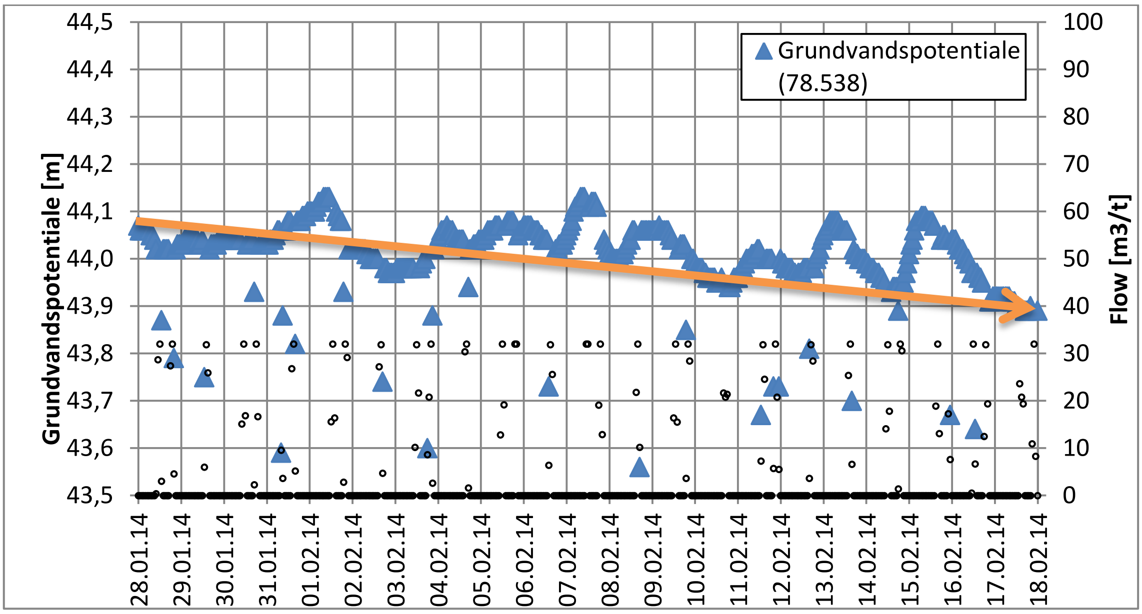


Figure 35: Drawdown in well 78.538 [Reference 14]

And the drawdown from the well 78.432 (confined aquifer) in 881 meters distance is 0,42 meters whereas the value for the drawdown from well 78.538 is 0,1 can be seen in diagram (figure 35). In the unconfined aquifer of the same well the drawdown is -0,07 meters.

2.3.3. Conclusion

It is assumed that this aquifer is confined because the results are comparable to the given data. The closest wells were taken because the distance is not big and in this case the pumping can be influenced mostly. The reason of the difference in values from the theory (0.42 m) and the reality (0.1 m) could be caused by the different values of transmissivity and storativity, as well as the fact that the aquifer in Ristrup does not react exactly as a pure confined aquifer or a pure unconfined aquifer.

In the geological profiles (appendix D – figure 46) the aquifer around some wells seems to be a confined one, though [Reference 10] that the layer was made by a mixture of clay and sand, so there may be a possibility of leaking water down through this sediment. This fact could also influence in the result.

2.4. CHEMICAL ANALYSIS

2.4.1. Introduction

The chemical analysis for Ristrup will be focused on these compounds that need special treatment or are simply dangerous, but not on these which are the most common ones as iron and manganese. A comparison of the chemical conditions between Sabro and Rstrup wells will be presented , because, as it was said in the introduction, it is possible to see an influence from

Ristrup well field onto Sabro well field. It means that probably groundwater is able to move from Sabro to Ristrup while both are abstracting water.

In this section, groundwater processes in Ristrup well field is not the goal of the study, but it is the chemical composition of water and how it changed during the last years.

Current concentration of the chemical compounds is shown in the tables below, as well as the concentration of the most relevant chemicals and these concentrations above the criteria:

Compound	**$C_{current}$ (mg/L)**	**$C_{criteria}$ (mg/L)**
Ammonia	0,046	0,05
Ca^{2+}	76	-
CO_2	< 5mg/L	2
Fe^{2+}	0,86	0,1
Mn^{2+}	0,16	0,02
NO_3^-	0,5	50
O_2	1,1	-
Water type	Redox conflict	

Table 23: Main compounds in well 78.433 (whole table in appendix F)

Compound	**$C_{current}$ (mg/L)**	**$C_{criteria}$ (mg/L)**
Ammonia	0,088	0,05
Ca^{2+}	77	-
Fe^{2+}	0,77	0,1
Mn^{2+}	0,085	0,02
NO_3^-	2,4	50
NO_2^-	0,025	0,01
O_2	1,6	-
Water type	Redox conflict	

Table 24: Main compounds in well 78.486 (whole table in (appendix F)

Compound	**$C_{current}$ (mg/L)**	**$C_{criteria}$ (mg/L)**
Ammonia	0,085	0,05
Ca^{2+}	78	-
CO_2	< 5mg/L	2
F^-	0,22	0,05
Fe^{2+}	0,85	0,1
Mn^{2+}	0,086	0,02
NO_3^-	1,1	50
O_2	0,46	-
Water type	Type C	

Table 25: Main compounds in well 78.432 (whole table in appendix F)

Looking at these three tables (tables 23, 24 and 25), each of them for a different well, it can be concluded that all of them have something in common. First of all, all of them show an excess concentration of iron and manganese, probably related to the second common characteristic: a very low level of oxygen and nitrate (oxidising compounds) - the redox water type is C for 78.432 or redox conflict for the well 78.433 and 78.486 - still with low oxidising agents.

Besides, in some of them (78.433, 78.432 and 78.860) the concentration of ammonia is above the criteria, whereas in others (78.486, 78.432 and 78.860) it concerns the concentration of carbon dioxide criteria and finally in the first well (78.433) there is an excess of nitrite.

If this analysis is compared to the analysis made for Sabro well field in the section 2 of the project (chemical analysis), it can be concluded that the quality of the water in both areas does not differ too much, which means that the water quality in Ristrup will not be influenced significantly by Sabro well field.

Analysis of chemical parameters and evolution of chemical concentrations are shown in detail in appendix F.

2.4.2. Conclusion

Nitrite and ammonia do not appear in Sabro well field, but both are related to nitrate by the oxygen (both react with oxygen and nitrate is produced). The concentration of oxygen in Ristrup is not very high, because actually the redox conditions seem to be reduced, but in this case the source of oxygen for such process will come from Sabro (the wells more closed to Ristrup have very oxidised conditions – high level of oxygen and nitrate). However, the concentrations of these components are very low related to the criteria of the nitrate, so their presence will not be dangerous at all in Ristrup.

In the case of the carbon dioxide, as it was explained in section 2 of the report (chemical analysis of Sabro), has high concentration in Ristrup well field, but its removal is very simple because only standard treatment is needed.

2.5. CONCLUSION

After carrying out this analysis it is concluded that the influence between Ristrup and Sabro wells exists. The geological layers show a clear connection between the wells of both areas as well as similar characteristics. The chemical study shows that the chemical background of both areas is connected. Looking at the chemical characteristics such as redox type of water, processes that the water experienced and the compounds that appear in the analysis, it is obvious that they are connected. Finally, the clearest result comes from the pumping test. It is shown mathematically that there is an influence between both wells, because of the pumping test that was made for both areas and because of the study that we have made.

The aquifer where the closest well from Ristrup to Sabro is located was said to be confined, which means that the influence is more visible than in the case if it was unconfined. Besides, there is a movement of water from Sabro to Ristrup, and in the mandatory part (chemical analysis section) Sabro was claimed to be under the risk of nitrate contamination and that contamination can be moved to Ristrup.

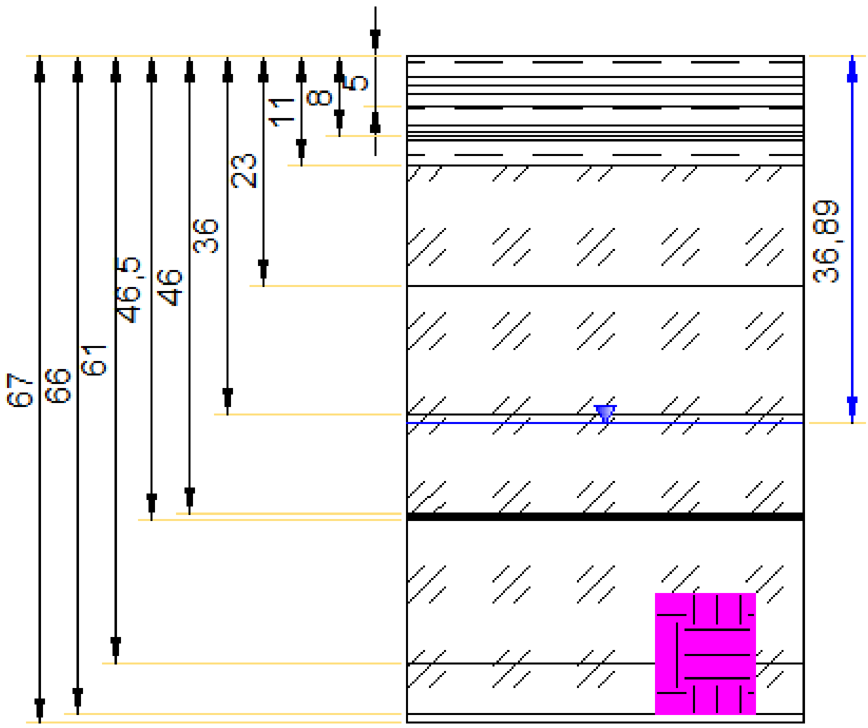
3. APPENDIX

APPENDIX A: Geological part (mandatory part)

- Profiles

Well	78.538	88.1102	88.1401
Year	1980	1993	2005
Depth [m]	50	67	144
Capacity [m³/h]/draw down [m]	40/2,3	13,2/2,1	unknown
		24,6/3,7	
		17,4/2,7	

