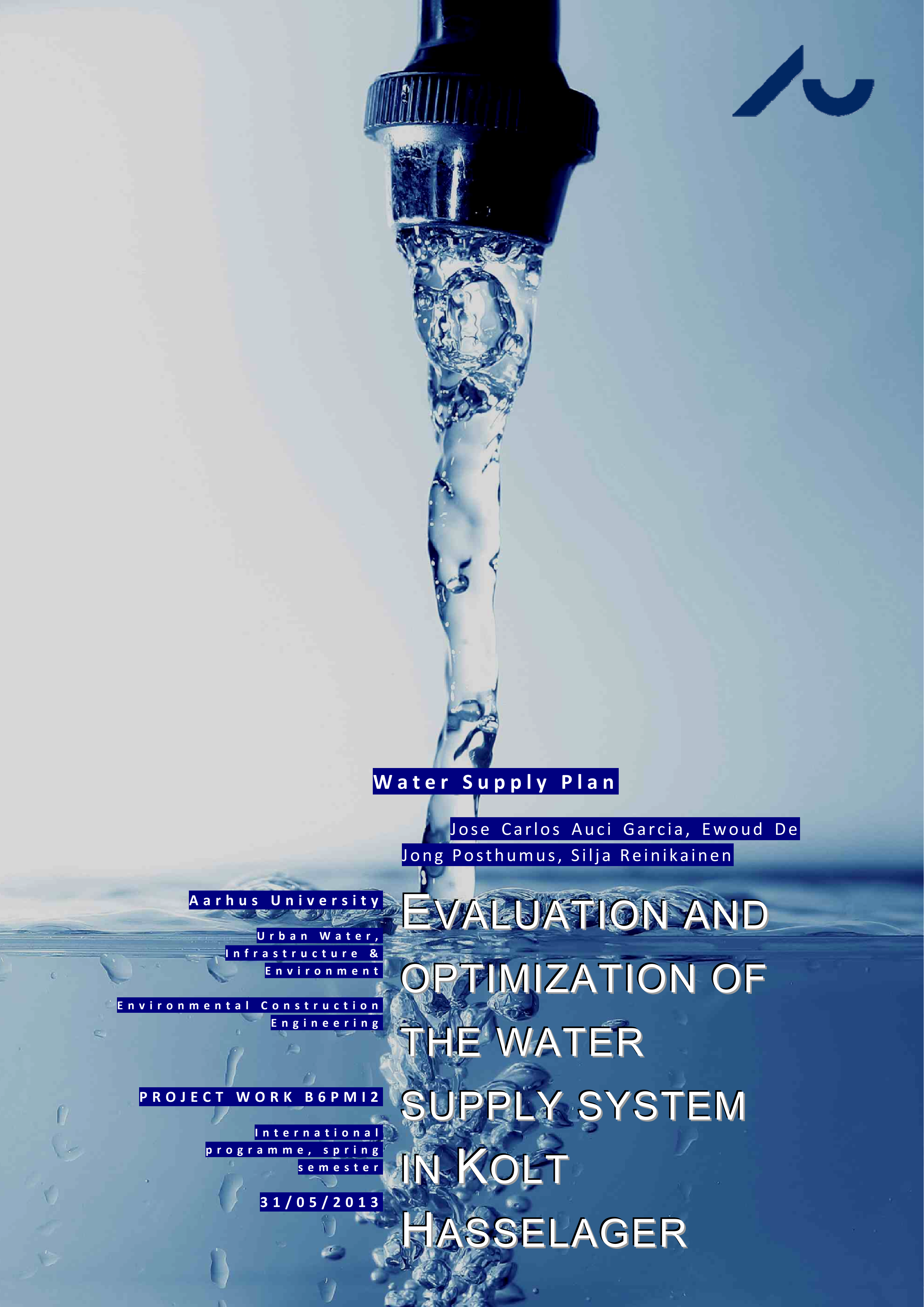

Water Supply Plan

Jose Carlos Auci Garcia, Ewoud De Jong Posthumus, Silja Reinikainen

Evaluation and optimization of the water supply system in Kolt Hasselager

Aarhus University

Urban Water, Infrastructure & Environment

Environmental Construction Engineering

PROJECT WORK B6PMI2

International programme, spring semester

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AARHUS UNIVERSITET

SCHOOL OF ENGINEERING

WATER SUPPLY PLAN

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International programme, spring semester,
31th of May, 2013
Aarhus, Denmark

Abstract

The water supply network and the waterworks facilities of Kolt-Hasselager are analysed. The supply network is analysed with the hydrodynamic model MIKE-Urban EPA-net tool. From the environmental point of view, in the municipal water plan is proved that increasing sulphate levels in the western well field indicate overexploitation of the resource there, since the well fields have insufficient capacity to supply the whole distribution area with water. Increasing the capacity by new wells for ground water abstraction could be an appropriate solution to fulfil the demand of water. Besides, the actual perform of the existing waterworks at Pilegaardsvej is analysed, from the design and performance point of view. Likewise, the waterworks of Kolt Skovvej is resigned to ensure that it is possible to generate a better supply. It is also taken into account that the new wells located further away from the waterworks than the existing wells. The new wells are enjoying better abstraction conditions to meet the total water demand. It seems very appropriate that the water abstracted from this new wells, might belong to the same aquifer as the current ones.

This research contributes to reorganise the water supply network presenting additional information about the well field simulation, waterworks facilities and supply network infrastructure. Under this idea, pioneer models based on ground water, pipe networking, well field analysis, raw water abstraction and transportation are used.

Key words: Kolt-Hasselager waterworks, water supply, standard treatment, wells, ground water, water abstraction, well-field modelling, raw-water modelling, pressurise pipes system.

Contents

Foreword

The process of urbanisation led to a considerable growth of the city services. This increment of people activities may across with the local authority that needs to continue protecting the environment and dealing with parallel working activities such as intensive agriculture. In 1988 the Ministry of Environment approved a Statutory Order on Water Quality and Supervision of Water Supply Plants introducing quality monitoring of abstracted groundwater. The most important parameters are now analysed for all the groundwater abstractions. The Danish Authorities, involved in these decisions, claims for better solutions to canalise all these new demand of services in a better way. Accordingly, farm lands in the rural areas become an additional challenge providing extra supply of inorganic sources of pollutants increasing the chance of alternating the normal water quality. In 1994 the Danish Government began a dialog with farmers and possible field work that could represent a risk of the underground water. By the end of 1997, Denmark opened a classification according to the degree of drinking water interest.

Placed at the suburbs of Aarhus area, Hasselager and Kolt are located in the south-western part of the Aarhus municipality. Hasselager-Kolt waterworks is a limited waterworks company that is in charge of supplying water to the residents in the area of Hasselager and Kolt. The water production in the year 2010 was 333.860 cubic metres. Hasselager and Kolt encompass a slow but progressive expansion of residential areas, intensive agricultural and some industrial activities. Consequently brings new demand for environmental services as water abstraction and domestic supply. The raw water supply is based on groundwater intake is from three well fields, each one connected to a separate waterworks (located at Koltvej 14, Kolt Skovvej and Pilegaardsvej).

With this in mind, this University Report is designed as a *Consulting Company* hired by the municipal technical department to provide a specific overview focused in the suburbs of Aarhus area, Hasselager and Kolt, in order to find out how the waterworks facilities performs according to the abstraction regulations. Henceforth, it is provided an extended analysis about the supplying services processes. Moreover, this Report studies if there are appropriate conditions to support a future expansion of the population on the other hand the facilities should be implemented in either specific direction. At the end, conclusions will be described in each comprehensive part of the project.

The research purpose is concretized in the following tasks of this Project:

- Provide overall information about the location of Hasselager and Kolt from the environmental engineering point of view specified in water supply activities,
- Identifying new urban develop areas and new consumers connected directly with water demand,
- Dimensioning of a new water supply network and evaluate if this can be connected to the existing system in order to create a well working supply network for the area.
- The raw water quality, the intake situation, water treatment facilities and distribution network are to be evaluated in light of the new well-field,
- Analyse the hydrogeological situation:
    - The intake aquifer in terms of reservoir characteristics. Evaluate aquifer yield and vulnerability to antropogeneous contamination. Estimation of pipe roughness coefficients and head loss in wells,

- The present intake wells (age, depth, capacity). Chemical quality of the raw water in relation to the geological conditions in the aquifers.

- Find out the currently situation of the Waterworks such as:
    - The present water consumption and assess future consumption needs,
    - The evaluation of the lay out facilities, including the process concept and key process parameters (filter design, filter velocity, wash water consumption and treatment, treated water quality, filter operation time (quantity / time between back-wash), storage and distribution capacity).
- Information about the water abstraction in a new well location placed in a rural area:
    - Basic dimensioning and design of a new raw water pipe and the new planned waterworks (two separate lines).
    - Including dimensioning of key technical installations.
    - Structure and sectioning of the supply network and associated technical installations in relation to the demand.

The suggested technical solutions to the above mentioned challenges, are focused towards the consumers according with the environmental regulations, thus implicit the efficiency of the engineering facilities to be analysed in the project scope, and hence with this the main concern is the protection of the water abstraction as a paramount part of the Water Framework Directive and the Groundwater Directive.

This comprehensive document consists of the following structure:

- A Mandatory Part and an Optional Part divided 50% each approximately,
- The general conclusions of the Report are exposed in a first part as a reasonable consulting demand,
- The calculation results and further technical details necessary for the approved conclusions are presented in a second part of the Report,
- Additional information with relevant value shall be located at the end of the document into appendixes.

The Report has a limitation:

- The economical details are not object of this research.

This Report was written by international students:

- *Carlos Auci, Spain; Ewoud de Jong Posthumus, Nethererlands; Silja Reinikainen, Finland.*

This course takes part of the Environmental Engineering Studies at the School of Engineering at Aarhus University during the spring semester, 2013, and corresponding to20 ECTS.

During the execution of this university thesis, this team has consumed the amount of 21370 cubic metres of tap water including households, services, coffee, tea and any other sort of suitable drink.

List of symbols

A [m²]: *area*

A_t [m²]: *total abstraction area*

B [m]: *aquifer thickness*

BOD: *biological oxygen demand*

C: *concentration*

COD: *chemical oxygen demand*

EBCT [min]: *empty bed contact time*

HRT [hours]: *hydraulic retention time*

I_a: *area gradient*

I_a: *gradient upstream*

I_w: *gradient around the well*

I_w: *well gradient*

K [m/s]: *hydraulic conductivity*

mWC: *metre water column*

NVOC: *non volatile organic carbon*

OC [kg O_2/d]: *oxygen capacity*

PE: *population equivalent*

Q [m^3/s] [m^3/h]: *flow, pumped flow*

Q_{max} [m^3/y]: abstraction amount

r [m]: *filter radius*

s [m]: *draw down*

S: *storativity value at confined or unconfined aquifer*

Ss: *specific storativity*

SS: *suspended solids*

Sy: *specific yield*

T [K]: *temperature*

T [m²/s]: *transmissivity*

t [s; min; hour; year]: *time*

TOD [mg O_2]: *theoretical oxygen demand*

T_{res} [min]: *residence time*

V [m³]: *volume*

V_f [m/h]: *filtration velocity*

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1 Introduction

Total water consumption in Denmark is almost 1000 million cubic metres per year, which comes entirely from groundwater abstracting by wells.[1] Denmark's water supply is decentralised, with companies operating countrywide. Unlike electricity suppliers, water suppliers cannot be changed, as each municipality has its own water supplier. Local municipal offices can provide information on the local water supplier. Dealing with it, there are two small suburban areas in the south-western part of Aarhus, and these are Hasselager and Kolt as shown in the following map (figure 1).

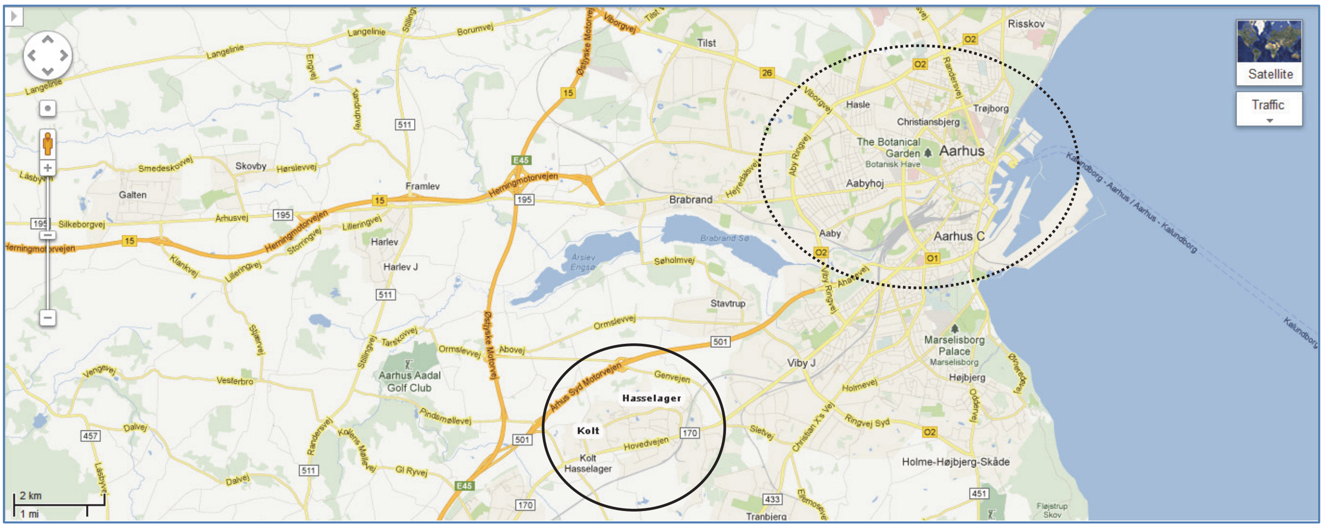


Figure 1 General view of Hasselager-Kolt area respect from Aarhus. Google Maps

Hasselager and Kolt obtain the supplying water by three waterworks, Koltvej 14, Kolt Skovvej and Pilegaardsvej (Figure 2), but due to a future implementation the Koltvej 14 waterworks will be close, and the Kolt Skovvej waterworks will be rebuilt. The raw water abstracted for these waterworks comes from six wells: three for Kolt Skovvej, one for Koltvej and two for Pilegaardsvej. In addition there are two new wells ready to abstract water in the north part of Hasselager. The interest in these wells increase as their raw water will be treated in Kolt Skovvej too. Therefore Kolt Skovvej will have additional raw water to be treated. This is positive because it prevents overexploitation of the current aquifer but, on the other hand, it is interesting to find out if water abstracted by the new wells comes from the same aquifer. If this is the case, existing abstraction wells might be closed.

In a first step, the water supply system comprising the water abstraction, treatment and distribution, in Hasselager and Kolt is analysed according to the actual water demands. It is presented by an extended evaluation of the whole water supply system taking into account additional propositions for future plans connected with the urban growth. This evaluation of the water supply system encompasses a description of Hasselager and Kolt area giving a special attention to its hydrogeological situation and the terrain and conditions of the wells.

The chemistry analysis gives the reference of the water quality as the raw water composition has a big influence with the applied treatment after the abstraction process. In order to know how much water is requested in the supplying areas current and future consumption are analysed.

[1] Well: a shaft sunk into the ground to obtain water, oil, or gas. Here referrers to water abstraction only.

The waterworks' evaluation performances are basic in the way of knowing what characteristically processes are kept for the future. This includes the description of all the equipment components and several parameters description. The final test of the water supply cycle is the evaluation of the existing distribution system. The network analysis is done by using the software 'EPANET' extended with the Mike Urban package.[2] Mike Urban performs a steady state simulation of hydraulic and water-quality behaviour within pressurized pipe networks in both raw water abstraction pipes and water supply pipes.