Table 26: Wells' characteristics



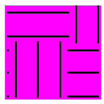


Figure 36: Well 88.1102

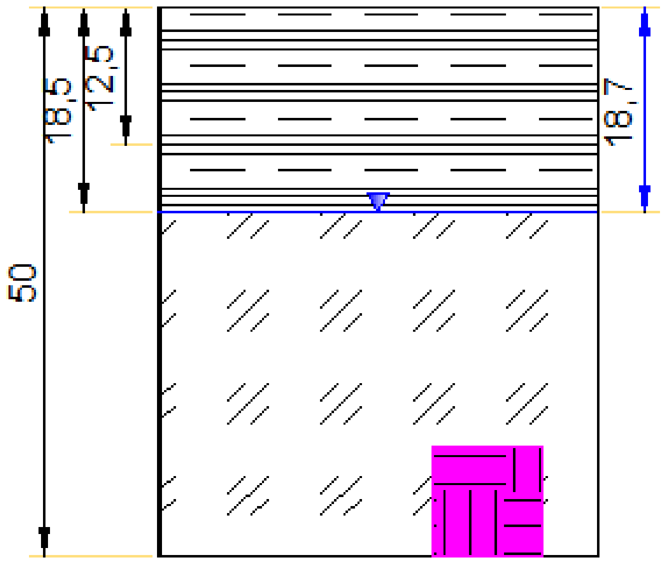


Figure 37: Well 78.538

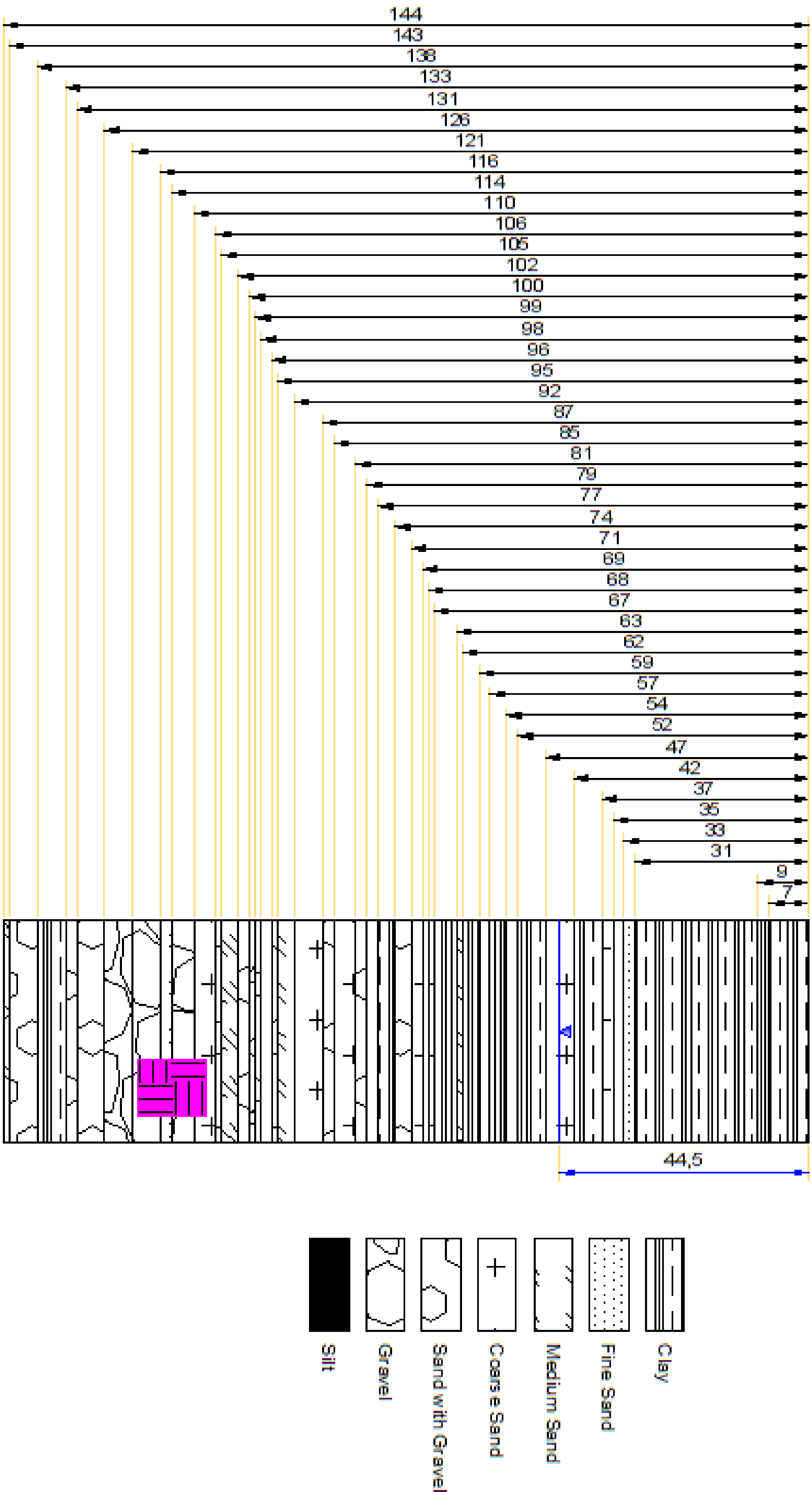


Figure 38: Well 88.1401

- Geological calculations for transmissivity

Well No.	Confined Unconfined	Formula	Abstraction from the well Q(m3/h)	Depression of the water in the well S(m)	T (m^2/s)
88.1102	**Unconfined**	**0.0003Q/S**	17.4	2.7	0.001933333
			13.2	2.1	0.001885714
			24.6	3.7	0.001994595
88.1401	**confined**	**0.00042Q/S**	**No data**	**No data**	**No data**
78.538	**Unconfined**	**0.0003Q/S**	40 (m^3/h)	2.3	0.005217391

Table 27: Transmissivity calculation 1

Well No.	Confined Unconfined	Formula	Abstraction from the well Q(m3/h)	Depression of the water in the well S(m)	T (m^2/s)
88.1102	**Unconfined**	**0.000265109Q/S**	17.4	2.7	0.001708482
		0.000264943Q/S	13.2	2.1	0.001707409
		0.000266182Q/S	24.6	3.7	0.001715395
88.1401	**confined**	**No data**	**No data**	**No data**	**No data**
78.538	**Unconfined**	**0.000287379Q/S**	40 (m^3/h)	2.3	0.00499789

Table 28: Transmissivity calculation 2

- Also in appendix, pdf files: “78.538”, “88.1102” and “88.1401” which are attached at the end.
- Potentiometric map

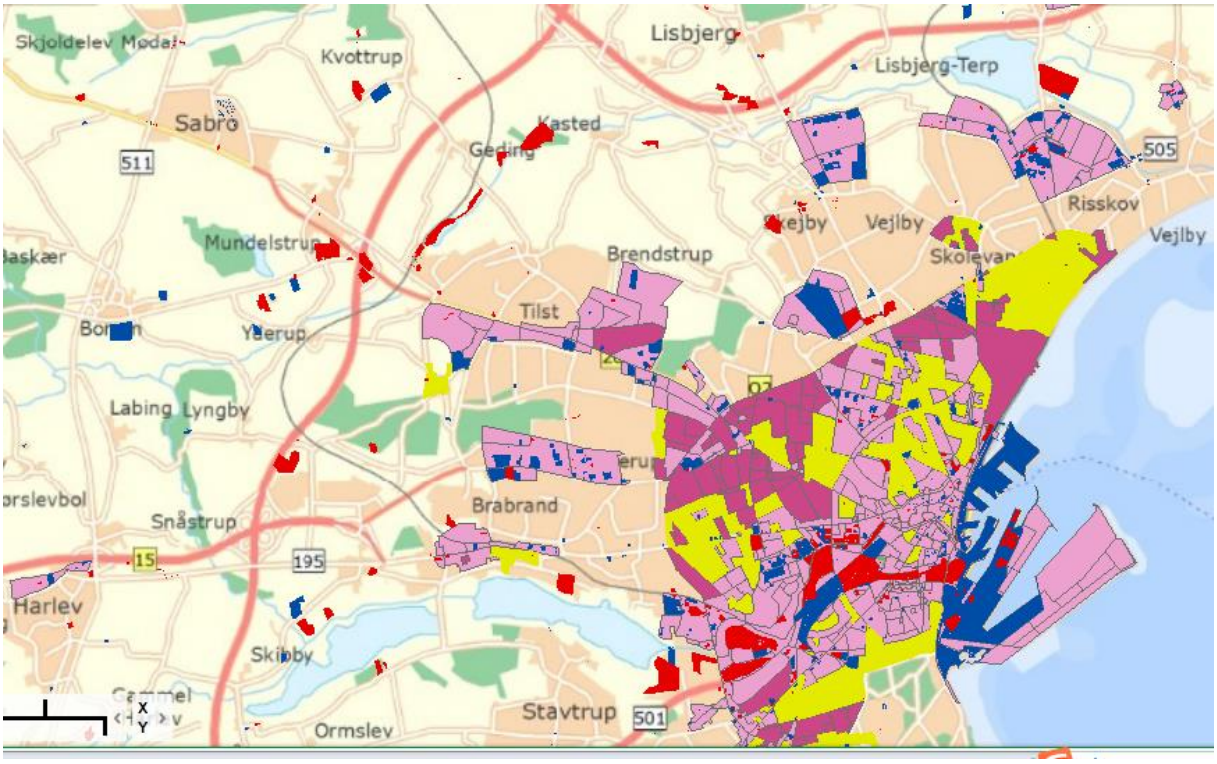


Figure 39: Aarhus municipality contamination map

APPENDIX B: Chemical analysis (mandatory part)

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,01	0,05
Ca^{2+}	67	-
NVOC	0,93	4
CO_2	< 2mg/L	2
Cl^-	20	250
F^-	0,2	1,5
HCO_3^-	170	-
Fe^{2+}	0,01	0,1
K^+	1,1	10
Mg^{2+}	3,9	50
Mn^{2+}	0,023	0,02
Na^+	14	175
NO_3^-	25	50
NO_2^-	0,006	0,01
O_2	2,7	-
Tot-P	0,12	0,15
SO_4^{2-}	38	250
Compound	**$C_{current}$ (µg/L)**	**$C_{criteria}$ (µg/L)**
As	1,4	5
Ba	64	700
Ni	20	20
Organic Compounds	< 0,01	1
Pesticides	< 0,01	1
Bacteria	0	0

Table 29: Chemical data of well 78.538 compared with the Danish criteria

General data		Meaning
pH	7,5	Buffered
Conductivity (mS/m)	45	Typical
Parameters		
I	1,08	Little ion exchange
F	1,31	Existing pyrite oxidation
dH	10	Middle water
logSI	0.16	Not aggressive sample
Ion balance (%)	-5,66	Correct analysis

Table 30: Chemical parameters of well 78.538 with the meaning of every of them

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,01	0,05
Ca^{2+}	91	-
NVOC	0,83	4
CO_2	< 2mg/L	2
Cl^-	34	250
F^-	0,21	1,5
HCO_3^-	175	-
Fe^{2+}	0,055	0,1
K^+	1,1	10
Mg^{2+}	3,7	50
Mn^{2+}	0,011	0,02
Na^+	14	175
NO_3^-	17	50
NO_2^-	0,012	0,01
O_2	6,4	-
Tot-P	0,021	0,15
SO_4^{2-}	76	250
Compound	**$C_{current}$ (µg/L)**	**$C_{criteria}$ (µg/L)**
As	0,43	5
Ba	130	700
Ni	0,57	20
Organic Compounds	< 0,01	1
Pesticides	< 0,01	1
Bacteria	0	0

Table 31: Chemical data of well 88.1102 compared with the Danish criteria

General data		Meaning
pH	7,5	Buffered
Conductivity (mS/m)	56	Typical
Parameters		
I	0,63	Little ion exchange
F	1,69	Existing pyrite oxidation
dH	13,32	Middle water
logSI	0.30	Not aggressive sample
Ion balance (%)	-3,71	Correct analysis

Table 32: Chemical parameters of well 88.1102 with the meaning of every of them

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,02	0,05
Ca^{2+}	71,9	-
NVOC	0,7	4
CO_2	< 5mg/L	2
Cl^-	18	250
F^-	0,2	1,5
HCO_3^-	189	-
Fe^{2+}	0,19	0,1
K^+	1,57	10
Mg^{2+}	3,33	50
Mn^{2+}	0,14	0,02
Na^+	11,2	175
NO_3^-	0,5	50
NO_2^-	0,003	0,01
O_2	0,1	-
Tot-P	0,05	0,15
SO_4^{2-}	37	250
Compound	**$C_{current}$ (µg/L)**	**$C_{criteria}$ (µg/L)**
As	2,6	5
Ba	66	700
Co	0,18	
Ni	0,14	20

Table 33: Chemical data of well 88.1401 compared with the Danish criteria

General data		
pH	7,4	Buffered
Conductivity (mS/m)	44,5	Typical
Parameters		
I	0,96	Little ion exchange
F	1,25	Typical
dH	10,59	Middle water
logSI	0.13	Not aggressive sample
Ion balance (%)	0,22	Correct analysis

Table 34: Chemical parameters of well 88.1401 with the meaning of every of them

- Ion exchange:

$$I = \frac{\frac{Na}{23.0}}{\frac{Cl}{35.5}} = 1.54 \cdot \frac{Na}{Cl}$$

  - Na: concentration of sodium taken from the chemical analysis. [mg/L].
  - Cl: concentration of chloride taken from the chemical analysis. [mg/L].
  - Criteria:

Interval	Category
<0.6	reversed ion exchange
0.6-0.9	no ion exhange
0.9-2.0	ion exchange
> 2.0	strong ion exchange

Figure 40: Ion exchange criteria

- Degree of weathering:

$$F = \frac{2 \cdot \left(\frac{Ca}{40.1} + \frac{Mg}{24.3}\right)}{\frac{HCO_3}{61.0}}$$

  - Ca: concentration of calcium taken from the chemical analysis. [mg/L].
  - Mg: concentration of magnesium taken from the chemical analysis. [mg/L].
  - HCO_3^-: concentration of hydrocarbonate. [mg/L].
  - Criteria:

Interval	Category
< 1.0	none
1.0-1.3	typical
1.3-3.5	pyrite oxidation
> 3.5	extreme pyrite oxidation

Figure 41: Degree of weathering criteria

- Hardness:

$$dH = \frac{1dH}{10\frac{mg}{l_{CaO}}} \cdot \frac{56\,mgCaO}{mmol\,Ca} \cdot \left(\frac{Ca}{40.1\frac{mg}{mmol}} + \frac{Mg}{24.3\frac{mg}{mmol}}\right)$$

  - Ca: concentration of calcium taken from the chemical analysis. [mg/L].
  - Mg: concentration of magnesium taken from the chemical analysis. [mg/L].
  - Criteria:

Interval	Category
0-8	soft
8-18	middle
18-32	hard
> 32	very hard

Figure 42: Hardness criteria

- Calcite saturation index:

$$LogSI = pH - 11.4 + \log(Ca^{2+} \cdot HCO_3^-)$$

  - Ca: concentration of calcium taken from the chemical analysis. [mg/L].
  - HCO_3^-: concentration of hydrocarbonate. [mg/L].