The second part of this project focuses on the new wells field's performance. The new well field is located about 3 kilometres north of the existing waterworks in Hasselager-Kolt (Figure 2). This location encompasses a vast valley and it is presumed for better supplying activities. It is very interesting to find out if the water abstracted by these new wells belongs to the same aquifer[3] as the existing wells. Dealing with this favourable case, it would represent a great advantage as a possibility to reduce costs and improve the supplying services.

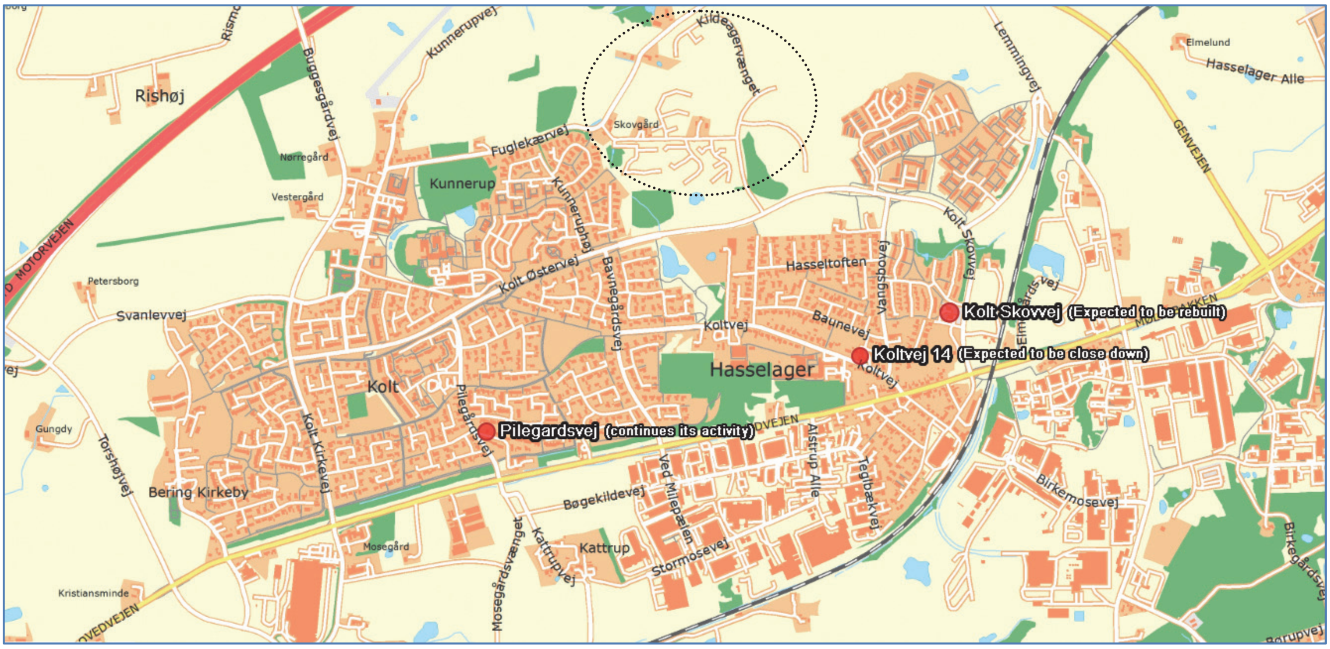


Figure 2 The plan of the project scope including the waterworks locations and new area. Danmarks Miljøportal

Computer modelling complemented with other relevant information could reveal if the aquifer from the new wells is connected to the aquifer from the existing wells visiting the waterworks and testing the pumps contributes with useful data that afterwards are introduced in the computer modelling. The software is based on pipe modelling well field analysis and it is specific in the raw water abstraction and transportation. It is known as "well-field & raw-water modelling".

[2] EPANET is a public-domain, water distribution system modelling software package developed by the United States Environmental Protection Agency's (EPA)
[3] Aquifer: a body of permeable rock that can contain or transmit groundwater.

2 Case-Study

The suburbs Hasselager and Kolt are located in the south-western part of the Aarhus municipality with a current population of 4000 residents. Hasselager-Kolt waterworks[4] is a limited waterworks company that is in charge of supplying water to the residents in the area of Hasselager and Kolt (mainly households and a few small industries), see figure 2. The water production in year 2010 was 333.860 cubic metres according to the current data provided. The location is 9 kilometres from the city centre of Aarhus. The average elevation in the area is 72 metres above sea level and the area is located 10-12 kilometres far from the coastline. The continuous increase of population and industrial facilities in the area asked higher production of water. Therefore, it was decided to close one of the existing three waterworks and rebuild the other one in order to meet the future requirements of water supply.

Engaged with the future perspectives, the waterworks Hasselager-Kolt Vandværk has decided to close down Koltvej 14. Moreover Kolt Skovvej is been rebuilt while the water works at the Pilegaardsvej will be working the same manner as now.

3 Geological characteristics: the origins of the Danish underground

The landscapes of Denmark are modelled by the large glaciers through the last ice age. The ice covered most of the country, but the glaciers stopped for a longer time in the middle of the peninsula Jutland (Jylland). In the south western parts of Jutland the soil are sandy due to sediments from the large rivers of melting water running out from the glaciers and the landscape is rather flat. Where the glaciers stopped in the middle of Jutland the underlying soil were pressed up in the highest hills in Denmark. The result is seen today as a north-south running "mountain range" with "peaks" up to 172 m above sea level. The rest of Jutland and the Danish islands are generally built up of sediments deposited through melting of the ice cap (morain). The soils are loamy or clayey and the landscape is much varied. In some places the rivers from the glaciers has deposited smaller plains of sandy sediments e.g. in Djursland (the "nose" of Jutland) and in North Western Seeland (Sjælland).

The supplying water of Denmark is abstracted from underground resources. These underground resources are the aquifers. Aquifers are the geological beds from which water is stored along the time and they are generally formed of lose deposits of sand and gravel, and deposits of limestone. In particular, the island of Bronholm abstracts the ground water from basement rock and sand stones which are fractured.

The uppermost geological beds are quaternary beds which are the youngest, contain glacial deposits, and cover the prequaternary beds. The geological beds are also called rock species which are consistent of various types of minerals. Generally in Denmark the upper beds with aquifers consist of sedimentary rocks (soft rock) while in Bronholm metamorphic and igneous rocks exist right on the ground surface (hard rock).

[4] Water Company: Hasselager-Kolt Vandværk, AMBA, www.hkvand.dk

3.1 The geology of Aarhus' area

Roughly, it is important to mention that Aarhus area is placed (figure 3) in a transition zone among what is considered the Late Tertiary and the Early Tertiary boundary, therefore, sand aquifers like quartz and mica sand aquifers are expected to be found. Towards north, still nearby Aarhus area, it should be possible to find ground water such as limestone aquifers but unfortunately the limestone is situated so deeply that groundwater abstraction is impracticable.

Figure 3 Denmark division among the Late Tertiary and the Early Tertiary boundary. Facts about surface water - Water Supply

The stippled area shows where Late Tertiary sand aquifers can be found. It is noted how the location of Aarhus and its surrenders are not well defined yet as a part of the boarder. The deposits at the highest parts are eroded and then sedimented at the lowest because of the tectonic movements. The geological beds in Denmark have been affected by the three main tectonic processes: regional movement of the earth's crust, glacial-tectonic disturbance and local tectonics in salt domes.

3.2 The characteristic geo-profile

The geological profile of Hasselager-Kolt is presented by the 3D software called GeoScene. The data in GeoScene gives a macroscopic view of the case-study underground. The followed figures are two geological profiles (figures 4 & 5) of the area Hasselager-Kolt. The Profile-48 is a cross-section from the west to the east part of the area, whereas Profile-12 is perpendicular to this one (Profile-48), in the middle of the area and it is included just as an extended reference. As it is possible to see there are only a few layers responsible of the dominion of the underground. The hydrogeology can be observed via internet with GEUS data base. The GEUS[5] data base is in charge to register all the significant details of the underground morphology including the groundwater activity. Further details of the groundwater are presented in the chapter 3.3 the hydrogeological activity.

[5] An abbreviation for Danmarks og Grønlands Geologiske Undersøgelse, is the Danish independent sector research institute under the Ministry of Climate and Energy. The English name of this institute is Geological Survey of Denmark and Greenland, an advisory, research and survey institute in hydrogeology, geophysics, geochemistry, stratigraphy, glaciology, ore geology, marine geology, mineralogy, climatology, environmental history, air photo interpretation, geothermic energy fields concerning Denmark and Greenland.

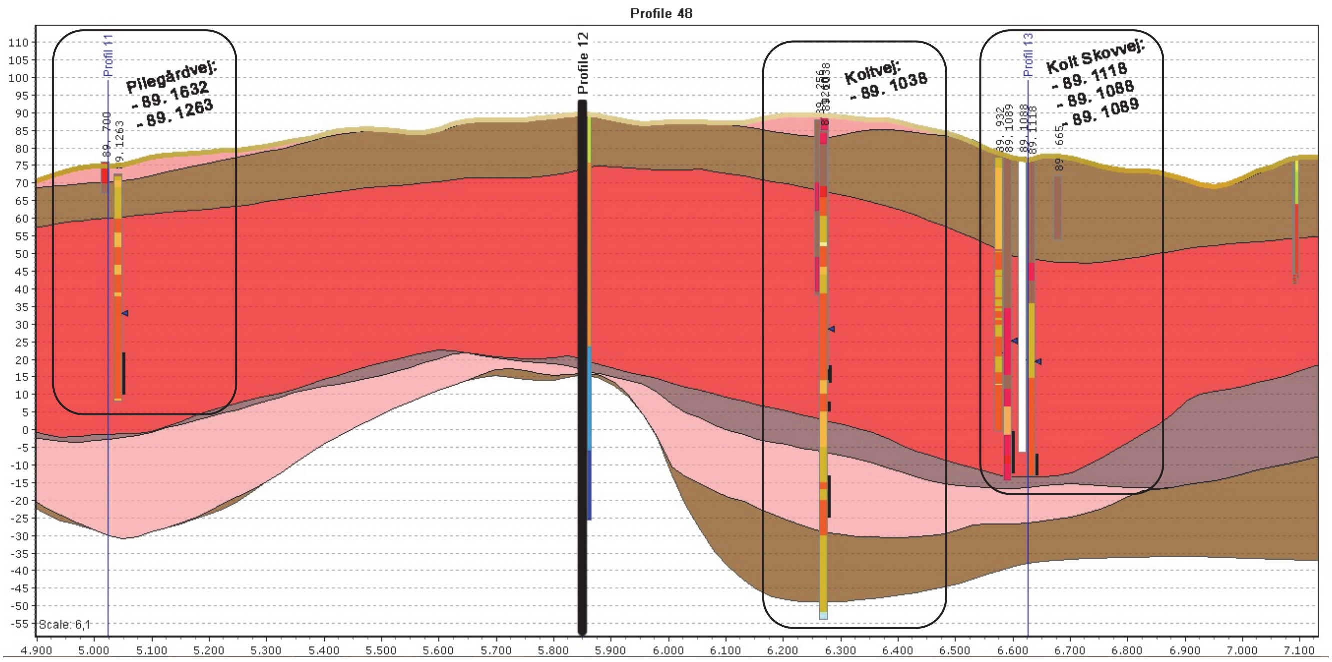


Figure 4 Geological profile of Hasselager-Kolt encompassing the current wells associated to their waterworks respectively. Profile 48 - 3D Geoscene

A first impression shows that the 3 wells are abstracting water from different type of ground, however, it is known that both Pilegaardsvej and Kolt Skovvej abstract water from a glacial deposits.[6] Pilegaardsvej gets water from an unconfined aquifer whereas Kolt Skovvej is confined because it is located just after a clay layer. In a different manner, the abstraction from Koltvej is made from a deeper well and retries water from a Late Tertiary[7] deposit it contains also various layers of clay with increasing depth but they do not affect the aquifer which is unconfined.

A resume observation through the different layers shows that at the beginning are predominant layers of glacioflubial sand and gravel followed by till with clay and fine sand and sandy and gravelly till. After in clearer grey colour is possible to identify a glaciomarine clay, silt and sand. After this layer a till with clay and fine sand appears once again before arriving to the Late Tertiary layers.

This characteristic geo-profile can be identified as well in a perpendicular cross-section, shown in the following figure. Although this can be considered as the basic situation bellow the underground, in reality the underground activity is not always corresponding to these maps and it is very necessary to provide additional information to contrast all these possible situations. Specific information about the geological profiles comes out from the wells drilling. Moreover it is possible to appreciate the different colours in the boreholes shown in the cross-sections and hence, to know more in detail about the underground sediments, further specifics analysis must be done. This operation takes place when a borehole is drilled. As a result, the information obtained by the 3D Geoscene is contrast with the laboratory results after collecting all the excavated sediments and as mentioned, the specific information can be seen in the GEUS data base under the files 'Borerapport'.

[6] Glacial deposit is a lay down of sediments which have been removed and transported by a glacier. The sediments —known as till, or drift— are deposited when the ice melts; that is, when ablation is dominant.

[7] Late Tertiary deposit is characterised by system of rocks with sedimentary deposits from the first period of the Cenozoic Era.

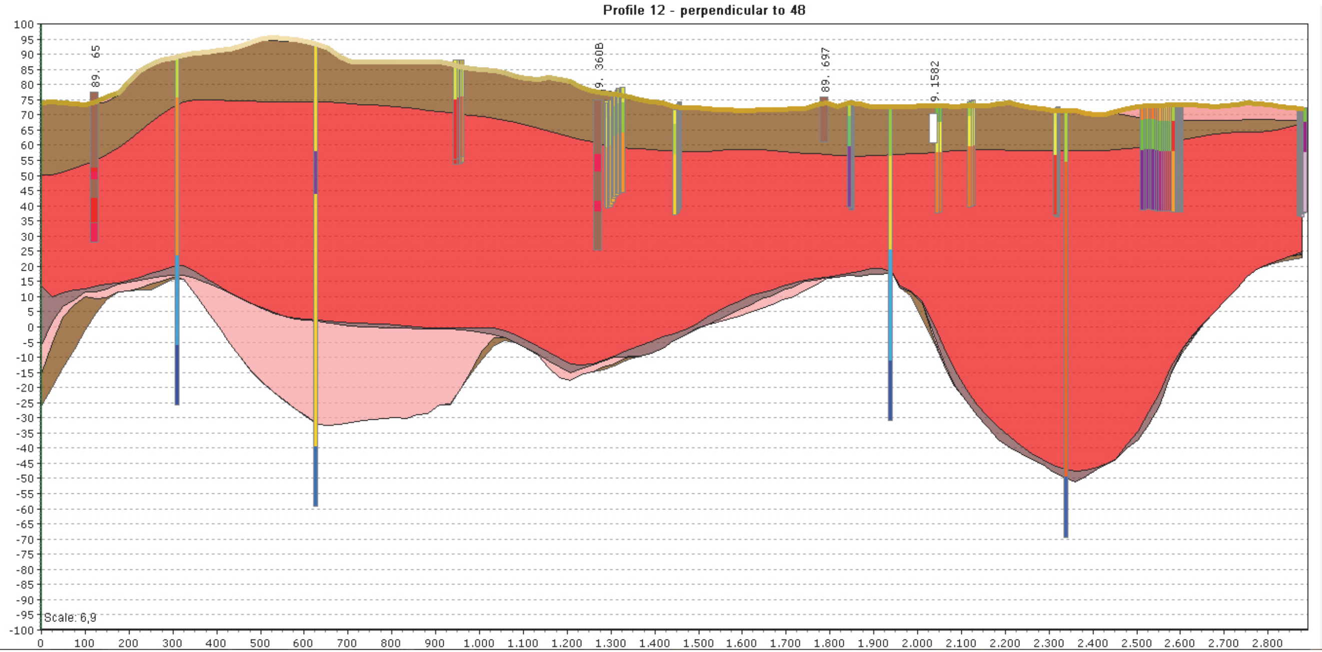


Figure 5 Geological profile of Hasselager-Kolt in perpendicular direction to the previous one number 48. Profile 12 - 3D Geoscene

From the environmental perspective, in Pilegaardsvej there is an unconfined aquifer that contains a bed of clay above the abstraction area which is approximately 13 metres thick. This layer protects the underground water from a possible contamination. In Koltvej the abstraction comes from another unconfined aquifer in a deeper place. Kolt Skovvej has the only confined aquifer of these three aquifers, the clay guarantees protection against an infiltrating pollution. Although the clay layers are present during all the geo-profile, the protection against a source of pollution from the surface is not completely assumed, on the other hand, the abstraction level is deeper than before which gives additional precaution.

3.3 The hydrogeological activity

The underground water is preserved within the nature in aquifers. These are the water saturated rocks from which water could be abstracted. Aquifers are limited by an impermeable layer from beneath which prevents further infiltration. In general there are two main kinds of aquifers: unconfined and confined.

If the potentiometric surface[8] lies within the permeable rock the aquifer is unconfined aquifer. There are two kinds of confined aquifers, one confined aquifer where the potentiometric surface is over the upper boundary and the other confined where the potentiometric surface is above the ground surface; in this case it means also that is artesian aquifer. The water flows under pressure to the surface.

The GEUS is used to determine the geology and the type of aquifers is in Hasselager and Kolt. The project takes into consideration nine wells, six of them are in use and, two new are ready to work and one has been closed. Their identification facts are shown in table 1.

[8] A hypothetical surface representing the level to which groundwater would rise if not trapped in a confined aquifer (an aquifer in which the water is under pressure because of an impermeable layer above it that keeps it from seeking its level). The potentiometric surface is equivalent to the water table in an unconfined aquifer.

Groundwater abstraction wells – Location and identification					
Waterworks	**Borehole number**		**Well field**	**Aquifer**	**Currently**
	Nº	DGU nº			
Kolt Skovvej					
	1	89. 1118	Buen 24	Unconfined	Stand by
	2	89. 1088	Buen 24	Confined	Working
	3	89. 1089	Buen 24	Confined	Working
	4	89.1904	Buen 24	Confined	Working
Koltvej					
	5	89. 1038	Koltvej 14	Unconfined	Working
Pilegaardsvej					
	6	89. 1632	Pilegårdvej 33	Unconfined	Working
	7	89. 1263	Pilegårdvej 33	Unconfined	Working
Hasselager					
	8	89.1754	Genvejen	Unconfined	New
	9	89.1852	Genvejen	Unconfined	New

Table 1 Groundwater abstraction wells. Well nº 1 is not running since 27 Dec. 2012. Well Nº 4 will be close down.

In the current situation, in Hasselager-Kolt the water is supplied by three waterworks and the abstraction is taken from the wells. Pilegaardsvej is running in night time from 17:00 to 5:00. In daytime the waterworks Kolt Skovvej takes over and runs from 5:00 to 17:00 hours. The waterworks Koltvej is smaller compared to the others and it is running the same time as Pilegårdvej from 17:00 to 5:00. The followed figures 6 and 7, locate the wells together with the waterworks responsible of the treatment and supply.

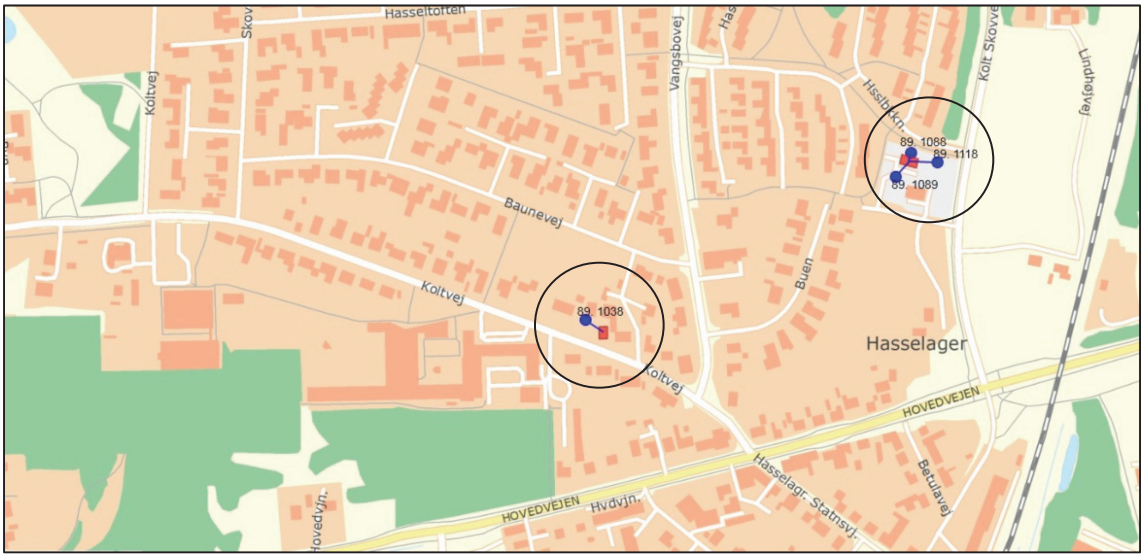


Figure 6 Koltvej and Kolt-Skovvej waterworks with their wells connected. Danmarks Miljøportal

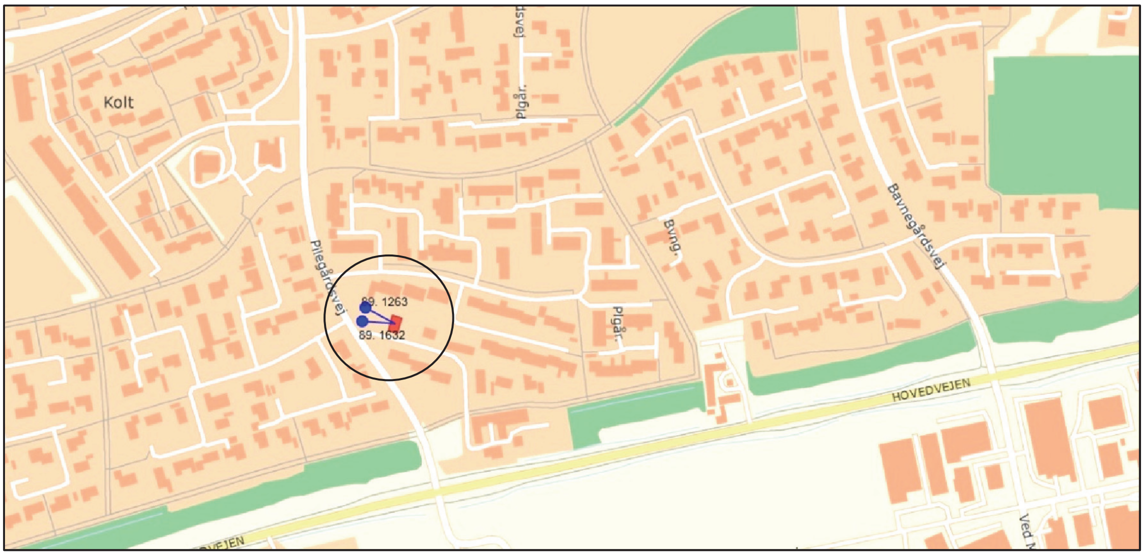


Figure 7 Pilegårdvej waterworks with its connected wells. Danmarks Miljøportal

Due to the demographic growth the water consumption tends to increase. Therefore the municipality has decided to construct a new well field further north after the new residential area. This well field will increase the capacity to abstract groundwater and should prevent overexploitation of the aquifer. The borings are already established. These are the numbers 89.1852 and 89.1754. Both wells obtain water from glacial melt water sand aquifers; the distribution of the layers is very similar. Both wells have water levels close to each other, the aquifer is unconfined. As the aquifer is covered with a thick clay layer, the risk of contamination from the surface is lower. The plan is to distribute water from the new well in a new raw water pipe to new waterworks at Kolt-Skovvej.

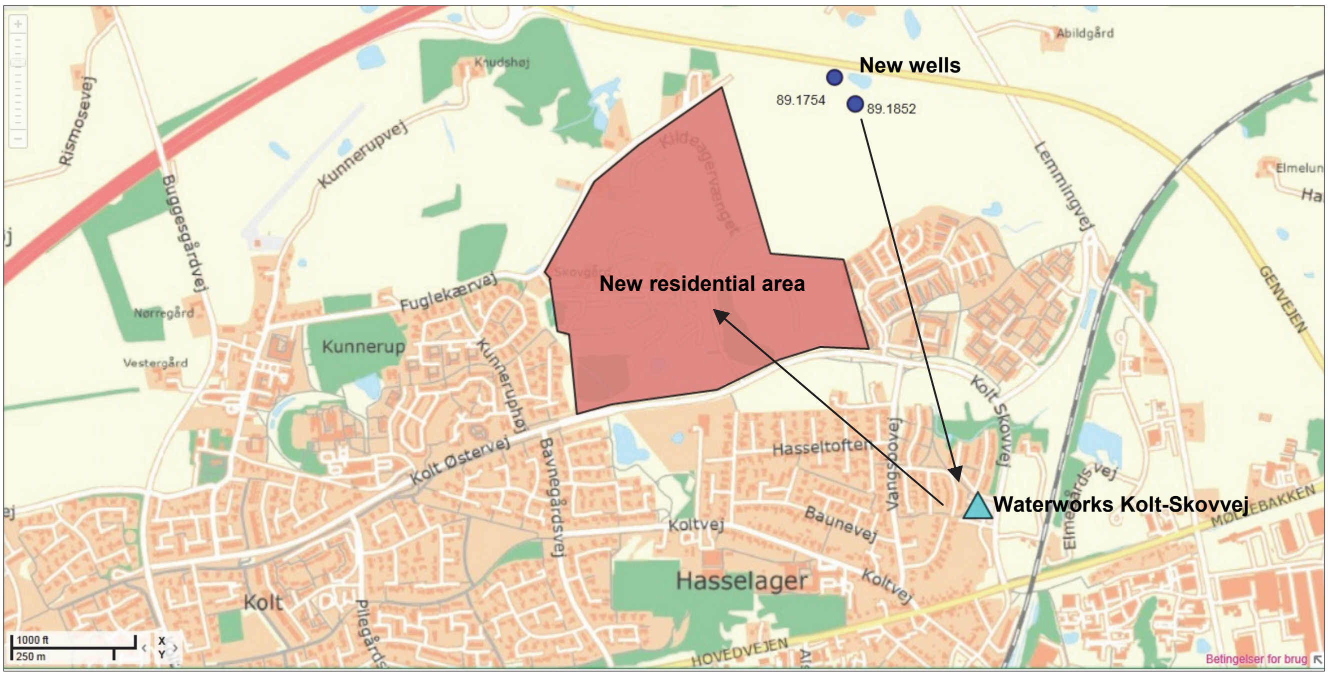


Figure 8 Scope of the new urban expansion, new well fields and waterworks of Kolt-Skovvej. Danmarks Miljøportal

It is assumed that the abstraction of these new wells comes from the same aquifer but it is not possible to know unless a pump test is applied.

In addition, the second part of this project is focused to find out if these new wells are connected with the same aquifer as the current abstraction.

3.4 The hydrogeological model: aquifer properties

The water cycle is the perpetual movement of water on Earth and the groundwater occurrence as well, and when the precipitation occurs to earth with rain, hail or snow, it may:

- Returns to the atmosphere through evaporation;
- Contribute directly to surface water bodies, glaciers or snow;
- Fall on the landscape and run-off to streams and rivers that feed into the seas;
- Infiltrates into the ground and be taken up by plants and returned to the atmosphere through transpiration; and
- Permeates into the ground to recharge groundwater systems.

Water that permeates becomes ground water and it can be described geologically through these characteristics: head, gradient, storativity, transmissivity and conductivity.

3.4.1 Hydraulic head

Hydraulic head is the height to which water will rise in a bore. It is the resting groundwater level. Usually, it is measured as the depth below natural surface as it shows the figure 9. The hydraulic head may also be measured against sea level to compare between different bores. Groundwater will always move from high to low hydraulic head.

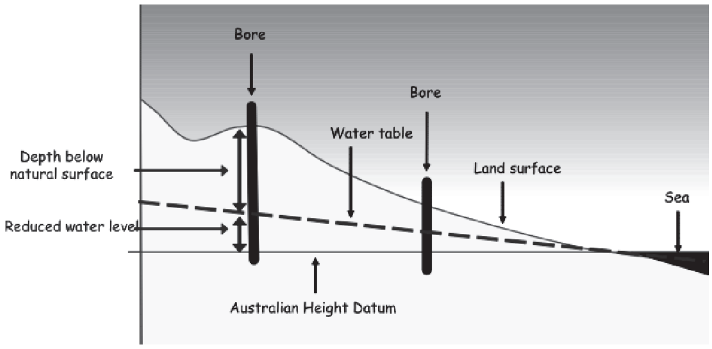


Figure 9 Measures of groundwater level depth below natural surface and against the Australian height datum.

3.4.2 Hydraulic gradient

A hydraulic gradient (I) is the difference between the hydraulic head measured at two points in an aquifer divided by the distance between them (Figure 10).

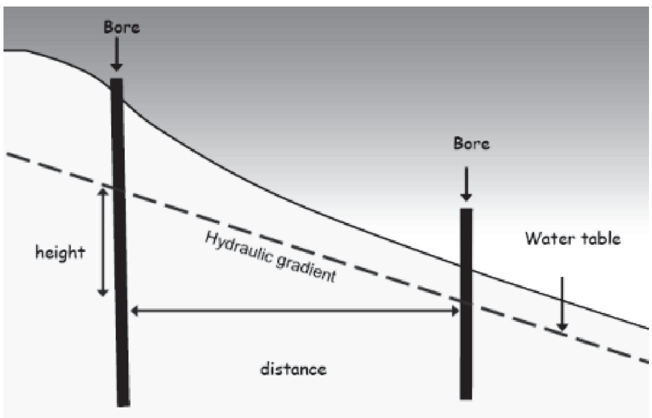


Figure 10 Hydraulic gradient slope between two bores.

3.4.3 Storage coefficient

The storage coefficient or storativity is the volume of water released from storage with respect to the change in head (water level) and surface area of the aquifer. Storativity (S) tells how much water is released from 1 m³ sediment if the water level is lowered by 1 m. The value of the storage coefficient is dependent upon whether the aquifer is unconfined or confined.