- Ion balance:

$$IB = \frac{(\sum cations - \sum anions) \cdot 100}{\frac{1}{2} \cdot (\sum cations + \sum anions)}$$

  - $\sum cations$: Sum of cations (ammonia, calcium, iron, potassium, magnesium, manganese, sodium). [mg/L].
  - $\sum anions$: Sum of anions (chloride, fluoride, hydrogen carbonate, nitrate, nitrite and sulphate). [mg/L].

- Redox process:

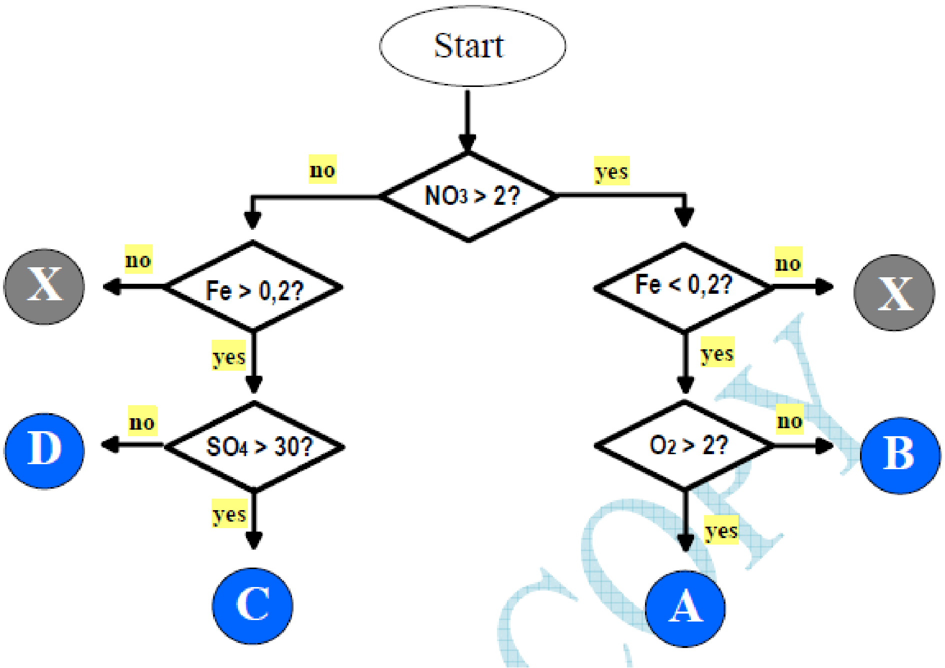


Figure 43: Algorithm for redox water type determination

- pH conditions:

Acid/base water type	Value (pH-units)
acidic	< 4.5
aggressive	4.5-7.0
buffered	7.0 – 8.5
alkaline	> 8.5

Figure 44: pH classification

- Conductivity:

Interval	Value (mS/m)
low salt content	< 30
typical	30 – 130
elevated salt content	> 130

Figure 45: Conductivity criteria

APPENDIX C: Waterworks (mandatory part)

- Consumption

Q (m^3/year)	Q (m^3/day) (for 1 filter)	Q (m^3/h) (for 1 filter)
143,474.2	196.54	14.04

Table 35: 2013 year consumption

- Filter area

$$S = \pi r^2$$

r (m)	π	S (m^2)
0.75	3.14	1.77

Table 36: Filter area calculation

r: radius of filter

- Filtration rate FR

$$\mathrm{FR} = \frac{\mathrm{Q}}{\mathrm{A}}$$

Q (m^3/h)	A (m^2)	FR (m/h)
14.04	1.77	7.95

Table 37: Filtration rate calculation (without new area)

Q: Flow

A: Filter area

Q (m^3/h)	A (m^2)	FR (m/h)
16.99	1.77	9.62

Table 38: Filtration rate calculation (with new area)

- True filter velocity

$$\mathrm{V_{true}} = \frac{FR}{\varepsilon}$$

FR (m/h)	ε	V_{true} (m/h)
14.04	0.4	19.87

Table 39: True velocity calculation (without new area)

ε: Porosity

FR: Filtration Rate

FR (m/h)	ε	V_{true} (m/h)
16.99	0.4	24.04

Table 40: True velocity calculation (with new area)

- Empty Bed Contact Time (EBCT)

$$\text{EBCT} = \frac{A \cdot H}{Q}$$

A (m^2)	H (m)	Q (m^3/h)	EBCT (h)
1.77	2.29	14.04	0.29

Table 41: Empty Bed Contact Time calculation

A: Area of filter

H: Height in

Q: Flow

- Residence time (T_{res})

$$T_{res} = EBCT \cdot \varepsilon$$

EBCT (min)	ε	T_{res} (min)
17.29	0,4	6,91

Table 42: Residence time calculation

EBCT: Empty Bed Contact Time

ε: Porosity

- Backwash calculations

Fe max 0,192 mg/l $\xrightarrow{\frac{C_{Fe} \cdot Q}{A}}$ **0,021 kg Fe/day/m²**

C_{Fe}: concentration of iron (kg/m^3)

Q: water consumption (appendix C – table 35)

A: filter area.

$\text{Backwash}_{\text{time}} = \frac{0,5}{0,021} = 23,4 \text{ days}$ (Maximum Fe concentration in filters: 0,5 kg/m^2)

APPENDIX D: Geological profiles (optional part)

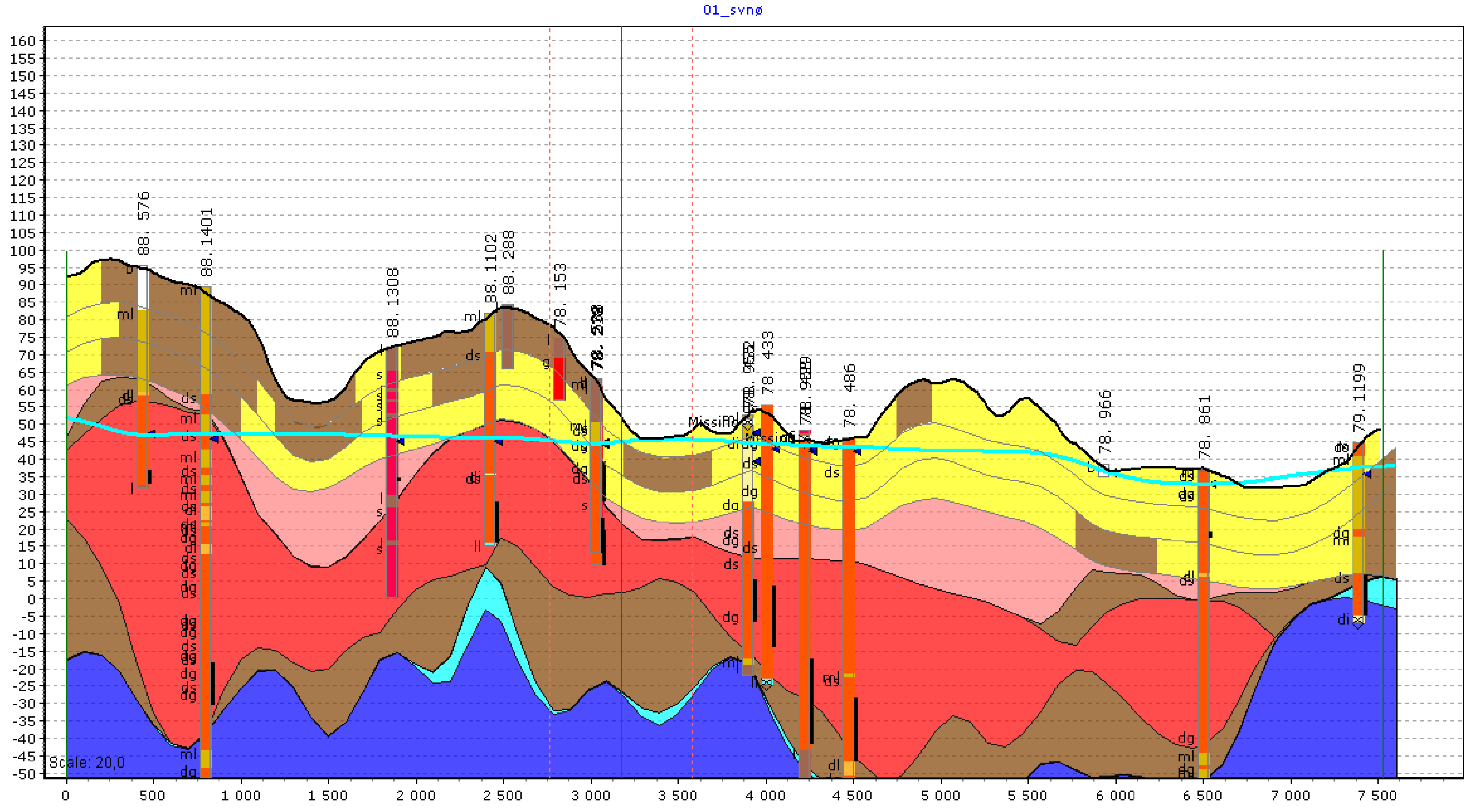


Figure 46: The geological profile combining the data form Ristrup and Sabro wells

APPENDIX E: Pumping test (optional part)

- Process steps for calculations of drawdown

    1. Calculation of Transmissivity

Transmissivity is calculated by the graphic shown in figure 47. In the graphic (log(Drawdown) vs log(time)), the equation of the function is approximated to a line, whose slope is the Δs that is shown in the equation below:

$$T = \frac{0,183 \cdot Q}{\Delta s}$$

Where:

Δs: taken from the slope of the line. The value is 0.17.

Q: 46 m^3/h, whose value in seconds is 0.013 m^3/s.