For a confined aquifer the water table is above the aquifer/sand, so lowering the water table will not cause gravity drainage of that 1 metre. The only water that is released from a confined aquifer is caused by the pressure drop causing the sand grains to expand a little bit and hence there are less room for water, which is then released (Specific storativity, S_s). Confined: $S = S_s$ If you have an unconfined aquifer the storativity will be almost the same as the porosity since lowering the water table by 1 metre in a cube of 1 cubic metre is equal to emptying the pores of that 1 m³ (Specific yield, S_y). For the unconfined aquifer you will have both S_y and Ss but Ss is smaller than S_y, so normally you only use S_y for unconfined aquifers. Unconfined: $S = S_y + (S_s)$

3.4.4 Transmissivity

Transmissivity (T [m²/s]) is hydraulic conductivity (K [m/s]) multiplied by aquifer thickness (B [m]): T = K * B. It tells about how well the ground conducts water. It describes the ability of the aquifer to transmit groundwater throughout its entire saturated thickness. Transmissivity is measured as the rate at which groundwater can flow through an aquifer section of unit width under a unit hydraulic gradient. Transmissivity can be determined from a pumping test using the time-drawdown data. In the next table is possible to visualise the wells transmissivity results calculated by interpretation of results considering the followed storativity (S) assumption:

Waterworks	Borehole number		S-value	Q (m³/h) – s (m)	T (m²/s)
	Nº	DGU nº			
Kolt Skovvej					
	1	89.1118	-	-	-
	2	89.1088	0.0004	-	-
	3	89.1089	0.0004	55 – 3	0.007659326
	4	89.1904	0.0004	25 – 15	0.000602785
Koltvej					
	5	89.1038	0.2	25 – 4.5	0.001346038
Pilegaardsvej					
	6	89.1632	0.2	50 – 5.53	0.002297225
	7	89.1263	0.2	29.4 – 3.3	0.002260384
Hasselager					
	8	89.1754	0.2	-	-
	9	89.1852	0.2	32 – 13.2	0.000538399

Table 2 Transmissivity values obtained from estimation: $S_{Confined} = 0.0004$ $S_{Unconfined} = 0.2$

The current transmissivity shows very similar results between the wells that supply each waterworks and this is an additional prove to identify each aquifer. With these results it is possible to assume that there are four different aquifers in between Kolt Skovvej and Hasselager.

3.4.5 Hydraulic conductivity

Hydraulic conductivity is the ease with which water can move through an aquifer. Hydraulic conductivity can be determined by dividing the transmissivity of the aquifer by the aquifer thickness. The hydraulic conductivity can vary in a geological unit over relatively short distances, particularly in fractured rock aquifers. The typical values for hydraulic conductivity are:

Geological composition/unit	Hydraulic conductivity (m/d)
Fine sand	1 to 5
Coarse sand	20 to 100
Gravel	100 to 1000
Shale	$5x10^{-8}$ to $5x10^{-6}$
Sandstone	$1x10^{-3}$ to 1
Basalt	0.0003 to 3

Table 3 Values for hydraulic conductivity. Source: http://www.connectedwater.gov.au/

3.5 Groundwater chemical analysis

Ground water is sampled to assess its quality for a variety of purposes. Each purpose can only be achieved if results are representative of actual site conditions and are interpreted in the context of those conditions. In this situation, the ground water studied pursuit the drinking Danish standards of water supply. In the followed table (table 4) is presented the results obtained from each well. According with the Danish standards it is found out that the water quality is kept inside the average levels of drinking quality.

Groundwater Hydro-geochemistry analysis results of the wells

Wells	89.1632	89.1263	89.1904	89.1088	89.1089	89.1038	89.1754	89.1852	
Date	25.10.04	29.05.89	05.12.12	01.06.69	01.06.79	01.01.60	14.10.10	20.01.12	
Well depth (m)	72	65	90	84	92	77	136	118	
Water table (depth, m)	40,1	39,7	52,2	52,4	52,3	60,6	50,1	49,7	
Pump capacity (m3/h)	50	30	25	27	55	25	35	35	
Address	Pilegaardsvej	Pilegaardsvej	Buen 24	Buen 24	Buen 24	Koltvej 14	Genvejen	Genvejen	
Chemistry	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	Standards
Sample date	15.11.11	21.05.12	22.01.13	04.02.13	15.10.03	15.12.09	05.05.11	18.10.10	
Iron	2,14	2,08	1,55	1,24	1,3	0,002	3,4	3,4	0,1
Manganese	0,221	0,317	0,295	0,247	0,25	0,001	0,28	0,32	0,02
Ammonium	0,2	0,1	0,38	0,23	0,28	0	0,2	0,18	0,05
Phosphorus	0,05	0,05	0,12	0,35	0,13	0	0,1	0,13	0,15
Calsium	99,6	108	86,1	82,5	88,1	101	100	100	-
Chloride	21	23	24	24	19	20	20	21	250
Magnesium	6,6	8,98	14,4	3,58	12,5	8,86	9,3	8,9	50
Potassium	1,43	1,69	4,52	3,82	3,8	2,69	2,4	2,4	10
Sodium	12,4	12,5	25,9	21,1	17,2	15,7	16	16	175
Sulfate	43	63	19	20	18	32	43	44	250
Hydrogencarbonate	259	284	357	303	319	305	291	297	-
NVOC	1,6	1,3	1,4	0,7	0,91	1	2,5	3,1	4
Fluoride	0,2	0,2	0,2	0,3	0,25	0,2	0,23	0,23	1,5
Nitrate	0	0	1,2	0	0	0	0	0	50
pH	7,6	7,45 (3.10.08)	(ass. 7,3)	7,4 (15.9.12)	7,2	7,44	7,5	7	7-8,5
K (mS/m)	54,8	56	75	56,5	56,1	54	58	no data	30
Pesticides (sum)	0	0	0	0	0	0	0	0	0,0005
Calculations									
Hardness	15,44	17,16	15,29	12,35	19,56	16,15	16,11	16,02	
	Middle	Middle	Middle	Middle	Hard	Middle	Middle	Middle	
Ion excange	0,91	0,84	1,67	1,36	1,40	1,21	1,23	1,18	
	Ion ex.(close)	No ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.	
Degree of weathering	1,3	1,32	0,94	0,89	1,04	1,15	1,21	1,18	
	Normal(close)	Pyrite ox.	No pyr.ox.	No pyr.ox.	Normal	Normal	Normal	Normal	
Ion balance	1,5%	1,5%	-3,1%	-11,1%	2,2%	4,5%	4,1%	1,6%	
Calsite saturation index	0,61	0,54	0,39	0,4	0,25	0,53	0,56	0,57	
	Saturated	Saturated	Saturated	Saturated	Saturated	Saturated	Saturated	Saturated	
Redox type	C	C	D	D	X	X	C	C	

Table 4 Groundwater Sampling and Analysis. Chemical signatures of groundwater, in terms of concentrations and isotopic ratios, can be used to understand groundwater processes and quality. Redox type description note: A: Strongly oxidised, B: Weakly oxidised, C: Weakly reduced, D: Strongly reduced, X: Sample not valid.

The results of the different water quality parameters showed that the groundwater aquifers chemistry from each well field is in good condition. The abstraction area is characterised by overlaying clay. Clay protects aquifer before intrusion of impurities. The water is easy to treat and required standard treatment. The details of the treatment are explained in the following section, chapter 4.

In the next part of the report it is explain the most important chemical parameters: *ion balance, the degree of weathering, the degree of ion exchange, the degree of hardness, calcite saturation index, water redox type, the conductivity, the pH and the organic matter contents.*

3.5.1 Ion balance

When a groundwater sample is analyzed for the major ions, a calculation between cations and anions help us to determine is the analytical result correct. If deviation is under 5%, we can assume that the chemical analyse is correct. Only well 89.1088 has deviation more than 5%. It's probably because magnesium level is very low, only 3.58 mg/l. In database can be seen that magnesium level in that well has been between 10 mg/l and 15 mg/l during last 50 years. Second last sample was taken 15.9.2011 and on that time magnesium level was 12 mg/l. We used anyway this latest sample (4.2.2013) and its information. It's assumed that there has to be mistake when taking the sample.

3.5.2 Degree of weathering

Degree of weathering is ratio between calcium, magnesium and hydrogen carbonate. High F value (1.3) indicates pyrite oxidation. If F value is between 1 and 1.3 situation is normal. In Pilegaardsvej wells there are signs of pyrite oxidation even in well 89.1632 in theory there is no pyrite oxidation. Value is very close and it can say there is pyrite oxidation in both wells as they are close to each other. Wells 89.1088 and 89.1904 doesn't have pyrite oxidation while rest of the well are in typical/normal range.

3.5.3 Degree of ion exchange

Ion exchange is a process in groundwater. Ions which are loosely bound to aquifer solids, exchange with ions dissolved in the groundwater. In Pilegaardsvej wells there is in practise no ion exchange even the other well (89.1632) is actually having ion exchange but number is so close to not to have ion exchange. All the other 6 wells don’t have ion exchange.

3.5.4 Hardness, °dH

Hardness of the water is important information for consumers. Very hard water causes disadvantages. Only well 89.1089 has hard water, others have middle hard water.

3.5.5 Calcite saturation index

Buffered water type can be recognized by the calculation of calcite saturation index, Si

In new wellfield and old wellfield water is saturated, as calcite saturation index is above zero. It means water is buffered, and pH levels say the same.

3.5.6 Redox water type

Redox conditions were determined based on redox algorithm.

New wellfield and Pilegaardsvej waterworks' wells ranks in category C, weakly reduced. In this category iron, ammonia and manganese are present.Wells 89.1904 and 89.1088 are in category D, strongly reduced. Hydrogen sulphide and methane are present in category D.

Wells 89.1089 and 89.1038 have redox conflict. 89.1038 has hardly any iron, that's why it has redox conflict. Well 89.1089 has degree of weathering bigger than 1, that is reason to redox conflict comparing to iron and sulphate levels.

3.5.7 Conductivity

Conductivity is useful parameter to indicate how much there is salt in water. It measures ions ability to transport electrical charge in water. In all the wells, conductivity is around 55, in well 89.1904 it's 75. They are in typical range even though drinking water criteria say the conductivity has to be no more than 30.

3.5.8 pH conditions

The pH scale gives an indication of the water's acidity/basicity conditions. Scale is logarithmic.

In the drinking water criteria the pH has to be in neutral range, between 7 and 8.5, water is buffered. In all wells pH is in this range, and pH conditions are good.

3.5.9 Organic matter

Natural organic matter level in groundwater is generally low. Most of the wells have NVOC - level (non-volatile organic carbon) in typical range. Only wells 89.1088 and 89.1089 has this level under 1, which means that the level is low. For all the wells NVOC - level tells about good quality.

4 Raw groundwater: abstraction and treatment

The groundwater water from Denmark is based on the criteria that it should be able to drink directly from the abstraction point, however, groundwater might doesn’t taste, smell or looks necessarily attractive for consumption. Contaminated groundwater became unsuitable for use. An appropriate treatment or remediation, it is the process that is used for instance, to remove pollution or unnecessary matters from groundwater. In Denmark, groundwater is the source of drinking water that, in addition is used for industry or households respectively.

Water is abstracted from the underground through the wells, the raw water without treated is pumped to the waterworks where it is treated. As the water abstracted should be able to drink without treatment, the treatment process is based only in aeration and filtration and this is known as the standard treatment. This chapter shows the standard treatment process in two waterworks, Pilegaardsvej and Kolt Skovvej.

4.1 Background

As it was mention before, in the area of Hasselager-Kolt there are currently seven wells from it is pumped water to the facilities of Kolt Skovvej, Koltvej 14 and Pilegaardsvej. Koltvej 14 is closing down and Kolt Skovvej will be entirely renovated. The details of the new waterworks at Kolt Skovvej are explained later on (chapter 4.3). The two aims of this part is to ensure that the water supply of Pilegaardsvej fulfil the consumer expectations and to introduce a new design for Kolt Skovvej waterworks. In chapter 4.2 is explained the plant performance of Pilegaardsvej waterworks[9] which is enjoying a modern facilities (figure 11). The groundwater is abstracted from two wells; 89.1632 and 89.1263. In similar way, Kolt Skovvej has been designed to be able to work independently and it is big enough to supply the whole network, for example if Pilegaardsvej waterworks stops to work.

Figure 11 Pilegaardsvej waterworks exterior view. Base from the Street View, Google

The plant was designed by the company Silhorko and operates in the night time from 17.00 to 5.00 hours. The plant automatically starts to pump water out to the network if the network pressure is below 3.8 bars. At 17.00 the pressure at Kolt Skovvej is lowered from 4.0 bar to 3.5 bar. This makes the pressure at Pilegaardsvej become below the limit of 3.8 bar, and this plant takes over the supply to the network. It was designer to run automatically and cooperates to supply no less than 12000 people approximately, the current population of Kolt-Hasselager according to the 2010 data.

4.2 Pilegaardsvej waterworks layout

Ground water is abstracted from two wells (89.1632 and 89.1263), the abstraction is done separately. It is better to provide water from two different sources in staid of one, because in case something unexpected occurs, the waterworks could switch the inlet source and keep running.

With the inlet flow the treatment process takes place in two pressurized filters working in series (figure 12: filters 1 & 2). The process is characterised by standard treatment[10]. In this situation, aeration is applied to the filters by a compressor and then aeration occurs together with the filtration. Aeration and filtration both takes place in the filter vessel –aeration at the top by spraying the water out and adding compressed air, and the filtration in the submerged sand layer below. The dimensions of the two filters encompass a circumference of 9.1m with the cylindrical part height of 2m. Both filters are the same model. 6-7 layers of sand filled with course gravel at the bottom (the filters materials are shown in enclosures chapter 4).

[9] Location is shown in the figure 7.

[10] In the Standard Treatment the inlet contains only light contaminants such as odour, turbidity and no toxic particles, possible to remove only by filtration and aeration.

There are three engines supplying air flow in the treatment process. One, with less capacity, supplies air during the aeration part at the top of the filters. The other two are installed for the backwash process. The backwash is made of return flow of clean water mixed with air. During this process the reverse flow demands substantially pressure conditions bigger than in the aeration blowing process. The dirty water with the removed particles or impurities is delivered to a sewer tank for future dewatering.

After filtration effluent goes to the clean water tank which placed below the building. The supply system has 6 pumps. Network is supplied by five pumps; these are equipped with frequency converters and the 6th pump has bigger capacity (without frequency converter) and is only for emergency situations.[11] The running activity occurs during the nigh time to save daily electricity consumption. The basic overview of the whole description is represented in scheme below (figure 12):

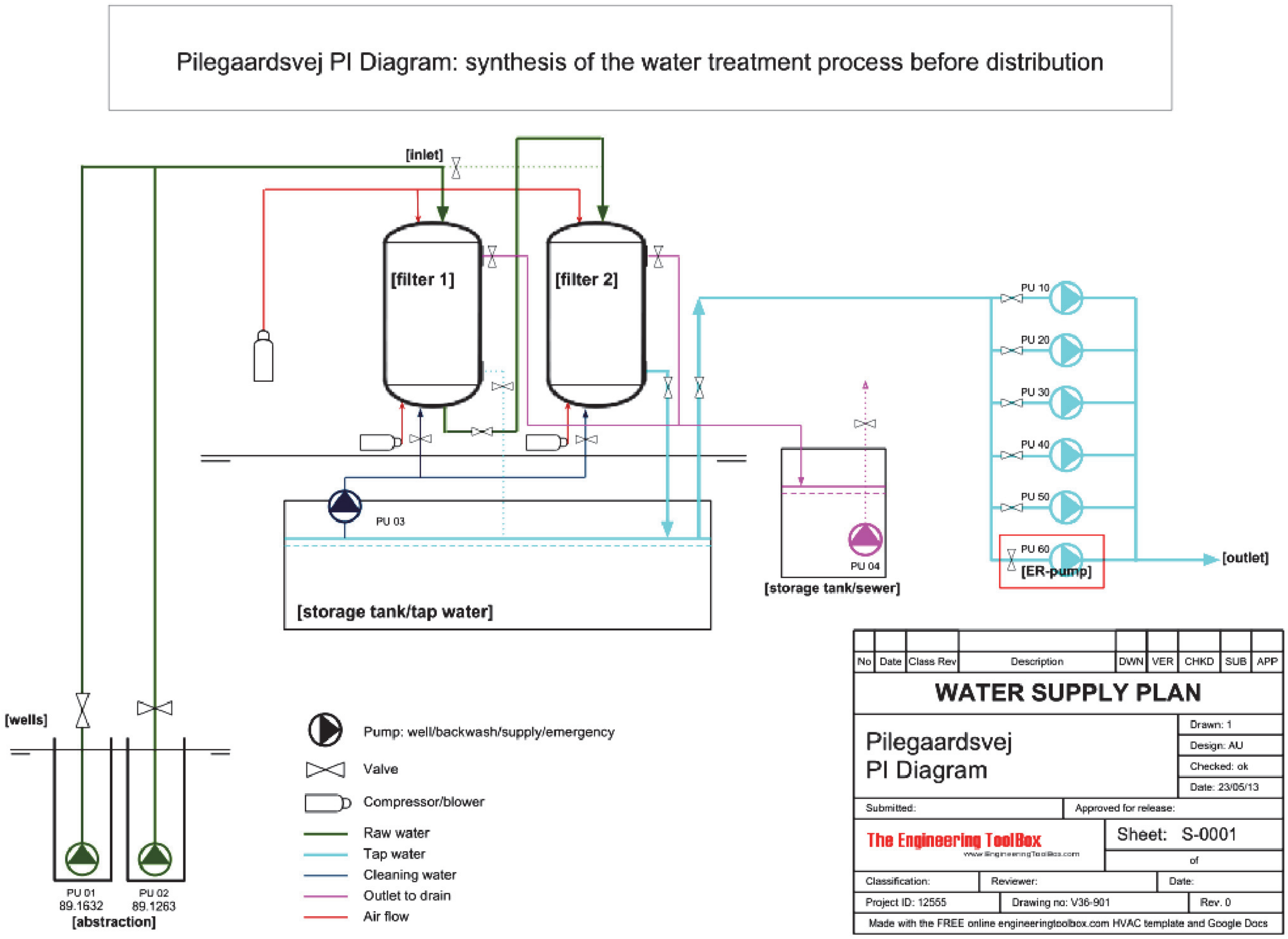


Figure 12 Scheme of the distribution plan processes at Pilegaardsvej waterworks. It is a synthesis of the original design provided by Silhorko. The diagram shows a normal filtration process working in series (abstraction from well 89.1632). It is based on the original design plan by Silhorko Company compared with the latest information provided by the plan manager in 2012, and the final inspection supervised by the scholar group of environmental engineering on the 4th of April 2013.Designed by a freeware app.