In that way, the transmissivity takes a value of 0.014 m^2/s.

time (s)	drawdown (m)
0,001	0,001
90	2,226
180	2,129
270	2,142
360	2,154
450	2,156
540	2,158
630	2,156
720	2,168
810	2,157
900	2,176
990	2,179
1080	2,17
1170	2,176
1260	2,18
1350	2,189
1440	2,195
1530	2,177
1620	2,196
1710	2,193

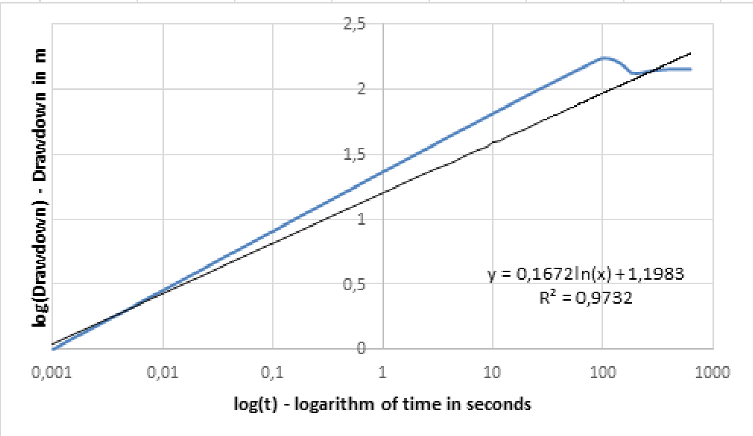


Figure 47: Graph of log(Drawdown) vs log(time) and values in table at the left side

2. Distances

They are calculated by knowing the coordinates of the position of the wells in Denmark. Knowing that the coordinates of well A are (x_1, y_1) and that the coordinates of well B are (x_2, y_2), the distance between two wells is calculated as:

$$Distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Following this equation, the distances between each well are:

Wells	Distance (m)
78.432 – 78.538	881

Table 43: Distances between wells

3. Assumption of the storativity

The assumed storativity will be different for considering confined or unconfined. As it can be known from the theory, the storativity for unconfined aquifer is always much bigger than for confined. The values assumed are:

- 0.0002 (confined)
- 0.2 (unconfined)

4. Write the transmissivity, storativity, distance and time in the function:

1. Unsteady flow to a well in a confined aquifer

				Distance	Drawdown
Q_w [m^3/t]	46			0,01	2,09
T [m^2/s]	1,40E-02			10	1,09
r [m]	VARIABEL			50	0,85
S []	2,00E-04			100	0,75
t [s]	2000000	23,1481	days	200	0,65
		555,556	hours	300	0,59
				400	0,55
Forudsætning:u << 0,001				500	0,52
eller store t				600	0,49
				700	0,47
Enter values in the green cells				800	0,45
				1000	0,42
				1500	0,36
				2000	0,32
				2500	0,28
				3000	0,26
				4000	0,22
				5000	0,18

Figure 48: Calculation table and data for confined aquifer

1. Unsteady flow to a well in a unconfined aquifer

$$\Delta h = \frac{Q}{4\pi \cdot T} \cdot \ln \frac{2{,}25 \cdot T \cdot t}{r^2 S}$$

		L/sek		Afstand	Sænkning	
Q_w [m³/t]	46	0,01278		0,01	1,59	
T [m²/s]	1,40E-02			5	0,69	
r [m]	VARIABEL			10	0,59	2,92524
S []	2,00E-01	days	minutes	20	0,48	
t [s]	2000000	23,1481	33333,33	30	0,43	
	31536000	365		40	0,38	
				50	0,35	
Forudsætning:u << 0,001				75	0,29	
eller store t				100	0,25	
				150	0,19	
				200	0,15	
				500	0,02	
				881	-0,07	

Figure 49: Calculation table and data for unconfined aquifer

The time chosen is taken from the figure 34 in the main report, which is the time the pumps have been abstracting water from the well 78.432. As it can be seen the value calculated of transmissivity (T [m^2/s]),the value assumed of storativity (S[]) and the value known of flow (Q [m^3/s]) are in the left table, and are used for the calculations in the drawdown of the right table of figures 48 and 49 (confined and unconfined aquifer respectively).

APPENDIX F: Chemical analysis (optional part)

- Chemical compounds and concentrations

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,088	0,05
Ca^{2+}	77	-
NVOC	0,76	4
CO_2	< 2mg/L	2
Cl^-	27	250
H_2S	<0,02	0,05
F^-	0,22	1,5
HCO_3^-	200	-
Fe^{2+}	0,77	0,1
K^+	1,7	10
Mg^{2+}	4,3	50
Mn^{2+}	0,085	0,02
Na^+	20	175
NO_3^-	2,4	50
NO_2^-	0,025	0,01
O_2	1,6	-
Tot-P	0,075	0,15
SO_4^{2-}	40	250
Compound	**$C_{current}$ (µg/L)**	**$C_{criteria}$ (µg/L)**
As	1,4	5
Ba	88	700
B	42	1000
Ni	0,2	20
Anioniske detergenter	<3	1
Pesticides	< 0,01	1
Bacteria	0	0

Table 44: Chemical data of well 78.433 compared with the Danish criteria

General data		
pH	7,8	Buffered
Conductivity (mS/m)	48	Typical
Parameters		
I	1,14	Little ion exchange
F	1,28	Existing pyrite oxidation
dH	11,47	Middle water
logSI	0,59	Not aggresive sample

Table 45: Chemical parameters of well 78.433 with the meaning of every of them

Compound	$C_{current}$ (mg/L)	$C_{criteria}$ (mg/L)
Ammonia	0,046	0,05
Ca^{2+}	76	-
NVOC	0,62	4
CO_2	< 5mg/L	2
Cl^-	28	250
F^-	0,25	0,05
HCO_3^-	219	-
Fe^{2+}	0,86	0,1
K^+	1,5	10
Mg^{2+}	4,2	50
Mn^{2+}	0,16	0,02
Na^+	17	175
NO_3^-	0,5	50
NO_2^-	0,005	0,01
O_2	1,1	-
Tot-P	0,085	0,15
SO_4^{2-}	30	250
Compound	**$C_{current}$ (µg/L)**	**$C_{criteria}$ (µg/L)**
As	3,7	5
Ba	97	700
B	47	1000
Ni	0,083	20
Anioniske detergenter	5,5	1
Pesticides	< 0,01	1
Bacteria	0	0

Table 46: Chemical data of well 78.486 compared with the Danish criteria

General data		
pH	7,5	Buffered
Conductivity (mS/m)	47	Typical
Parameters		
I	0,94	Little ion exchange
F	1,15	Existing pyrite oxidation
dH	11,31	Middle water
logSI	0,32	Not aggresive sample

Table 47: Chemical parameters of well 78.486 with the meaning of every of them

Compound	**$C_{current}$ (mg/L)**	**$C_{criteria}$ (mg/L)**
Ammonia	0,085	0,05
Ca^{2+}	78	-
NVOC	1,1	4
CO_2	< 5mg/L	2
Cl^-	36	250
F^-	0,22	0,05
HCO_3^-	206	-
Fe^{2+}	0,85	0,1
K^+	1,6	10
Mg^{2+}	3,9	50
Mn^{2+}	0,086	0,02
Na^+	24	175
NO_3^-	1,1	50
NO_2^-	0,005	0,01
O_2	0,46	-
Tot-P	0,099	0,15
SO_4^{2-}	49	250
Compound	**$C_{current}$ (µg/L)**	**$C_{criteria}$ (µg/L)**
As	1,1	5
Ba	79	700
B	44	1000
Ni	0,27	20
Anioniske detergenter	3,3	1
Pesticides	< 0,01	1
Bacteria	0	0

Table 48: Chemical data of well 78.432 compared with the Danish criteria

General data		
pH	7,8	Buffered
Conductivity (mS/m)	53	Typical
Parameters		
I	1,03	Little ion exchange
F	1,25	Existing pyrite oxidation
dH	11,54	Middle water
logSI	0,61	Not aggresive sample

Table 49: Chemical parameters of well 78.432 with the meaning of every of them

- Geographical location of wells from Sabro and Ristrup

Figure 50: Location of Ristrup wells. 78.860 is closed and it is not used

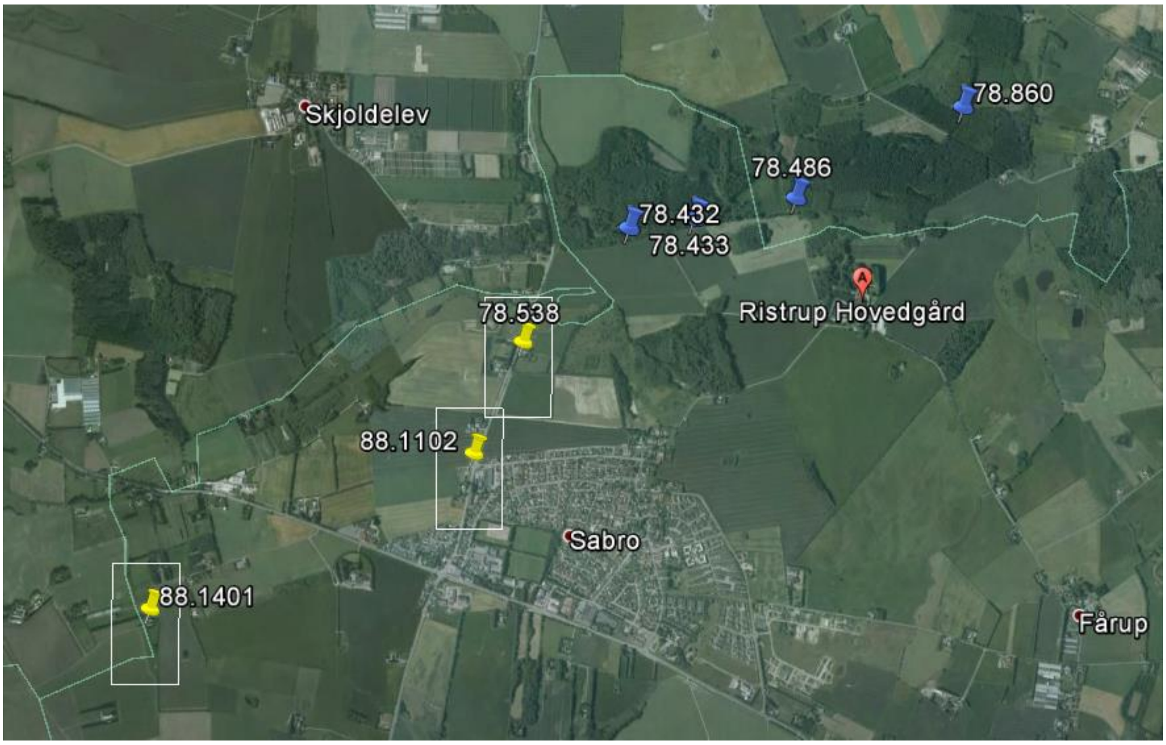


Figure 51: Situation of Ristrup and Sabro wells. 78.860 is closed and it is not used