In the scheme is possible to see that the filters are working in series but can also be connected in parallel. Filter installations with more than one filter can also be connected in parallel, the reason is simple, if there is a problem in one filter the other can continuing the treatment process or if there is a backwashing in one filter the other can supply water still.

[11] The first emergency situation considered is the fire extinction.

The plant has incorporated all the necessary informatics devises to follow every single process as well as the average behaviour of its performance. The first filter is backwashed after production of 1300 m^3 of water. The second filter is backwashed after approx. 2200 m^3 of water. The network supply pumps consists in 5 pumps with $45m^3/h$ capacity plus one extra pump of $64m^3/h$.

4.2.1 Standard treatment at Pilegaardsvej waterworks

The standard treatment occurs in the two pressurised filters[12] both aeration and filtration. The water is aerated by using compressed air coming though the top into the pressure filter. This type of aeration can be applied because there isn't content of unwanted gasses.

The aeration is known as "air in water". The aeration is highest at the filters' top part, whereas as the raw water is passing though the filters layers aeration decreases and physical filtration increases. The maximum pressure capable to support by the filters is 3 bars.

4.2.2 Aeration

Aeration is considered the first step of water treatment. Aeration prevents bacteria growth in sand filters, removes bad odour (caused by sulphate H_2S), helps with stripping out the gasses, ensures aerobic conditions in pipelines and improve taste of the water. Oxygen is included in the filters to provide proper diffusion to remove unwanted gases.

According to the water characteristics abstracted and the necessary amount of oxygen, the concentrations of parameters listed in the table were taken from analysis of wells no. 89.1263 and 89.1632. These are the results:

Parameters		TOD	O_2 requires	Influent C.	Effluent C.
Aggressive	(CO_2)	-	-	-	< 2 mg/l
Ammonium	(NH_4^+)	3.60 mg O_2	0.684 mg O_2/l	0.19 mg/l	< 0.05 mg/l
H. Sulphide	(H_2S)	0.51 mg O_2	-	-	< 0.05 mg/l
Iron	(Fe)	0.14 mg O_2	0.295 mg O_2/l	2.11 mg/l	< 0.20 mg/l
Manganese	(Mg^{2+})	0.29 mg O_2	0.075 mg O_2/l	0.26 mg/l	< 0.05 mg/l
Methane	(CH_4)	4.00 mg O_2	0.040 mg O_2/l	0.01 mg/l	< 0,01 mg/l
Oxygen	(O_2)	-	5.500 mg O_2/l	-	> 8 mg/l
			6.594 mg O_2/l		

Table 5 TOD & Quality results. Theoretical Oxygen Demand (TOD) is the calculated amount of oxygen required to oxidize a compound to its final oxidation products. Hydrogen Sulphide (H_2S) and Carbon Dioxide (CO_2) has no measurement concentration at the inlet. It is added the residual oxygen value of 5.5mg to ensure compliance with drinking water regulations.

The table shows how after adding 5.5 mg O_2/l (residual oxygen supply) the minimum value in water delivered to the consumer's property is achieved: 6.594 mg O_2/l. On the other hand there is no data of how much concentration of hydrogen sulphide (H_2S) and carbon dioxide (CO_2) are at the inlet filters, but the treatment inside the filters is designed to have a filtration processes no lower than 8 mg O_2/l and that is the final value assumed. It seems very clear that as long as the oxidation requirements does not exceed the supplied amount to the filtration process the drinking water regulations are perfectly achieved.

[12] Pressure filters: the filter bed together with the filter bottom is enclosed in a watertight steel pressure vessel.

4.2.3 Filtration

The filtration is usually the second step during the standard treatment. However, in this equipment occurs both filtration and aeration at simultaneous time. Filters are constructed to operate as "down-flow" (inlet at the top and outlet at the bottom) and in reverse way, "up-flow" (inlet at the bottom), when backwashing is in process (figure 13).

Filtration provides not only physical removal of small particles or an anti-clogging prevention for the system, but also the precipitation of particular elements which decrease the quality of the water. Examples of these elements are:

- Catalytic oxidation,
- Filtering of large particles,
- Formation of biofilm,
- Modify the pH through special filters material,
- Precipitation of iron and manganese,
- Sorption.

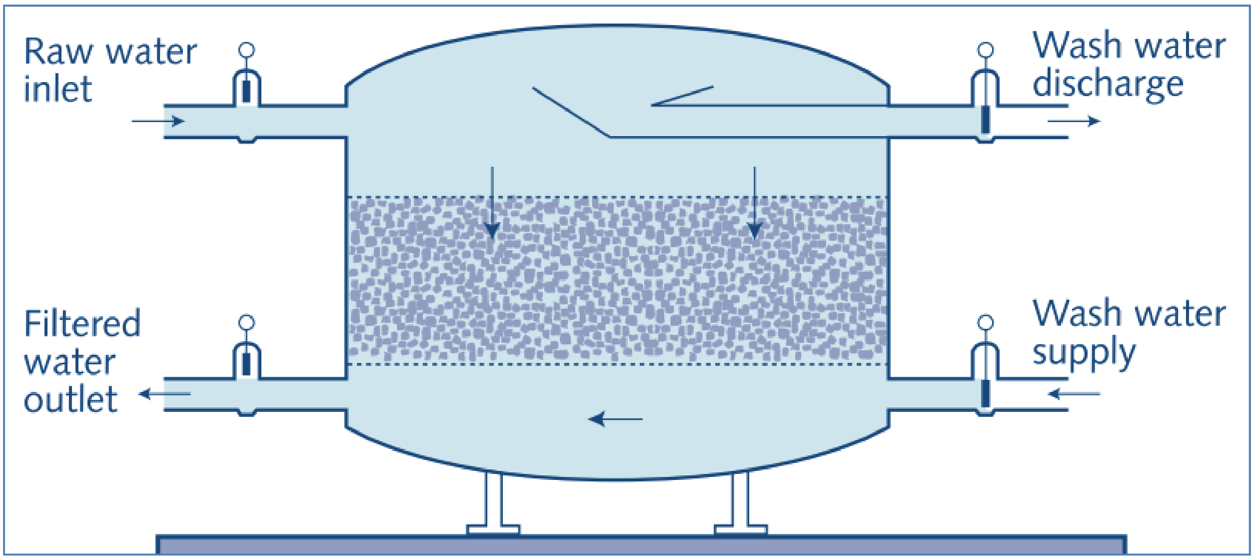


Figure 13 Pressurised filter operating as down-flow. Raw water comes through the top by the inlet and is removed at the bottom in the outlet. The backwash or filter cleaning is up-flow, pushing clean water in reverse way and discharging the dirty water through a different outlet. Rapid filtration by Luis di Bernardo

Due to the analysis in the raw water chemistry, in this process is interesting to provoke precipitation of manganese (concentration of manganese: 0.302 mg/l in well no. 89.1263). Manganese is harder to get rid of the iron, and very often it required an equivalent of double filtration.

Filtration method	Iron mg/l	Manganese mg/l	Ammonium mg/l
Single, quartz	< 2	< 0.1	< 0.5
Double, quartz	**< 2**	**< 0.3**	**< 1.5**
Single, 2-media	< 5	< 0.3	< 0.8
Double, 2-media + quartz	< 5	< 0.5	< 1.5
Double 2-media	< 8	< 0.6	< 1.5
	> 8	< 0.3	< 0.8

Table 6 Guiding values for filtration method (BTWSPL course). It is considered the Manganese proportion as well as iron, and Ammonium that match with the raw water composition.

The Pilegaardsvej waterworks layout incorporates two pressurised filters. The physical, physiochemical and biochemical reaction occur in contact with sand grains. Oxidised water pass through the filter bed with an existing biofilm.[13] This formation is responsible the iron oxidation, precipitation of manganese and nitrification process. Firstly, iron is oxidised. Removing iron is faster and it happens at top layer of the filter (aeration).

To remove the manganese, the iron must be oxidised first. Nitrification process is taking place at the lower part of the filter. Nitrobacteria convert ammonia to nitrate. Moreover, it is important to ensure that all unwanted gasses such as H_2S or methane, are stripped out. The presence of this gasses can blocked nitrification by poisoning the microorganisms and this is one of the reasons why there are many layers inside the filters rolling as border between processes.

4.2.3.1 Hydraulic filter parameters

The filter parameters tell how good is acting the filtering performance. There is an especial interest in three parameters:

Parameter	Unit	Result
Fv - Filtration velocity	[m/h]	7.59
EBCT - Empty bed contact time	[min]	15.8
Tres - Residence time	[min]	6.30

Table 7 Hydraulic parameters of filtering. The calculations where based in the technical characteristic of the filters and the amount of water treated. Pilegaardsvej waterwork operates 12 hours per day and the hour with maximum demand equals to 50m^3/h. The daily maximum demand equals to 600m^3/day.

The filtration velocity in pressurised filters has the typically range between 8-16 m/h. The filtration velocity for Pilegaardsvej is below this rank: 7.59 m/h, which is close to 0.5 m/h less than the minimum average. This is because the higher velocity the bigger head-losses and frequency of backwashing. Furthermore, high velocities could deteriorate the sand bed and these filters are made by seven beds of filtering, therefore by keeping the filtration velocity lower the waterworks prevent the care of the filtration equipment. There is one more issue to include and is the fact that the water in Denmark has a characteristic high level of calcium, calcium is not a main problem itself but with time could increase the chances of deteriorating the equipment because of the hard water.

Empty bed contact time is the length of time that water would be in the filter bed, if it would be empty, and the residence time[14] is the length of time that water is actually in the filter bed. When concentration of ammonium is higher, the residence time should be longer, more than 10 minutes; this is because the nitrification process takes time. In Pilegaardsvej, raw water ammonia concentration is quite small and the filters residence time is 6.3 minutes, at the end it is ensure that there is a good treatment process. The final effluent control is shown in the following table nr. 8:

[13] Biofilm consists of microorganisms growing on the surface of filter grains.
[14] Residence time depends mostly on ammonia concentration in raw water.

Water quality treated comparison

Impurities	Unit	Raw water	Water criteria	Effluent
Ammonium	[mg/l]	0.2	0.05	< 0.02
Chloride	[mg/l]	21	250	23
Fluoride	[mg/l]	0.2	1.5	0.2
Iron	[mg/l]	2.1	0.1	0.024
Manganese	[mg/l]	0.221	0.02	0.001
Nitrate	[mg/l]	0.5	50	0.5
Nitrite	[mg/l]	0.01	0.1	< 0.01
NVOC	[mg/l]	1.6	4	1.3
Oxygen	[mg/l]	0.25	> 5	8.2
phosphorous	[mg/l]	0.05	0.15	< 0.01

Table 8 Water quality after treatment (Effluent values) meet the effluent water criteria

4.2.3.2 Backwash process

The backwash is a necessary cleaning process when particles of the sand in filtration bed become clogged with iron and manganese compounds, in terms of standard treatments basically. At Pilegaardsvej the backwash is made by the wash water pump, "Grundfos" type CLM150/L245 marked with a capacity of 180m^3/h with 14mWC of pressure.[15]

The backwash is necessary as part of the filter maintenance to:

- Restore hydraulic properties of filter bed and,
- Remove iron oxides, other particles and microorganisms.

The method of backwashing applied in Pilegaardsvej waterworks consist:

- Only air flow - 3 minutes of air flux,
- Mix of air and water flow - 7 minutes of air and water flux,
- Only water flow - 3 minutes of water.

According with the waterworks description, the first filter is backwashed after production of 1300 m^3 and second filter is backwashed after production of 2200 m^3. Calculations are presented in enclosures 4.2. It is shown that when water is loaded by 2.1 mg Fe/l the backwash frequency for first filter should be done every 1.3 days or after the treatment of 1569 m^3 of clean water.

To remove iron in both filters, the second filter should be backwashed after approximately 2.6 days (2 times).

The clean water used for the backwash in each session is 11m^3 and the annual amount of water used for backwashing process is 4624.26m^3.

The water result collected at the outlet from sand filter after the backwash is treated as wastewater and conducted to the settling tank outside the building. Volume of the tank must consist of volume for sludge and backwash water. It happened that during the retention time, deposits are settled at the bottom of the tank then the separated water can be removed from tank, at certain time this settles must be removed. Tanks can also be repaired and the media filter changed if for any reason the system presents irregularities at the processes.

[15] mWC: metre of water column. Hydrostatic pressure in a water column. 1mWC = 0.1bar

4.2.4 Storage

The clean water obtained after the treatment process is storage down the facilities where there is an especial compartment placed in the underground as a basement form, the tank bottom of the clean water tank is approx. 2.80m below the top (ground level) and the max water level is approx. 2.20m (above bottom). This tank is used for storage the drinking water. It is filled when production is larger than demand and emptied when situation is opposite. In addition, the tank is supplying the water to the filters for backwashing. Storage tanks must be big enough to include the necessary volume for the consumers, backwash and any emergency such us the fire department demands. The volume of the tank in Pilegaardsvej is 290 cubic metres.

4.3 New Kolt Skovvej waterworks design

Kolt Skovvej waterworks is going to be rebuilt because of futures perspectives of demand and this section will introduce one solution for the supplying network.

4.3.1 Standard treatment at Skovvej waterworks

As the raw water is abstracted from an underground aquifer, a standard treatment is good enough to remove all impurities. The standard treatment will be performed by two pressurised filters where takes place both aeration and filtration. It is included one extra pressurised filter for standby. Considering the good results of Pilegaardsvej waterworks, the facilities for Kolt Skovvej is founded in similar characteristic. Pressurised filters are working down-flow with aeration process at the same time at the top part of the filters (a scheme of the filtration diagram is in enclosure 4.5, figure 33).

4.3.2 Aeration

For water treatment aeration is first thing to do. Oxygen is used to have biochemical and chemical reactions to remove unwanted compounds. Aeration prevents bacteria growth in filter sand and removes bad odour. It also helps with stripping gasses and improves the taste of the water. Raw water quality is relatively good so compressed air can be used.

For iron, manganese and ammonia removal theoretical oxygen demand was calculated. Result is shown in table:

New wellfield, line 1			
Parameter	Consentration (mg/l)	Theoretical O2 demand (mg)	O2 requirement (mg O2/l)
Iron	3,4	0,14	0,476
Manganese	0,32	0,29	0,0928
Ammonium	0,2	3,6	0,72
Methane	0	4,0	0
Hydrogen sulphide	0	0,51	0
Oxygen (residual)			5,5
Total			6,7888
For design			8

Old wells, line 2			
Parameter	Consentration (mg/l)	Theoretical O2 demand (mg)	O2 requirement (mg O2/l)
Iron	1,14	0,14	0,1596
Manganese	0,21	0,29	0,0609
Ammonium	0,26	3,6	0,936
Methane	0	4,0	0
Hydrogen sulphide	0	0,51	0
Oxygen (residual)			5,5
Total			6,6565
For design			8

Table 9 The necessary oxygen demand for aeration

On the time aeration was designed, I was not chemistry information available in well 89.1904, then it was used a close well, nr. 89.1118, only 5 meters away from 89.1904. It was assumed that chemistry is quite same because of close location. The total oxygen requirement is for treatment line 1 (new wellfield) 6.79 mg/l and for treatment line 2 (old wells) 6.67 mg/l. These results are after adding 5.5 mg/l oxygen (minimum value in water delivered to the consumer's property).

Minimum oxygen requirement for treatment where filtration processes occurs is no lower than 8 mg/l. That is why 8 mg/l of oxygen has to be used.

4.3.3 Filtration

In this waterworks the idea is to design three pressurised filters; one for new well field (line 1), one for old wells (line 2) and one for standby (line 3). These new treatment lines are designed to work alone, without Pilegaardsvej waterworks working at the same time.

Filters are designed based on the guideline graphs and chemistry of incoming water placed at the enclosures. By the time filters were designed, there wasn't information about well 89.1904, so that part of the chemistry is taken from closed well 89.1118, it is assumed that chemistry is the same.

4.3.3.1 Hydraulic Filter parameters

There was information that new wells are working 18-20 hours a day. It is chosen 18h a day. Maximum water is calculated based on 18h a day production and maximum daily need, 1330m^3. It is also taken into calculations the water loss, which is approximately 3m^3/h. The result of all these numbers is that filters have to treat 78 m^3/h of water when they are working. New wells are producing one at time 35m^3/h, therefore old wells has to produce together 43m^3/h.

Filtration method	Iron mg/l	Manganese mg/l	Ammonium mg/l
Single, quartz	< 2	< 0.1	< 0.5
Double, quartz	< 2	< 0.3	< 1.5
Single, 2-media	**< 5**	**< 0.3**	**< 0.8**
Double, 2-media + quartz	< 5	< 0.5	< 1.5
Double 2-media	< 8	< 0.6	< 1.5
	> 8	< 0.3	< 0.8

Table 10 Guiding values for filtration method (BTWSPL course). Filtration lines 1 and 3 needs single, 2-media filters and line 2 needs double filtration.

The filters are designed for these amounts of water. Standby filter is designed to replace one of these two filters in case of need.

Because standby filter is single, 2-media, it is selected to use this type of filter for all the lines. If line 2 needs repair, standby filter is then same type and suitable for both lines. 2-media filter also provides an increased filtration capacity, reduced risks of filter cake and decreased backwash frequency. In consequence, filter area will be smaller than what basic double filtration needs.

Parameters	Line 1	Line 2	Standby
	New wells	Old wells	Filter 3
Number of filters	1	1	1
Filter type	Single, 2-media	Single, 2-media	Single, 2-media
Filter material	Antracite+sand	Antracite+sand	Antracite+sand
Qmax (m3/h)	35	43	35/43
Area (m2)	4,9	4,9	4,9
Diameter (m)	2,5	2,5	2,5
Circumference (m)	7,9	7,9	7,9
Working time in a day (h)	18	18	18
Height (m)	5	4,5	5
Filtration velocity (m/h)	7,14	8,8	7,14/8,8
Volume (m3)	22,05	19,6	22,05
Porocity	0,4	0,4	0,4
Contact time, EBCT (min)	42,0	30,7	42/34,1
Residence time, T (min)	16,8	12,3	16,8/13,6
Retention time for NH4 removal (min)	15	10	15/10

Table 11 Filter parameters

4.3.3.2 Backwash process

There are several methods to do the backwash; water alone, air alone or air and water together. Taking into consideration the filters design, it was chosen to flux air and water together because it is considered that, will give the best result. Water speed was selected to be 10 m/h and air speed 60 m/h. Filters are washed separately by air and water with reverse flow through the filter bed and the wash water is removed to a different collecting channel separated from the supplying system.

The calculations of the backwash process are given in the following table:

Parameters	Filter 1	Filter 2	Filter 3
Fe (mg/l)	3,4	1,14	1,14/3,4
Filter area (m2)	4,9	4,9	4,9
Flow (m3/h)	35	43	35/43
Fe load (kg/m2/h)	0,024	0,01	0,024/0,01
Fe max. (kg/m2)	0,5	0,5	0,5
Backwash perioid (h)	20,8	50	20,8/50
Backwash perioid (m3)	728	2150	728/2150

Table 12 Backwash parameters

Taking all the conditions into the consideration it was decided to apply a backwash process every day to the filter 1 and every two days to the filter 2. Filters are working 18 hours a day. The calculations were done based on the maximum Fe content, 0.5kg/m^2. Backwash time for water was selected to be 10 minutes. Necessary amount of water are calculated to be 8.17m^3 for all the filters. Necessary air speed is 294m^3/h.

4.3.3.3 Settling tank

Backwash water will be taken to backwash water tank. One of the existing water tanks, which have a volume of 250m^3, will be used as a backwash water collection tank. Backwash process produces 24.51m^3 of water in two days and tank needs to be emptied every 20 days. The sludge precipitates and volume of the tank becomes smaller than at the beginning. For this reason the tank was estimated to empty it every 14 days, only once in two weeks.

According to the standards, backwash water needs at least 10 hours to settle, giving time to the sludge to precipitate. As the backwash is done only once a day or twice every other day, backwash water has enough time to settle. When emptying the tank, the sludge shouldn't be discharged to the sewer network.

4.3.4 Storage tank and pump design

A new clean water tank is planned to be built under the new Kolt Skovvej waterworks. The volume of the tank will be approximately 700 m^3. The water from the clean water tank will be pumped into the supply network. Therefore the pumps should be designed. The pumps have to deliver a constant pressure of 3,5 bar (see chapter 6.2.3) and according to the consumption calculations, the design flow should be 106 m^3/h (see chapter 5.1). Multiple pumps are used in waterworks to maintain the flow and the pressure.

The pump will be optimized based on water level in the clean water tank and daily water demand. The pump types are based on the pumps used in Pilegaardsvej waterworks. This pump has a capacity of 32m^3/h. By using excel, the pump curve and the consumption curve are drawn. By changing the water level in the clean water tank and the pumping time, the optimal pump scenario can be determined.

Two different pump design curves are made. The first design curve is based on average future consumption. The second curve is based on the maximum future consumption. The maximum consumption is the average consumption increased with 75%. On one hand the daily pumping hours should be as low as possible to keep the energy costs low. On the other hand, there should be a backup of clean water in the tank with regard to the safety. If for instances, in situations when the fire department ask for water, or when the water treatment fails. The pump curve should approach the consumption curve but it may not exceed it.

In figure 14 and 15 different pump scenarios are presented. One scenario with the lowest possible starting point of the water level in the tank, and the other scenario with a completely filled tank from the start. A compromise between the scenarios has to be found for the optimal situation.

Pump scenario	Number of pumps in operation	Total capacity (m^3/h)	Daily pumping time (hours)	Start level clean water tank (m3)
1	2	64	13	450
2	2	64	9	700
3	3	96	16	400
4	3	96	19	700

Table 13 Different pump scenarios

In table 13 the different scenarios are explained. For the future demand two of pumps with a capacity of 32m^3/h are enough to deliver the water. For maximum scenario three pumps are needed. Because the reservoir has a large capacity of 700 m^3, the pumps do not need to operate the whole day.

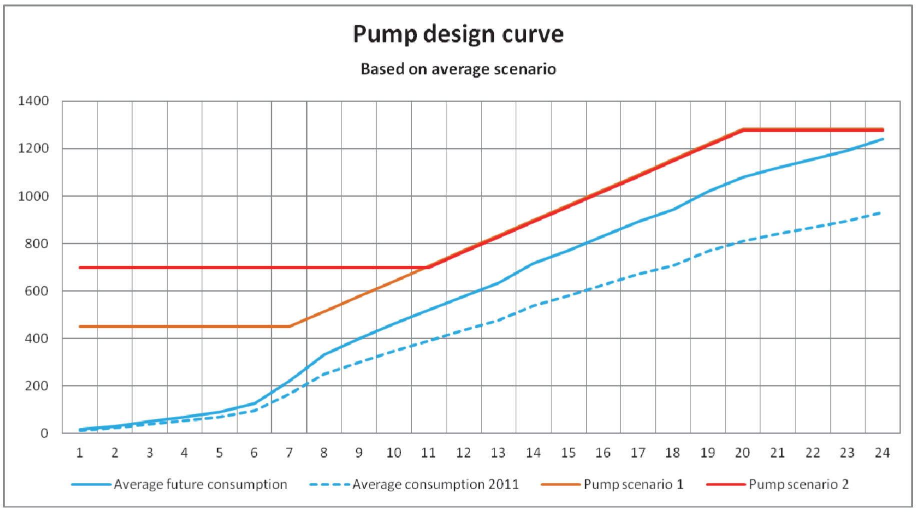


Figure 14 Pump curve of average scenario at Kolt Skovvej waterworks

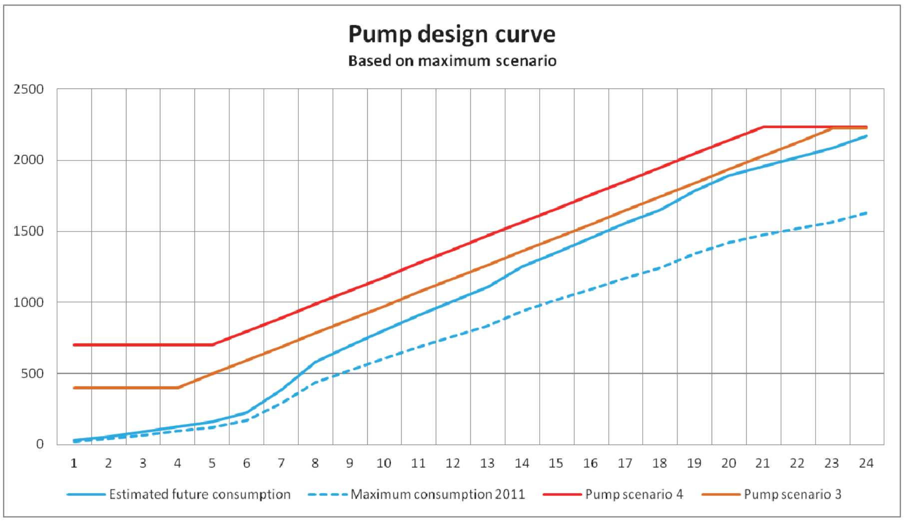


Figure 15 Pump curve of maximum scenario at Kolt Skovvej waterworks

It can be concluded that at least three pumps are needed to maintain the water delivery in the maximum situation. Besides, there should always be a backup pump in cases of pump failure and an extra pump when the fire department ask for water. Therefore it is assumed that five pumps with a capacity of 35m³/h will be applied in the new water works. One of the pumps is speed controlled by using a frequency converter. This pump will make sure that the pressure head and the flow is maintaining the required level of demand.

5 Water Consumption

For the project there were three different kinds of consumption data from Pilegaardsvej and Koltskovvej waterworks. Hourly flow data, daily consumption data and road based annual consumption data. It is found very soon that data is not entirely trustworthy by checking if daily data and hourly data give same result. For this reason, maximum daily consumption of year 2011 was chosen to be 1000 cubic metres.

During the day the water consumption fluctuates.[16] The fluctuations are caused by varying water demands from different water users. The waterworks should be designed for these fluctuations in order to supply water at all times. To get an understanding of the variations in water demand the consumption data has been analysed. The analysis provides information about the amount of water that is consumed and about the fluctuations in water demand. This information is applied by the waterworks to dimension the pipe network system, the pumps and the reservoirs.

5.1 Hourly water consumption

Hasselager and Kolt are suburbs about 8 kilometres southwest of Aarhus centre. Hasselager is practically grown along with Kolt, therefore also referred as Hasselager-Kolt. The population in both villages is more than 12000.[17] Hasselager has a large industrial area where many Aarhus farms belong. One of the industries situated in this area is a food industry called Hilter Food. The food industry consumes every year approximately 35.000 cubic metres of water. Table 14 shows the different water consumers and the evolution during the years.

Year	2000	2001	2002	Estimated 2011	Future	% more from 2011
Households	1713	1803	1827	2300	2300+630+100	31,00%
Industries	161	178	180	200	200+10	5,00%
Institutions	33	34	34	35	35+3	8,00%
Greenhouses	3	3	3	3	3+0	0,00%
Farms without animals	21	21	21	21	21+0	0,00%

Table 14 The waterworks consumers at Hasselager-Kolt from the 2002 cense. Average daily consumption was 465m3 in 2011.

We needed to find out how many households are going to be constructed in the new area.[18] From website can be found that there will be 630 new apartments. There is also older area[19] which has been under construction in 2011, and because of this reason, the calculations contains some of the households (aprox. 100) from this area.[21] The new residential area and a small part of the older area together will increase the water consumption from 2011 aprox. 33% (refer at the table 14). The dimensioning flow for existing and future supply areas together was calculated to be $106 m^3/h$.

The next curve is based on the water production data (provided by the waterworks). Over a period of three months data from both waterworks (Pilegaardsvej and Kolt Skovvej) are available. A representative day is chosen among the three month’s average. The 5th of May 2011 turned out to be the average day.

[16] Fluctuations are the irregular flow measurements in water flow when demands vary.
[17] January 1, 2010 population census.
[18] Lokalplan 831.
[19 & 21] Lokalplan 032.