- Well 78.433 and evolution in time of the concentration of relevant compounds

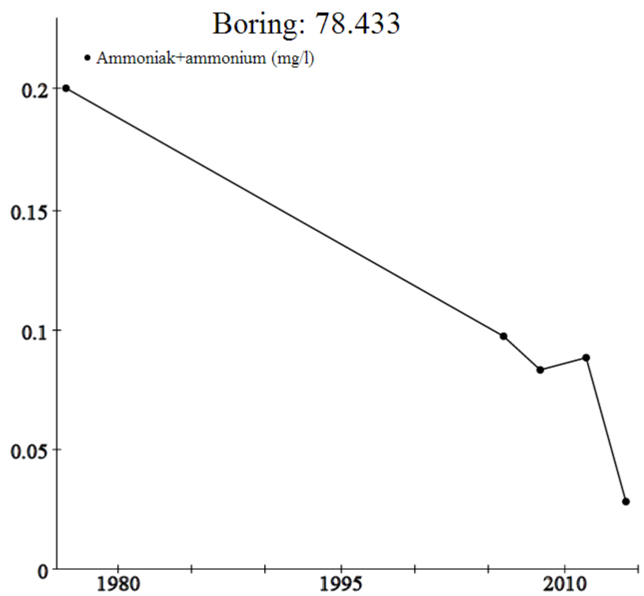


Figure 52: Evolution in concentration of ammonia in well 78.433 since 1980

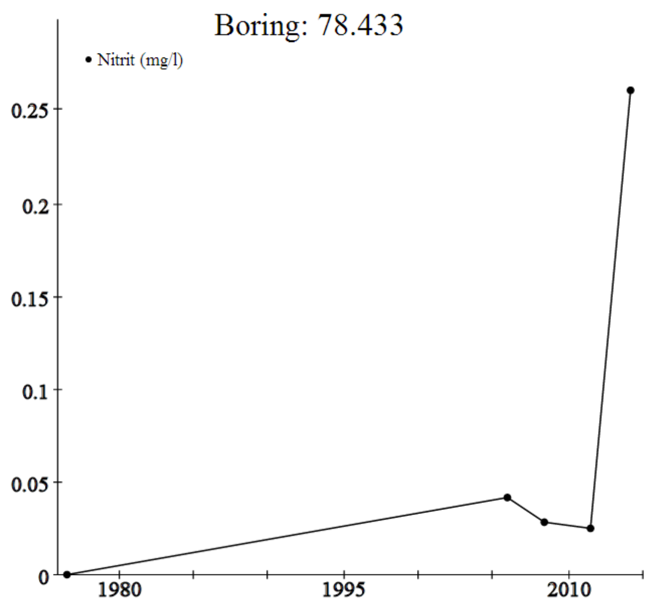


Figure 53: Evolution in concentration of nitrite in well 78.433 since 1980

- Well 78.486 and evolution in time of the concentration of relevant compounds

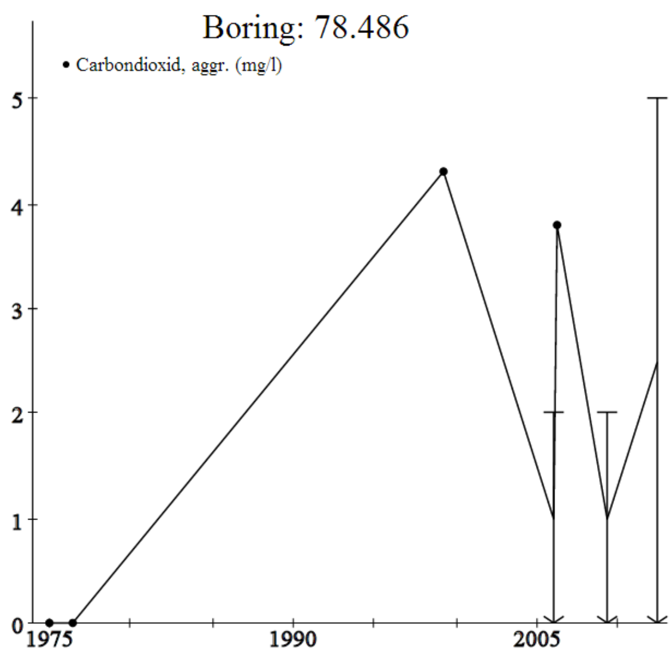


Figure 54: Evolution in concentration of carbon dioxide in well 78.486 since 1975

- Well 78.432 and evolution in time of the concentration of relevant compounds

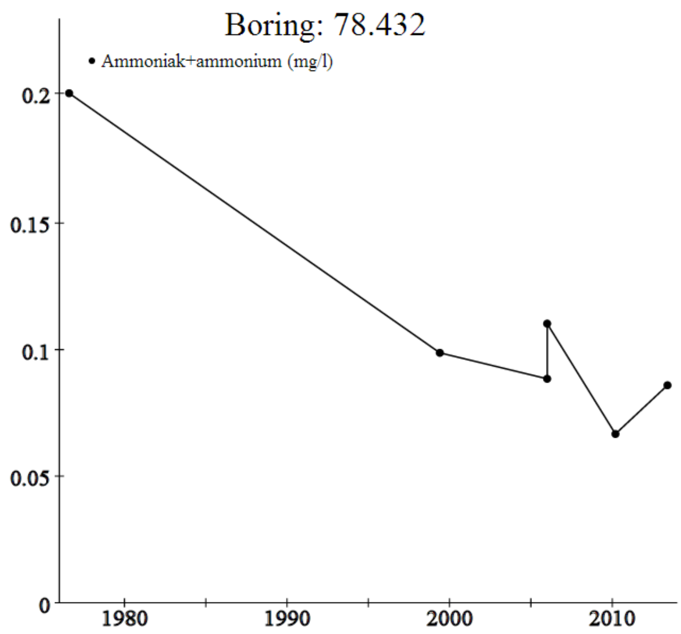


Figure 55: Evolution in concentration of ammonia in well 78.432 since 1980

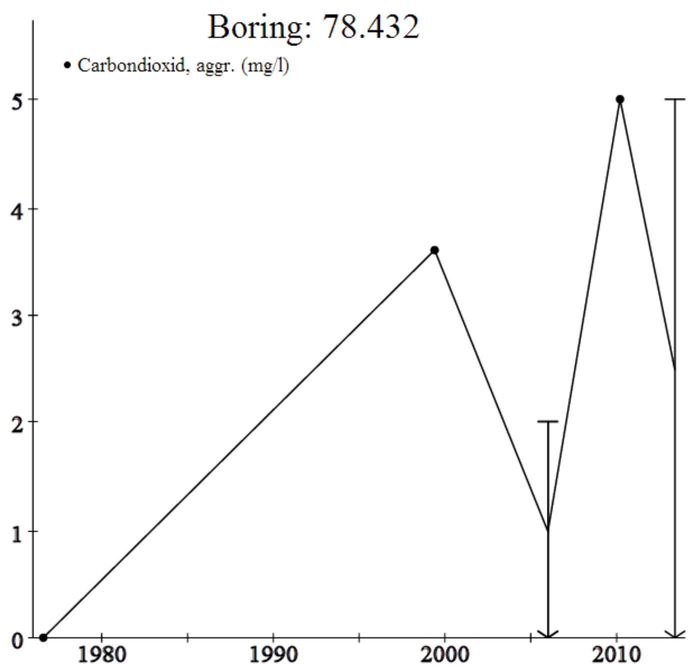


Figure 56: Evolution in concentration of carbon dioxide in well 78.432 since 1980

- Analysis of the main parameters

In the tables below, the main parameters that represent the main processes the groundwater can be exposed to while filtering are shown:

Parameters		
I	1,14	Little ion exchange
F	1,28	Existing pyrite oxidation
dH	11,47	Middle water
logSI	0,59	Not aggresive sample

Table 50: Parameters in well 78.433

Parameters		
I	0,94	Little ion exchange
F	1,15	Existing pyrite oxidation
dH	11,31	Middle water
logSI	0,32	Not aggresive sample

Table 51: Parameters in well 78.486

Parameters		
I	1,03	Little ion exchange
F	1,25	Existing pyrite oxidation
dH	11,54	Middle water
logSI	0,61	Not aggresive sample

Table 52: Parameters in well 78.432

Taking a look at the value of each parameter, it is seen that the values look like each other, and at the same time, the like look the values for the wells of Sabro.

It means that the processes that took place while filtering are the same as the written for the section 2 of the report (chemical analysis):

- The **ion exchange** took part, but not very strongly. The four wells are not very protected, and the water is relatively young.
- The **degree of weathering** shows that the pyrite oxidation took place, but with high intensity. Acid was produced while filtering, and it made the water harder, however the hardness in the four wells is not very high (considered medium hardness).

- The **Calcite Saturation Index** shows that the water sample is not aggressive, however, the chemical analysis shows that the wells 78.486, 78.432 and 78.860 have aggressive water (carbon dioxide concentration above criteria).
- Conductivity (in Appendix) in the four wells moves around the typical value.
- The Ion Balance values for the four wells are always under the range allowed, so the analysis for them is considered correct (see appendix).

- Evolution of the concentration of relevant chemicals

    - Ammonia

Ammonia appears in the wells 78.433 and 78.432 (see figure 51 and figure 54). In both wells, the ammonia has been disappearing during the last thirty years, until reaching a level of 0.088 mg/L in each one, which is above the criteria but not worrying.

- Carbon dioxide

The carbon dioxide appears above the criteria in the wells 78.486 and 78.432 (see figure 53 and figure 55). In both wells it has changed a lot from year to year but in general terms it has followed a concrete tendency: in well 78.486 the carbon dioxide tends to decrease in time, while in well 78.432 it tends to increase.

- Nitrit

The nitrit appears in the well 78.433 (figure 52). Its concentration increased rapidly the last two years until five times the criteria.

4. LIST OF FIGURES

5. LIST OF TABLES

6. LIST OF REFERENCES

[Reference 1]: maps.google.com – 14/04/14/

[Reference 2]: Årsrapport, intake and pumped out in months

[Reference 3]: groundwater flow presentation from Michael R. Pedersen

[Reference 4]: http://books.google.com.hk/books?id=RPvRW4hHQSMC&pg=PA111&lpg=PA111&dq=specific+yield+for+for+medium+sand&source=bl&ots=8JJzYwE2PK&sig=v6KCAUfxmYHJJubWSx8573Qq8sk&hl=zh-CN&sa=X&ei=pDR7U92rCIquyAPkmIGQCA&ved=0CEoQ6AEwBA#v=onepage&q=specific%20yield%20for%20for%20medium%20sand&f=false

[Reference 5]: PDF file from JUPITER, see Appendix A-PDF files “78.538”, “88.1102” and “88.1401”)

[Reference 6]: hydrological cycle presentation from Michael R. Pedersen

[Reference 7]: http://www.weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,arhus,Denmark

[Reference 8]: reference: Aarhus Kommune – Lokalplan 904

[Reference 9]: Vandforsyningsteknik 5. udg. – translation: water supply techniques

[Reference 10]: Jupiter Data Base

[Reference 11]: Water Supply Plan 2004-2015

[Reference 12]: http://sabro.vandforsyning.net/mainpage.aspx - 26/03/13

[Reference 13]: Data provided by waterworks

[Reference 14]: Data provided by Michael R. Pedersen

BORERAPPORT

DGU arkivnr: 78. 538

Borested : Sabro Vandværk, Stillingvej 7
8471 Sabro

Kommune : Århus
Region : Midtjylland

Boringsdato : 1/9 1980 **Boringsdybde** : 50 meter **Terrænkote** : 63.06 meter o. DNN

Brøndborer : Holger Pedersen,Skjød
MOB-nr : 16025
BB-journr :
BB-bornr :

Prøver
- modtaget : 25/3 1983 **antal** : 2
- beskrevet : 13/9 1990 **af** : OW
- antal gemt : 0

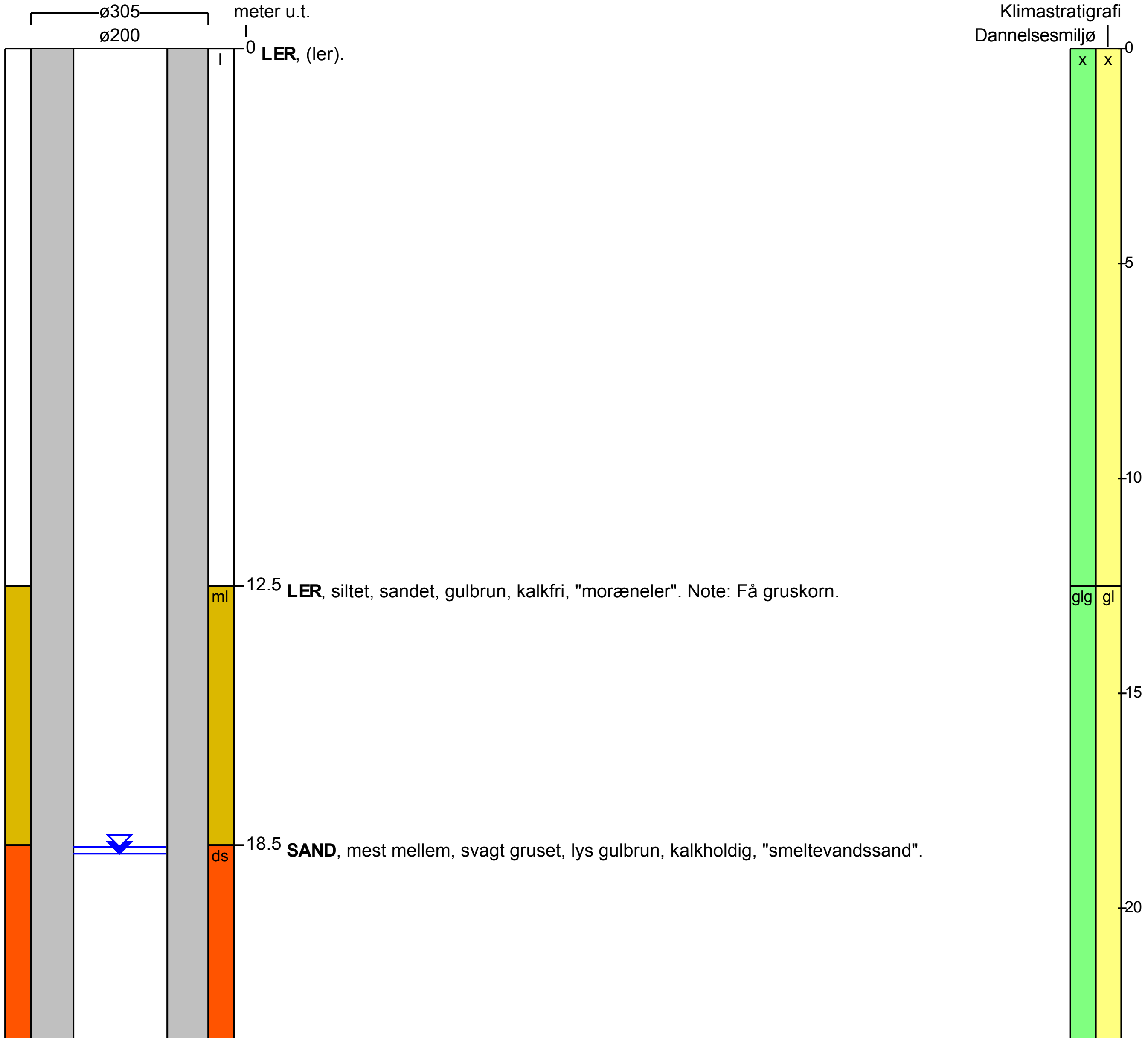
Formål : Vandværksboring
Anvendelse : Vandværksboring
Boremetode : Tørboring/slagboring