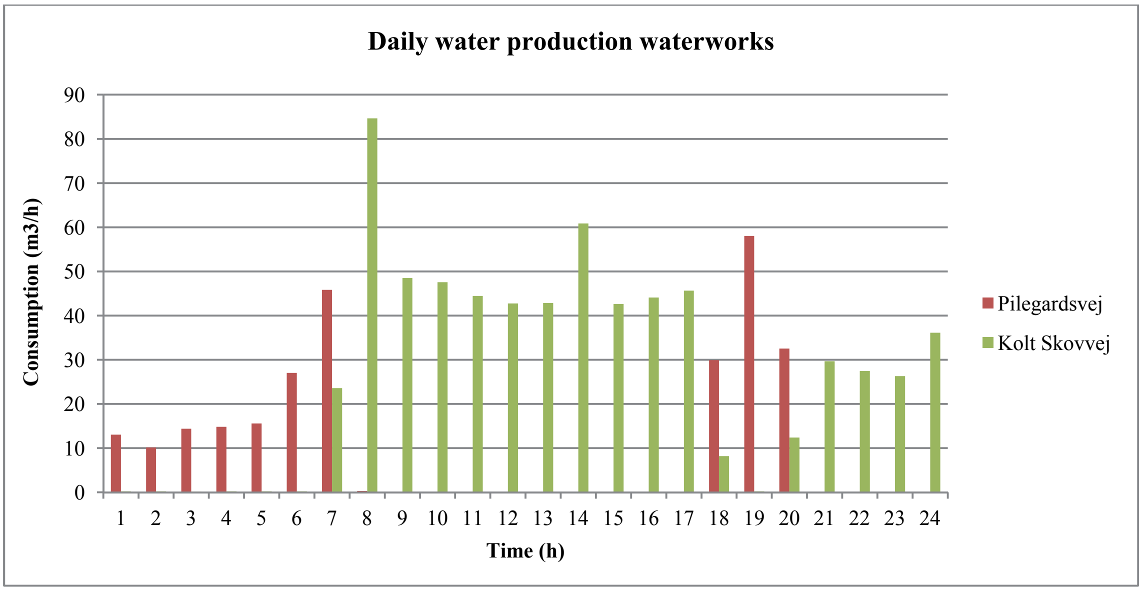


Figure 16 Waterworks water production

Figure 14 shows the time when each waterworks is pumping water out to the network. In a normal situation Pilegaardsvej is running in night time from 17:00 to 5:00 and Kolt Skovvej in daytime from 5:00 to 17:00. Pilegaardsvej automatically starts to pump water out to the network if the network pressure becomes below 3.8bar. At 17:00 the pressure at Kolt Skovvej is lowered from 4.0 to 3.5 bar. This makes the pressure at Pilegaardsvej to become below the limit of 3.8bar, and this plant takes over the supply to the network. It is remarkable in the graph of this figure that from 20h to 24h, Kolt-Skovvej waterworks is taking over the water supply. It might be that Pilegardsvej was in undergoing maintenance.

On the other hand, figure 15 shows the hourly fluctuations of the water production during an average day. The peak hour is 85m^3/h at 7:00.

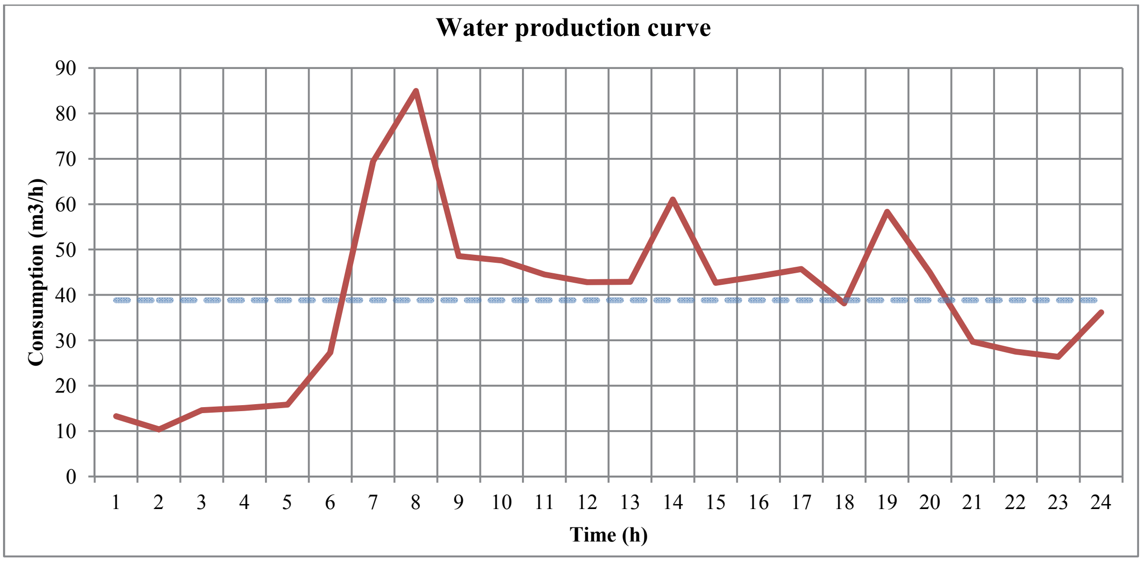


Figure 17 Hourly consumption on 5.12.2011

The graph interpretation seems to show a predictable pattern. Around 5:30 people wake up and start consuming water whether it is for showering, flushing toilet or cooking; households. After, between 9:00 and 13:00 the consumption is more or less constant and lower, but at 12:30 the lunch time starts for many people. The last peak is at 17:30 around dinner time.

6 Water Supply Network

The water supply network forms the connection between the waterworks and the consumers. The drinking water is transported through a pipe network to the consumers, in the category of houses, industries or institutions. In order to evaluate the existing drinking water network, and to simulate the future situation, the pipe network is visualised in a water supply network model. This model gives insight in the functioning of the supply network by varying water supply and demand. The model is established by using the software EPANET and the hydraulic modelling package called Mike Urban. This software allows drawing a distribution network and performing different hydraulic analyses. Hasselager-Kolt's water supply network is subjected to a steady state analysis, meaning an analysis for a situation that is unchanging in time.

6.1 Required information

To design the pipe network different data is needed. The following data is used to draw the water distribution system:

- Map of the infrastructure in Hasselager and Kolt provided by the waterworks, see annex 2. The map includes the existing water supply network. AutoCAD allows checking additional data such as the properties of the elements in the water supply network,
- Water consumption data provided by the waterworks, and
- Elevations from Google Earth.

6.2 Defining the Pipe Network System

The pipe network consist of different elements; junction nodes, pipes and reservoirs. For each of the elements data has been defined. In the following chapters the elements in the system will be explained.

6.2.1 Pipes

The pipe network system has been drawn according to the infrastructure map. Additional data as pipe lengths, diameters, roughness and thickness are added to the model as well.

The existing pipe network consists of pipes made of PVC and PE. The pipe lengths and diameters are determined using AutoCAD.

The following assumptions are made according to the pipes:

- Only main pipes are included in the model.
- The pipe roughness according to Darcy-Weis Bach is set to 0,015 mm. This corresponds to the average pipe roughness of PVC pipes.
- Pipes are situated 1 meter below surface level.
- Loss coefficients for bends and crossings are added to the model. The loss coefficients for a 60 degree bend and a 90 degree bend is set to respectively 0.35 and 0.8. For a crossing the loss coefficient is set to 0.5.

- The wall thicknesses for a PE and PVC pipe are considered to be respectively 4 mm and 15 mm.
- The minimum pressure delivered to the consumers is assumed to be 2 bar and the maximum operating pressure 6 bar.

6.2.2 Junction nodes

For all the junctions in the model are elevations and water demands defined. The elevations are found using Google Earth. The water demands are calculated according to the data provided by the waterworks. The data describes the water demand for the single streets in cubic meters per year. In cases where two or more streets reach a junction, assumptions are made for the distribution of the water demand per junction. In addition to the data from the waterworks, the future water demand for the new residential area north of Hasselager-Kolt is included in the model. This water demand is calculated in chapter 5.1.

6.2.3 Reservoirs

The graph interpretation seems to show a predictable pattern. Around 5:30 people wake up and start consuming water whether it is for showering, flushing toilet or cooking; households. After, between 9:00 and 13:00 the consumption is more or less constant and lower, but at 12:30 the lunch time starts for many people. The last peak is at 17:30 around dinner time. After treatment, the clean drinking water is stored in a clean water tank or reservoir. The reservoir serves as a buffer in the system. In times, when the water supply is bigger than the demand, the tank is filled. In times, when the demand is bigger than the water supply, the tank is emptied. By using a reservoir smaller pumps can be used to distribute the water. However, in this model, no pumps are used. It is important to know the pressure distribution and the flow velocities in the system under steady state conditions; therefore it is not necessary to use pumps. In this case a reservoir with a defined head pressure meets the requirements.

Both reservoirs are defined as tanks with a constant hydraulic grade line (HGL). This means that the pressure is kept at a constant level and the flow is infinite. The hydraulic head is determined according to the maximum scenario. This is a situation when excessive water demand occurs. The following table shows the defined data for the reservoirs.

Reservoirs	**Base elevation** (m)	**HGL** (m)	**Hydraulic head** (mWC)
Kolt Skovvej	77.5	112.5	35
Pilegardsvej	71.2	118.2	47

Table 15 Input data reservoirs

6.3 Pipe network simulations

Simulating the pressure distribution and the flow velocities in pipes can be done using the simulation tool in Mike Urban. After running the simulation different results can be shown in the model. The pressure distribution in the system and the flow conditions are of interest. The waterworks are running at different times. Pilegardsvej operates in the night time from 17.00 to 5.00 and Kolt Skovvej operates in day time from 5.00 to 17.00. Both situations are simulated in Mike Urban.

6.3.1 Pressure distribution in the pipe network system

The waterworks should deliver a minimum pressure of 2 bar to the consumers because, from one hand the system should be pressurized to prevent intrusion of groundwater, and on the other hand consumers desire enough water pressure at the tap outlets. At the same time the pressure should not be too high, because this can cause pipe bursting and it requires more head for the pumps to deliver, and thus higher energy costs. The maximum pressure in the pipes depends on the pipes pressure class. This is indicated with PN which means Pressure Nominal in bars. PE and PVC pipes can have an operating pressure up to 16 bar. Although a pressure class of PN 10 is more common.

For Hasselager-Kolt the maximum operating pressure is assumed to be 6 bar. Therefore the pressure in the system may not exceed 6 bar.

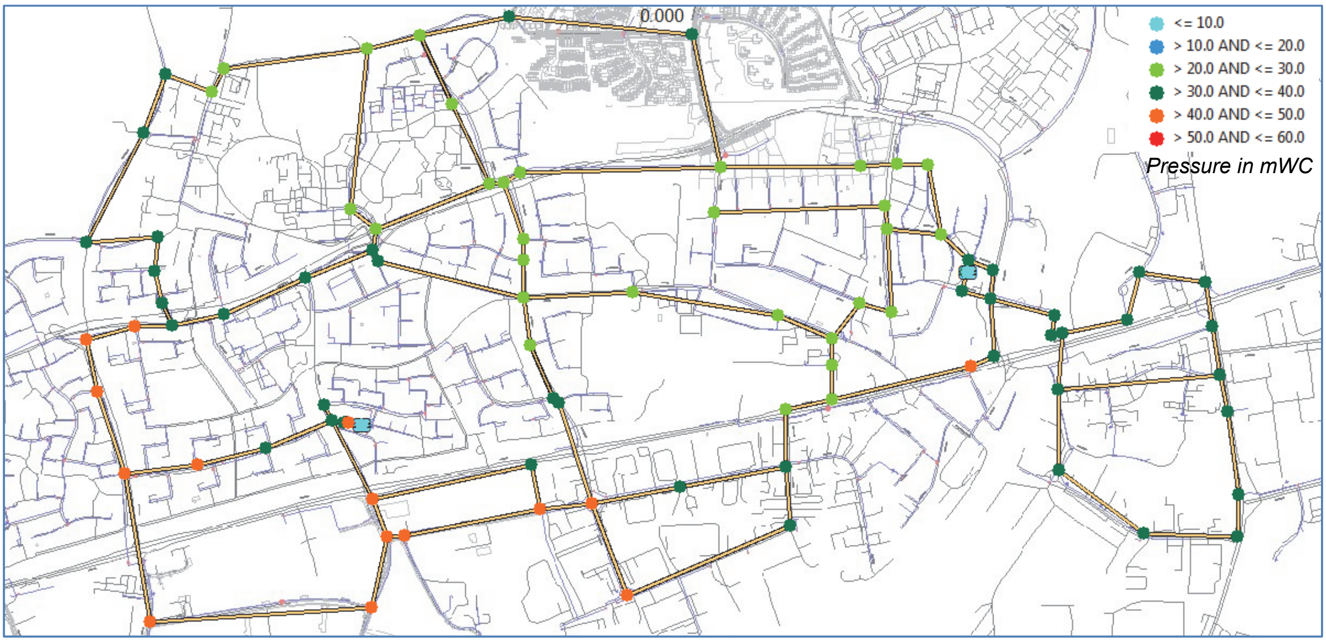


Figure 18 Pressure in junctions for average scenario - Kolt Skovvej waterworks in operation

Figure 16 shows the pressure in the junctions when the waterworks Kolt Skovvej is in operation. As can be seen the pressure is between 2 and 6 bars.[20] The highest pressure is 4.7 bar and the lowest pressure is 2.1 bar. In the south-west of Hasselager-Kolt the highest pressure is measured. This is the lower part in the area and the local water demand is considerable due to the food industry (Hilter Food). In the northern part the elevations are higher and thus the pressure is lower. The two light blue junctions are symbolizing the reservoirs.[21]

Figure 2 shows the pressure in the junctions when the Pilegaardsvej waterworks is in operation. In this situation the lowest pressure is 2.0 bar and the highest pressure 4.6 bar.

The applied output pressure in the waterworks in this model differs from the output pressure that is maintained by the waterworks. In the model an output pressure of 3.5 bar in Pilegaardsvej and 4.7 bar in

[20] 1 bar is equal to 10 meters of water column (mWC)

[21] As it can be noticed the model may differ from the reality. The input data is based on assumptions and only the main pipes are taken in consideration.

Kolt Skovvej turns out to be optimal. The waterworks maintain a pressure of respectively 4.1 bar and 4.8 bar.

According to the simulations can be concluded that the pressure in the main pipes is conform the requirements. There's no need for place booster pumps or pressure reducing valves to correct the local pressures in the system.

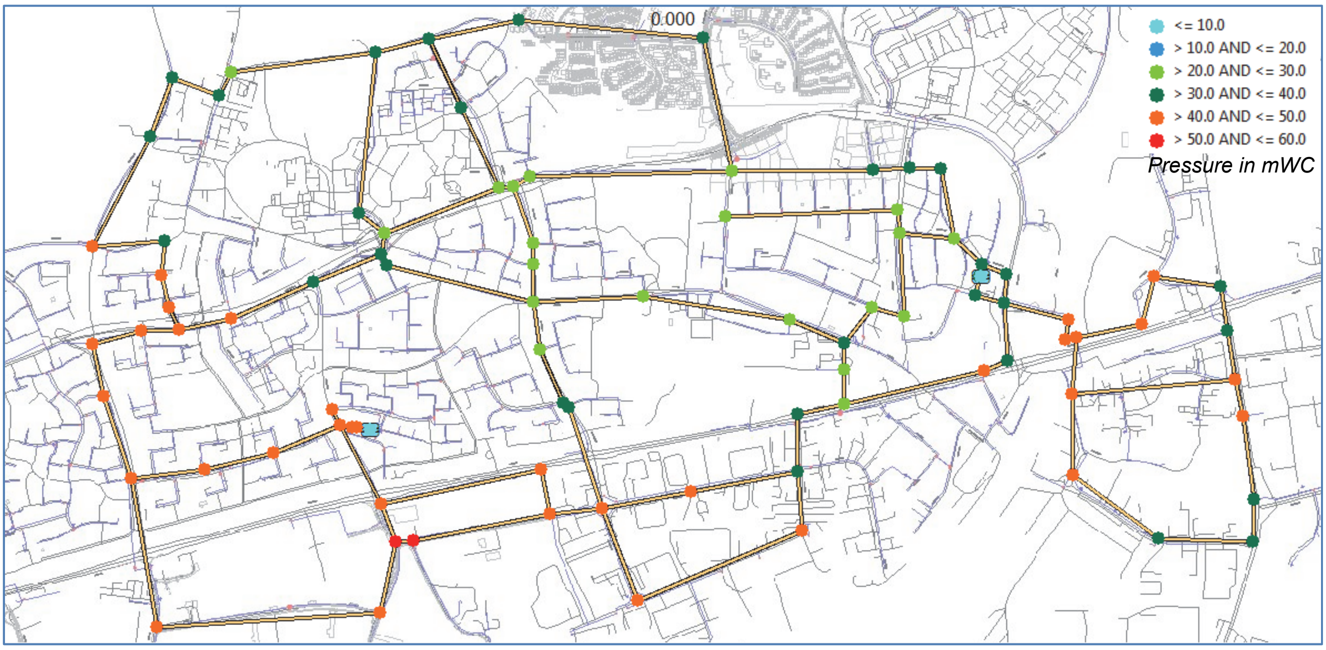


Figure 19 Pressure in junctions for average scenario – Pilegardsvej waterworks in operation

6.3.2 Flow velocities in the pipe network system

The flow velocities in the pipes are presented in figure 2 and 3. The maximum velocity, when Kolt Skovvej is in operation, is 0.4 m/s and when Pilegardsvej is in operation, the maximum value is 0.8 m/s.