Kortblad : 1315IIISV
UTM-zone : 32
UTM-koord. : 563712, 6231039

Datum : EUREF89
Koordinatkilde : Anden
Koordinatmetode : Differential GPS

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	18.7 meter u.t.	21/1 2013	40 m³/t	2.3 meter	1 time(r)
	(første)	18.55 meter u.t.	1/9 1980			

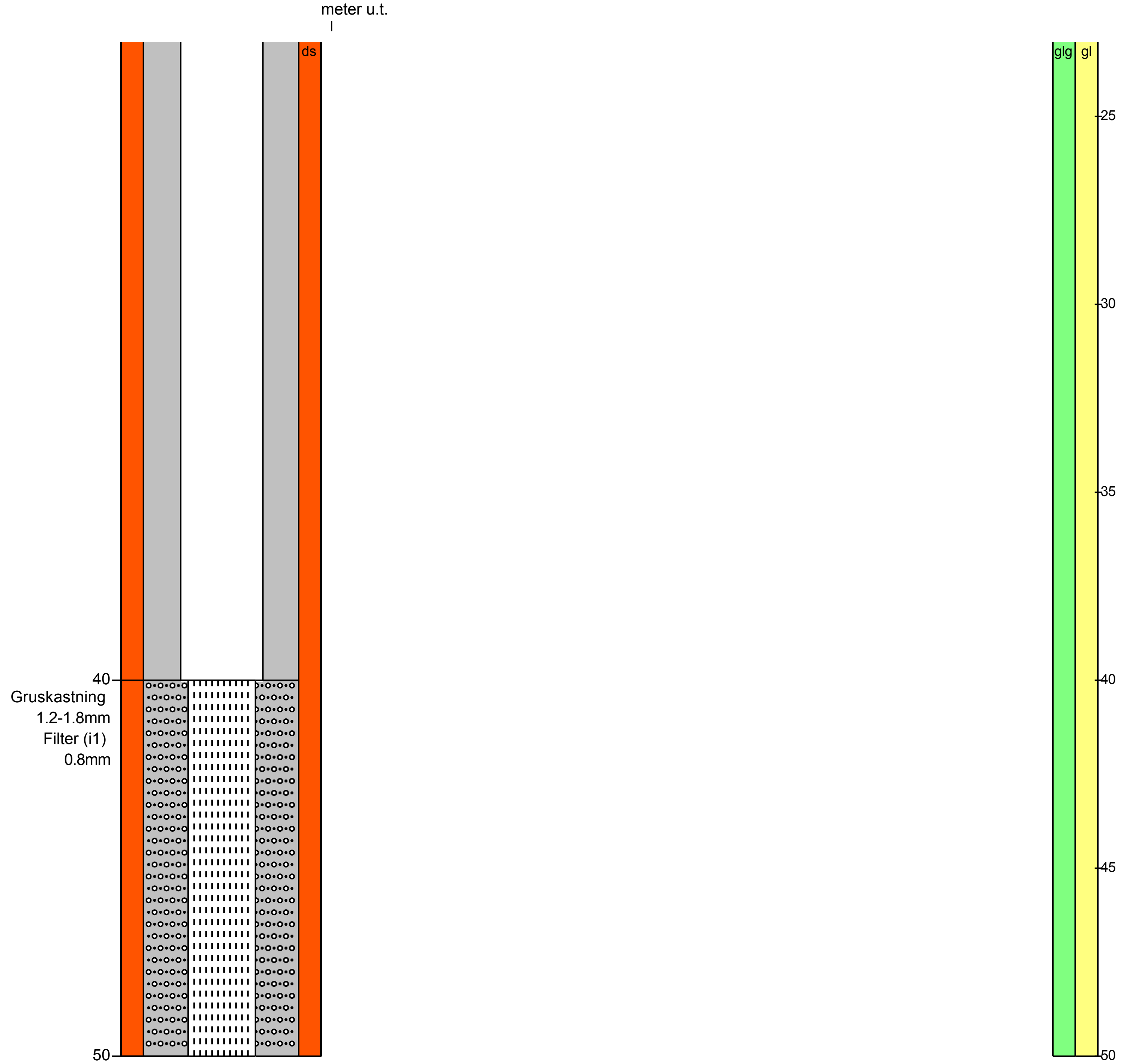
Notater : Gruskastning Lund nr.4 Århus Kommune: Koord. opdateret fra LOPIS database, okt. 2009



fortsættes..

BORERAPPORT

DGU arkivnr: 78. 538



Aflejringsmiljø - Alder **(klima-, krono-, litho-, biostratigrafi)**

meter u.t.			
0	-	12.5	mangler - mangler
12.5	-	50	glacigen - glacial

BORERAPPORT

DGU arkivnr: 88. 1102

Boredsted : Sabro Vandværk, Stillingvej 74
8471 Sabro

Kommune : Århus
Region : Midtjylland

Boringsdato : 16/2 1993   **Boringsdybde** : 67 meter   **Terrænkote** : 81.74 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr : 17916
BB-journr : 7/93
BB-bornr :

Prøver
- modtaget : 1/4 1993   **antal** : 10
- beskrevet : 28/4 2000   **af** : TC
- antal gemt : 0

Formål : Vandværksboring
Anvendelse : Vandværksboring
Boremetode : Lufthæve

Kortblad : 1314 IVNV
UTM-zone : 32
UTM-koord. : 563426, 6230512

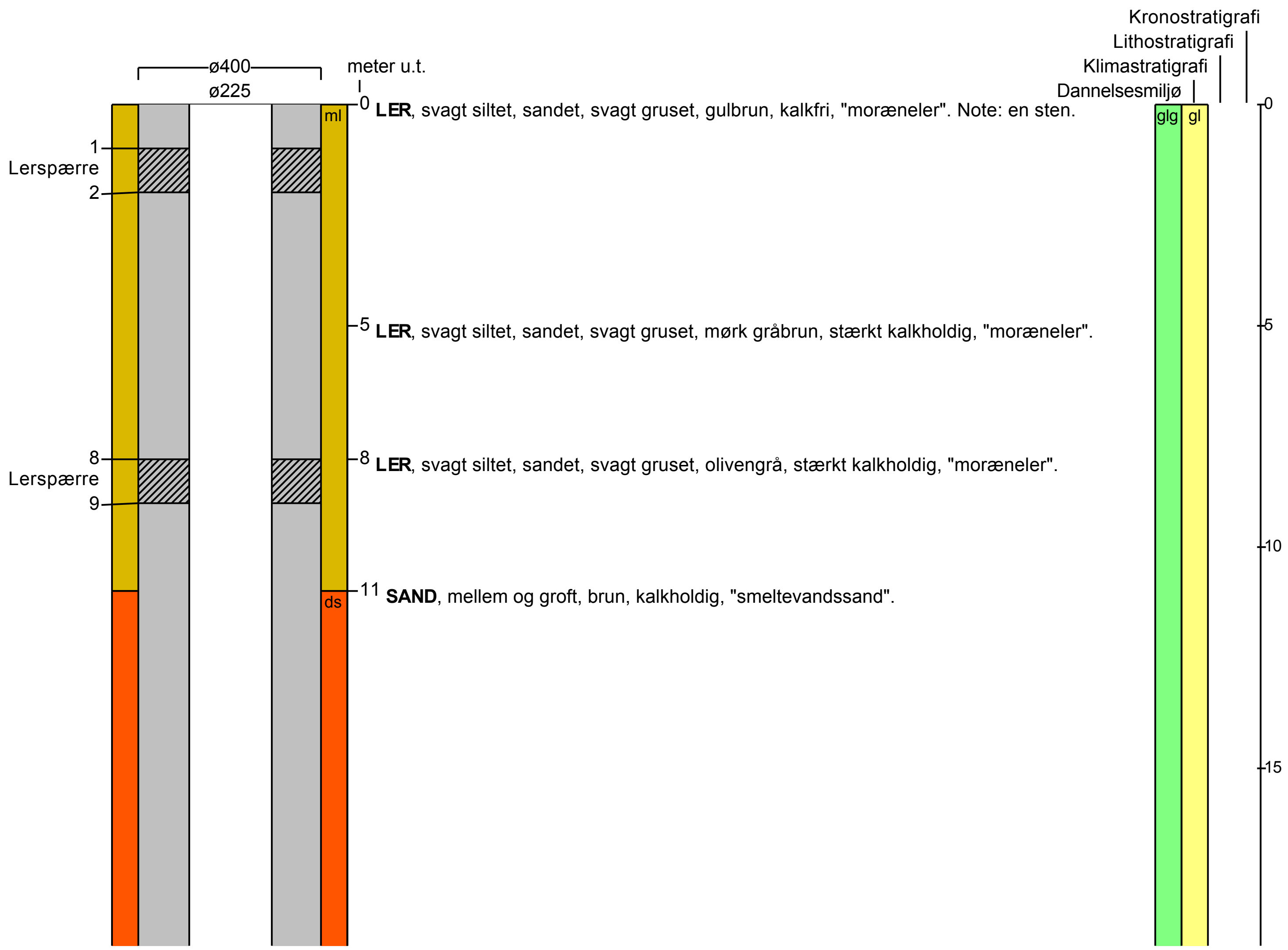
Datum : EUREF89
Koordinatkilde : Anden
Koordinatmetode : Differential GPS

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	36.89 meter u.t.	21/1 2013	13.2 m³/t	2.1 meter	
	(første)	36.36 meter u.t.	16/2 1993	24.6 m³/t	3.7 meter	
				17.4 m³/t	2.7 meter	

Tilbagepejling

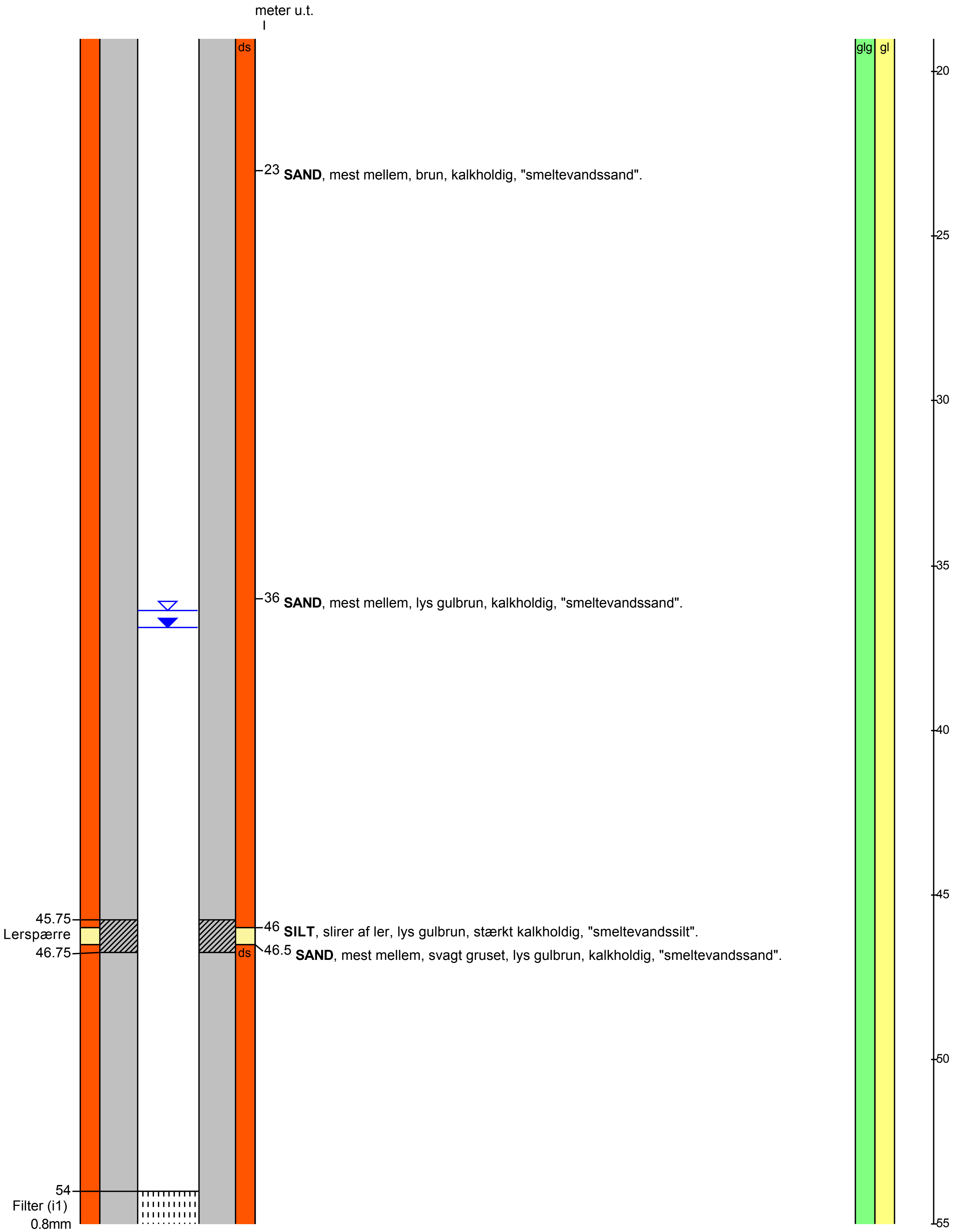
Indtag 1 Tid: 3min Vsp: 36.45m , Tid: 10min Vsp: 36.37m , Tid: 30min Vsp: 36.37m , Tid: 120min Vsp: 36.36m

Notater : Gruskastning nr.4



BORERAPPORT

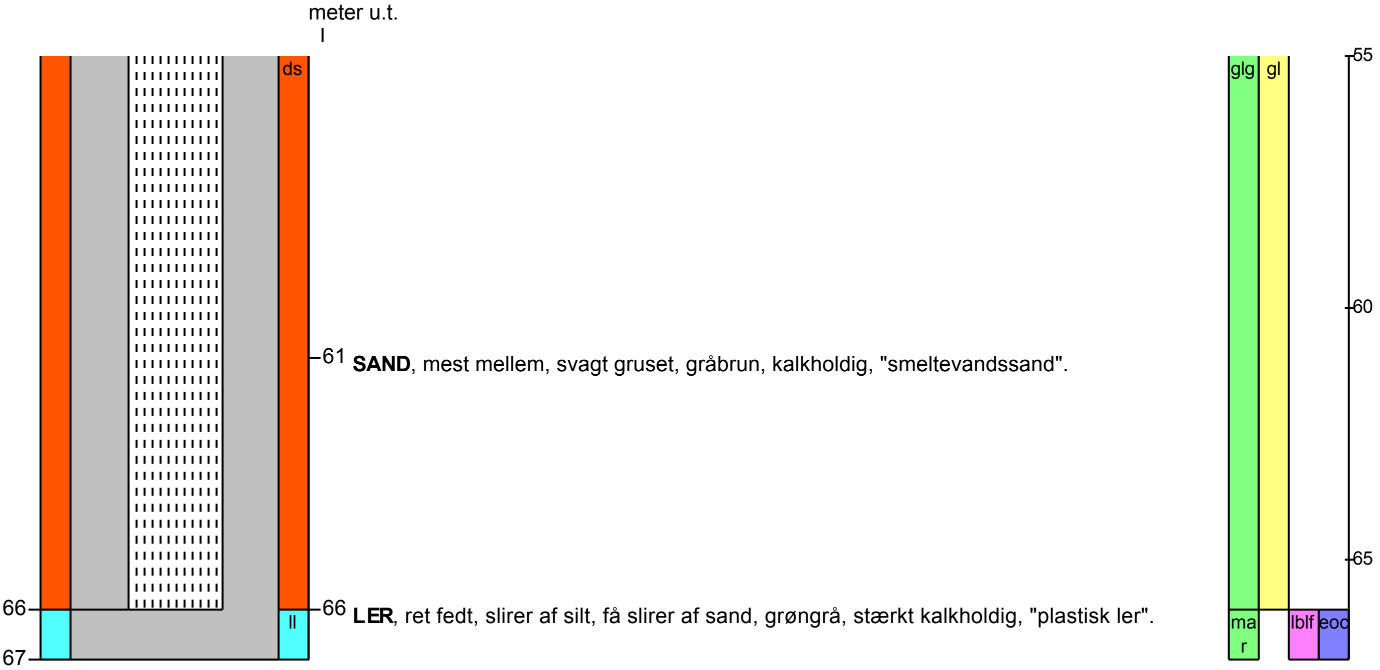
DGU arkivnr: 88. 1102



fortsættes..

BORERAPPORT

DGU arkivnr: 88. 1102



Aflejringsmiljø - Alder (klima-, krono-, litho-, biostratigrafi)

meter u.t.		
0	- 66	glacigen - glacial
66	- 67	marin - eocæn (lillebælt ler formation)

GEUS

BORERAPPORT

DGU arkivnr: 88. 1401

Borested : Sabro Vandværk, Eshøjvej 73
8471 Sabro

Kommune : Århus
Region : Midtjylland

Boringsdato : 12/12 2005 **Boringsdybde** : 144 meter **Terrænkote** : 89.48 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr :
BB-journr : 72/05
BB-bornr :

Prøver
- modtaget : 31/1 2006 **antal** : 50
- beskrevet : 14/4 2008 **af** : TC
- antal gemt : 0

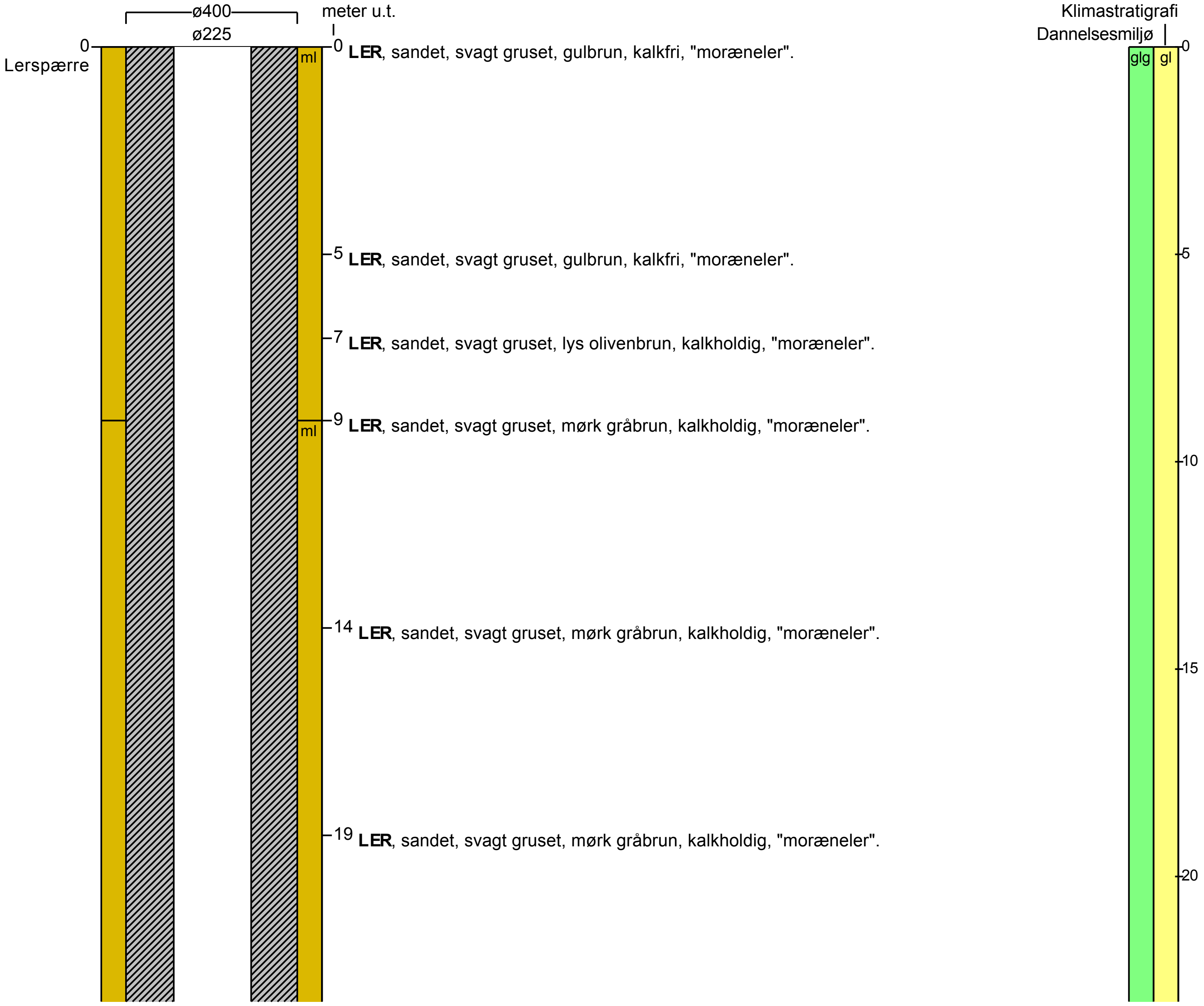
Formål : Vandværksboring
Anvendelse : Vandværksboring
Boremetode : Lufthæve

Kortblad : 1314 IVNV
UTM-zone : 32
UTM-koord. : 562100, 6229577

Datum : EUREF89
Koordinatkilde : Anden
Koordinatmetode : Differential GPS

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	43.77 meter u.t.	21/1 2013			
	(første)	47.2 meter u.m.	7/3 2010			

Notater : Prøve mellem 47 og 48 m kan ikke indlæses. Mellemkornet sand med en sten.

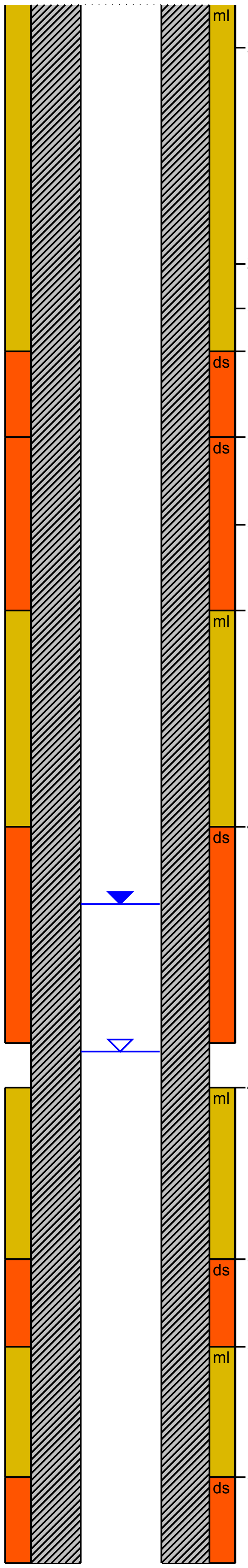


fortsættes..

BORERAPPORT

DGU arkivnr: 88. 1401

meter u.t.



24 **LER**, sandet, svagt gruset, mørk gråbrun, kalkholdig, "moræneler".

29 **LER**, sandet, svagt gruset, mørk gråbrun, kalkholdig, "moræneler".

30 **LER**, sandet, svagt gruset, mørk gråbrun, kalkholdig, "moræneler".

31 **SAND**, mest fint, få slirer af ler, olivenbrun, kalkholdig, "smeltevandssand". Note: 1 sten.

33 **SAND**, mest groft, gruset, olivenbrun, kalkholdig, "smeltevandssand".

35 **SAND**, mest groft, svagt gruset, olivenbrun, kalkholdig, "smeltevandssand".

37 **LER**, sandet, svagt gruset, lys olivenbrun, kalkholdig, "moræneler".

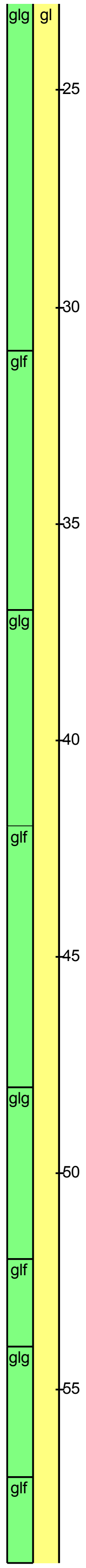
42 **SAND**, mest groft, svagt gruset, olivenbrun, kalkholdig, "smeltevandssand".

48 **LER**, sandet, slirer af sand, svagt gruset, lys olivenbrun, kalkholdig, "moræneler".

52 **SAND**, mest groft, gruset, få klumper af ler, olivenbrun, kalkholdig, "smeltevandssand".

54 **LER**, sandet, svagt gruset, lys olivenbrun, kalkholdig, "moræneler".

57 **SAND**, mest mellem, få slirer af ler, lys olivenbrun, kalkholdig, "smeltevandssand".

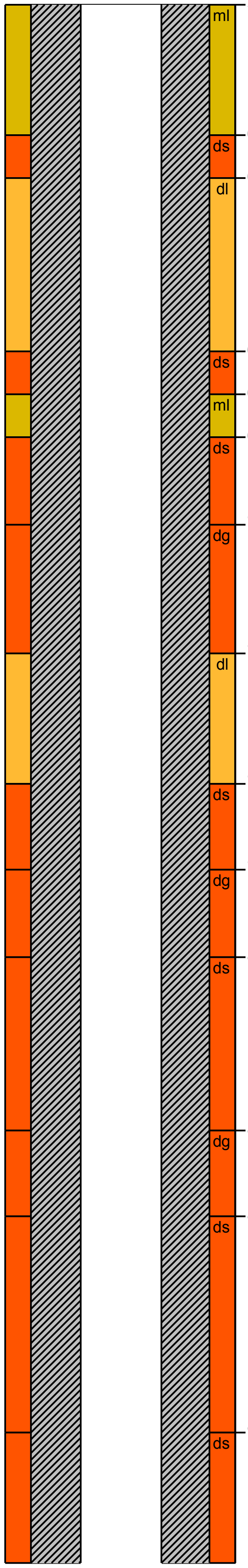


fortsættes..

BORERAPPORT

DGU arkivnr: 88. 1401

meter u.t.



59 **LER**, sandet, lys olivenbrun, kalkholdig, "moræneler". Note: få gruskorn.

62 **SAND**, fint-mellem, få slirer af ler, lys olivenbrun, kalkholdig, "smeltevandssand".

63 **LER**, ret fedt, slirer af sand, lys olivenbrun, kalkholdig, "smeltevandsler".

67 **SAND**, mest groft, gruset, gråbrun, kalkholdig, "smeltevandssand".

68 **LER**, sandet, svagt gruset, gråbrun, kalkholdig, "moræneler".

69 **SAND**, mest groft, svagt gruset, gråbrun, kalkholdig, "smeltevandssand".

71 **SAND OG GRUS**, groft og usorteret, gråbrun, kalkholdig, "smeltevandssand og grus". Note: 1 sten.

74 **LER**, slirer af sand, gråbrun, kalkholdig, "smeltevandsler".

77 **SAND**, mest groft, svagt gruset, slirer af ler, gråbrun, kalkholdig, "smeltevandssand".

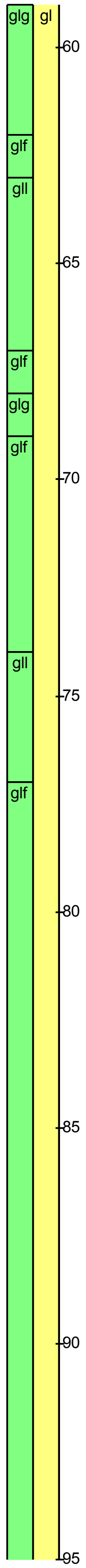
79 **SAND OG GRUS**, groft og usorteret, gråbrun, kalkholdig, "smeltevandssand og grus".

81 **SAND**, mest groft, gråbrun, kalkholdig, "smeltevandssand".

85 **SAND OG GRUS**, groft og fint, gråbrun, kalkholdig, "smeltevandssand og grus".

87 **SAND**, mest groft, gråbrun, kalkholdig, "smeltevandssand".

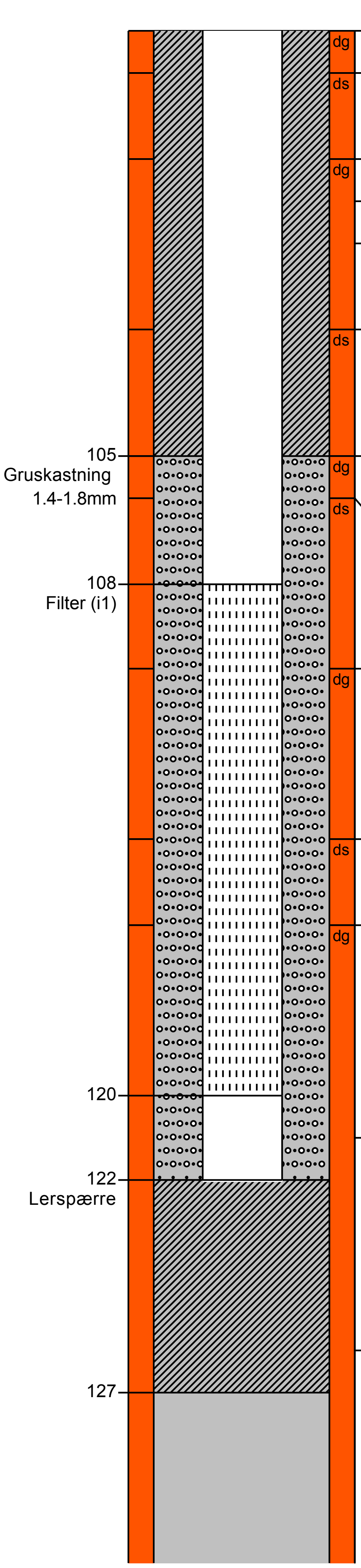
92 **SAND**, mest mellem, gråbrun, kalkholdig, "smeltevandssand".



fortsættes..

BORERAPPORT

DGU arkivnr: 88. 1401



95 **SAND OG GRUS**, groft og usorteret, gråbrun, kalkholdig, "smeltevandssand og grus".

96 **SAND**, mest groft, gruset, gråbrun, kalkholdig, "smeltevandssand".

98 **SAND OG GRUS**, groft og usorteret, gråbrun, kalkholdig, "smeltevandssand og grus".

99 **GRUS**, usorteret, svagt sandet, svagt stenet, gråbrun, kalkholdig, "smeltevandsgrus".

100 **SAND OG GRUS**, groft og usorteret, gråbrun, kalkholdig, "smeltevandssand og grus".

102 **SAND**, mest mellem, lys olivenbrun, kalkholdig, "smeltevandssand".

105 **SAND OG GRUS**, groft og usorteret, svagt stenet, gråbrun, kalkholdig, "smeltevandssand og grus".

106 **SAND**, mest groft, gråbrun, kalkholdig, "smeltevandssand".

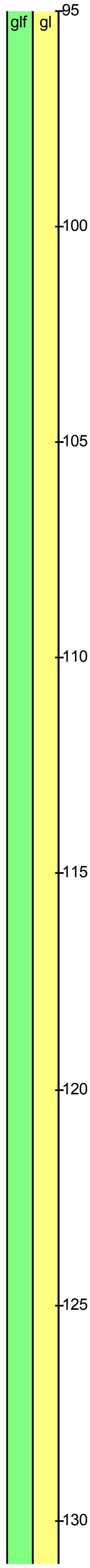
110 **GRUS**, usorteret, sandet, gråbrun, kalkholdig, "smeltevandsgrus".

114 **SAND**, mest mellem, gråbrun, kalkholdig, "smeltevandssand".

116 **GRUS**, usorteret, sandet, svagt stenet, gråbrun, kalkholdig, "smeltevandsgrus".

121 **GRUS**, usorteret, sandet, få klumper af ler, gråbrun, kalkholdig, "smeltevandsgrus".

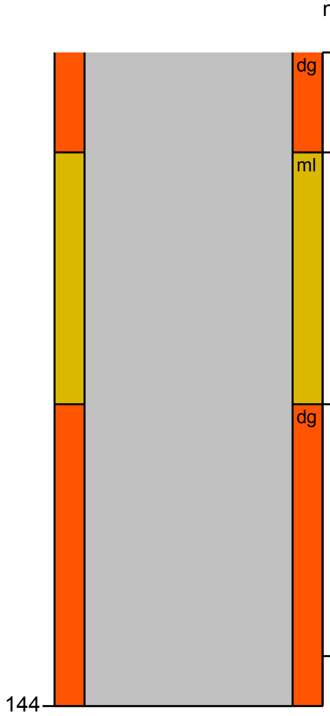
126 **SAND OG GRUS**, groft og usorteret, få slirer af ler, gråbrun, kalkholdig, "smeltevandssand og grus".



fortsættes..

BORERAPPORT

DGU arkivnr: 88. 1401

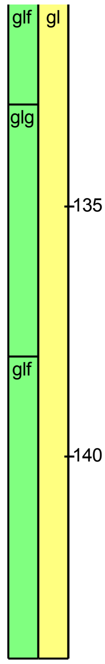


131 **SAND OG GRUS**, groft og usorteret, få slirer af ler, gråbrun, kalkholdig, "smeltevandssand og grus".

133 **LER**, stærkt sandet, gruset, olivengrå, kalkholdig, "moræneler".

138 **SAND OG GRUS**, groft og usorteret, få klumper af ler, grå, kalkholdig, "smeltevandssand og grus".

143 **GRUS**, usorteret, sandet, svagt stenet, grå, kalkholdig, "smeltevandsgrus".



Aflejringsmiljø - Alder (klima-, krono-, litho-, biostratigrafi)

meter u.t.		
0	- 31	glacigen - glacial
31	- 37	glaciofluvial - glacial
37	- 42	glacigen - glacial
42	- 47	glaciofluvial - glacial
47	- 48	glaciofluvial - glacial
48	- 52	glacigen - glacial
52	- 54	glaciofluvial - glacial
54	- 57	glacigen - glacial
57	- 59	glaciofluvial - glacial
59	- 62	glacigen - glacial
62	- 63	glaciofluvial - glacial
63	- 67	glaciolakustrin - glacial
67	- 68	glaciofluvial - glacial
68	- 69	glacigen - glacial
69	- 74	glaciofluvial - glacial
74	- 77	glaciolakustrin - glacial
77	-133	glaciofluvial - glacial
133	-138	glacigen - glacial
138	-144	glaciofluvial - glacial