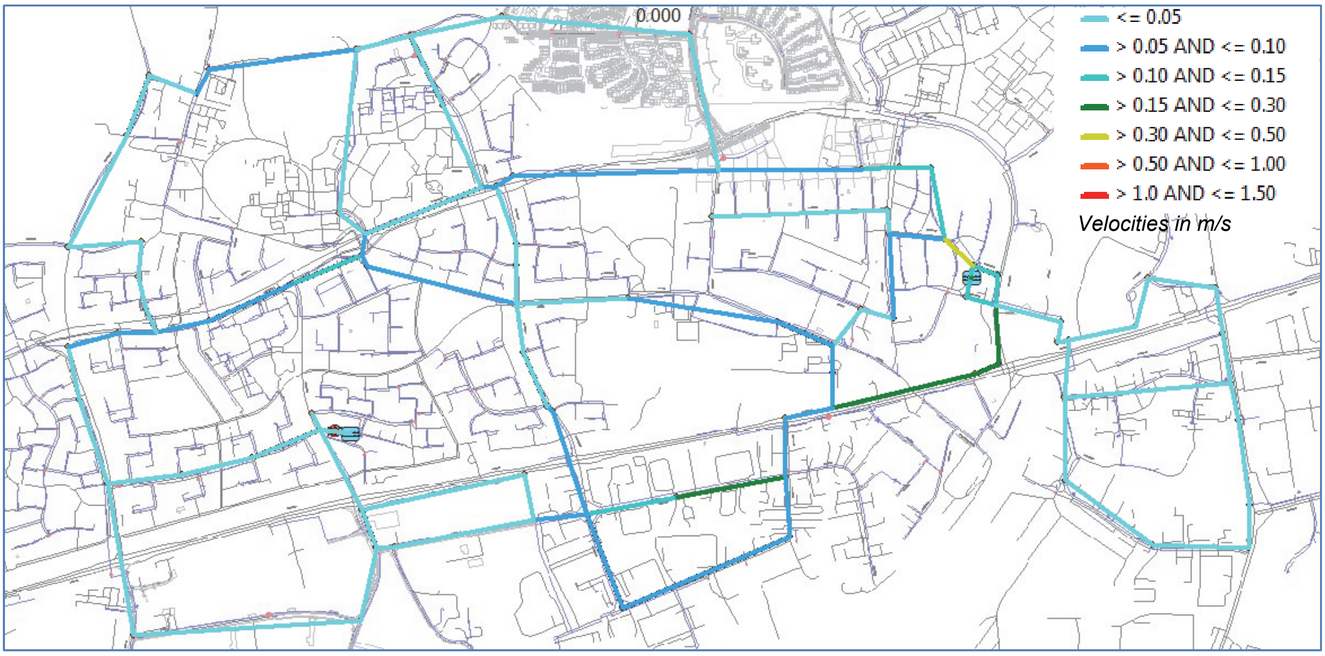


Figure 20 Results water velocities for average scenario - Kolt Skovvej waterworks in operation

A flow velocity of 0.5 m/s to 0.9 m/s should be ideal in this pipe system. The simulation shows that most of the velocities in the pipes are smaller than the ideal situation. This means a long residence time of the water in the pipes and stagnant water may occur. Stagnant water is detrimental to the water quality.

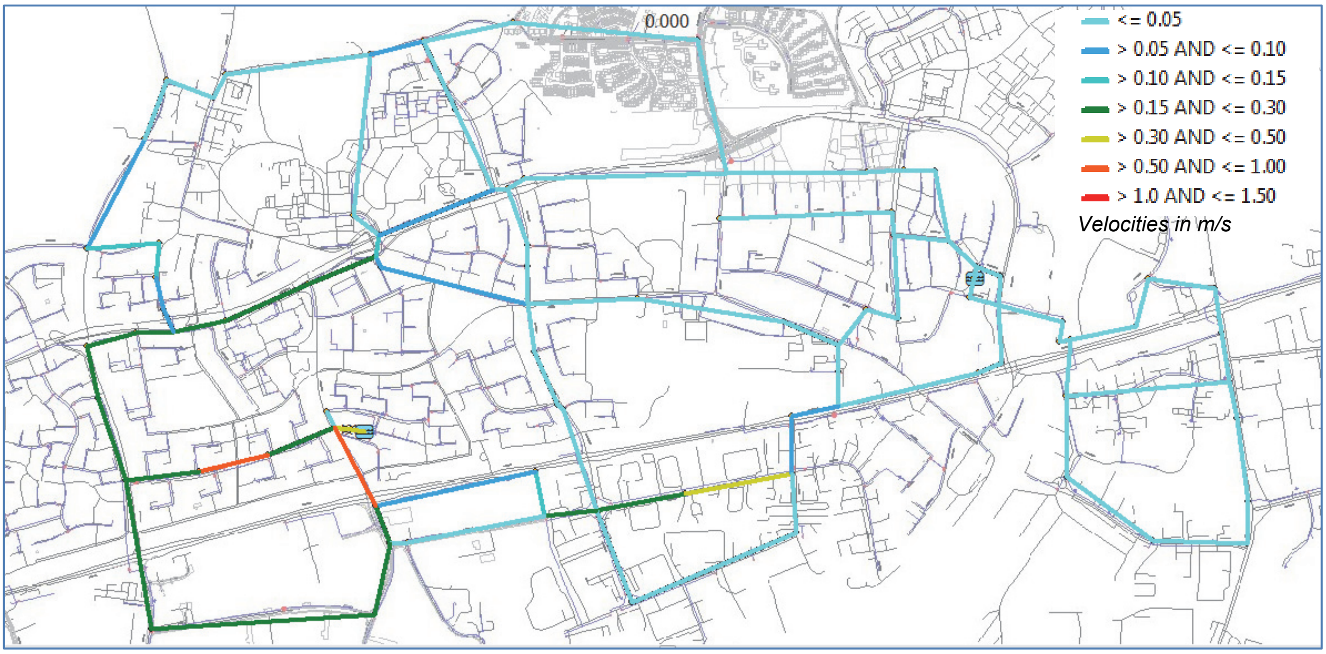


Figure 21 Results water velocities for average scenario - Kolt Skovvej waterworks in operation

One reason for the low velocities could be that the main pipes in the system are over-dimensioned, meaning that the diameters are quite big. Another reason is the possibility of missing consumption data in the model. Not for all the streets consumption data was available and are therefore not calculated in the model.[22] Moreover, it should be noted that the system is dimensioned on the maximum situation where the water demand is 75% higher than in the average situation.

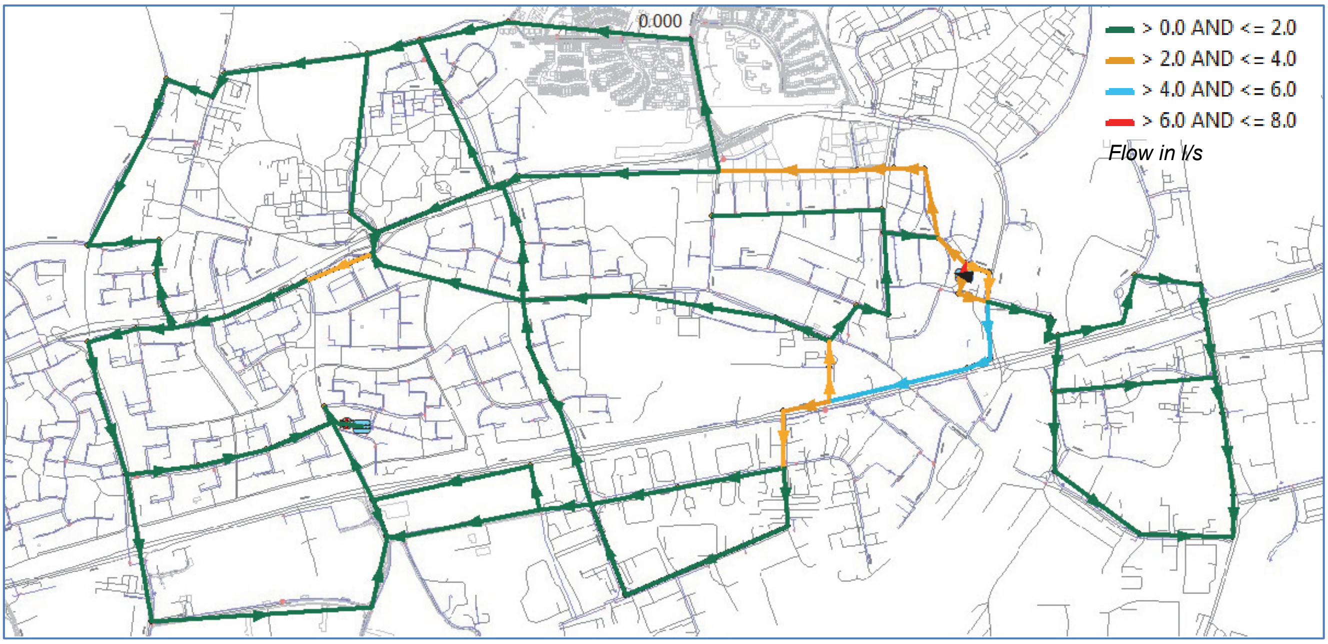


Figure 22 Pipe flow for average scenario, Kolt Skovvej waterworks in operation

It is important to know how the system responds to a maximum situation. In this scenario consumers ask a lot of water at the same time. To simulate this scenario an hour factor is used. The average consumption is multiplied by a factor 1.75; this means an increase of the water demand with 75%. When the demand raises the water flow and thus velocity will increase. A bigger flow means more pressure loss in the system (more information about the pressure loss in Annex 1). The pressure drop can be seen by comparing the simulations of the average scenario and the maximum scenario. The pressure results and velocity results of the simulation are shown in respectively annex 2 and 3.

[22] As it can be noticed the model may differ from the reality. The input data is based on assumptions and only the main pipes are taken in consideration.

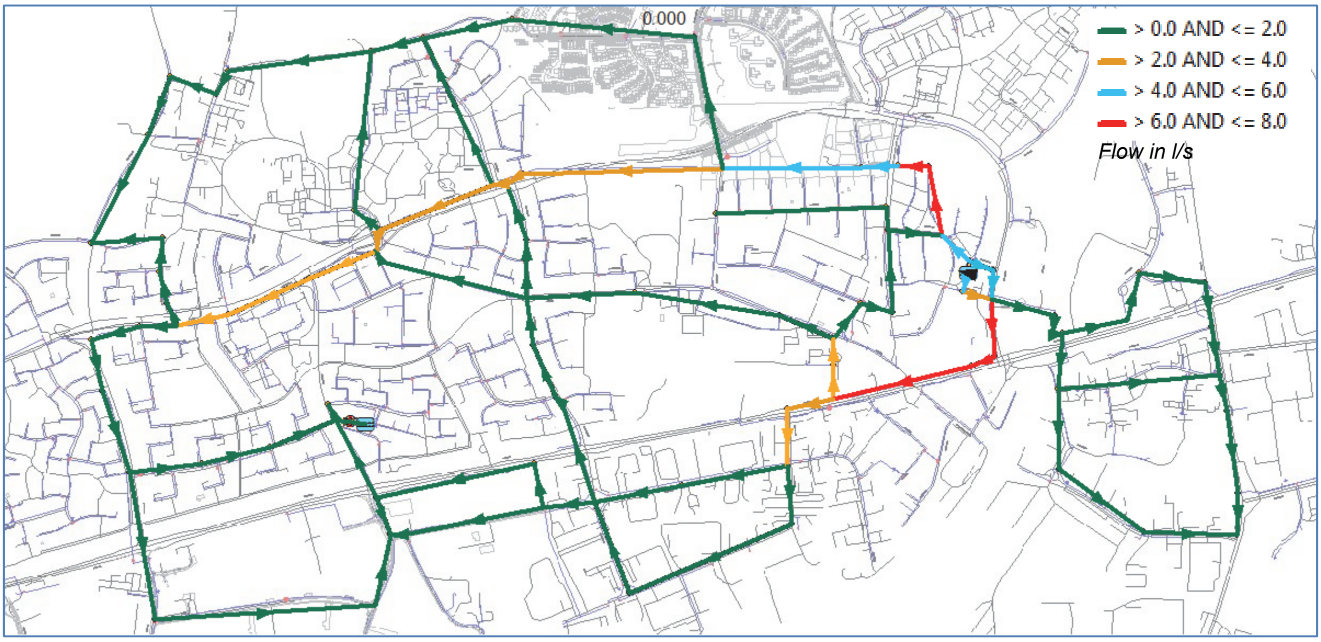


Figure 23 Pipe flow for maximum scenario, Kolt Skovvej waterworks in operation

6.4 Conclusion

On the basis of the model and the simulations, it can be concluded that the current network is working properly. The future water demand, included in the model[23], poses no problems for the existing water supply system. However, it should be noted that the velocities of the water in the pipe system are relatively low, but this but this can be attributed to the accuracy of the model.

Based on the model, it is even possible that the output pressure in Kolt Skovvej can be adjusted down slightly. This could save energy costs.

7 Well field modelling

In October 2010 a new well field has been constructed north of Kolt-Hasselager. The borings are equipped with filters and are ready for commissioning. However, to transport the water to the water treatment plant, the raw water pipe has to be constructed. The raw water will be transported by the new pipeline to the new waterworks at Kolt Skovvej. The final route of the pipeline is not clear yet. There are three potential routes for the new pipeline but the choice between them depends on permits.

In this section, the dimensioning of the pipes is described followed by a recommendation for the best pipe route. The dimensioning implies the pipe material, energy loss and the residence time of the water in the pipe.

7.1 Pipe layout and elevation profiles

The three different routes are shown in the figure. The orange line is the shortest route and crosses the residential area. The purple line is the medium route and bypasses the residential area on the west side. The yellow is the longest route and runs along the municipal roads.

[23] The future consumption also included in the model causes no problems according to simulations.

Option 1 and 2 are crossing private properties. The water company will have to ask the landowner for permission. If no permission is given, the water company can offer cost compensation or can try to buy the land. If the landowner is not willing to negotiate, then option 3 would be favourable. This route runs on municipal land. Therefore must be applied for a municipal permit.

Figure 24 Variants pipe routes (Google Earth)

Because there are two wells, it has to be considered whether a single pipe or two separated pipes will be constructed. A single pipe is cheaper because of lower construction and maintenance costs. However, the advantage of two separated pipes is that water can be transported from two wells independently. This means that more water can be transported while the residence time of the water in the pipes is shorter.

Pipe layout	Height difference (m)
Option 1	11
Option 2	15
Option 3	14

Table 16 Height difference pipe layouts

With Google earth, height profiles are made of the pipe routes, see annex 6. According to these profiles, the maximum height difference can be determined. The capacity of the well pump should be big enough overcome this height.

7.2 Pipe dimensioning

7.2.1 Pipe material

Nowadays, the most common materials for raw water pipes are PVC and PE. Both materials are made of plastic. The advantage of plastic is that has corrosion free and that it's easy to handle. The advantage of PE pipes compared to PVC is the flexibility and environmental friendliness. PE pipes are more flexible so that they can be coiled. This saves space and it's easier to handle. Therefore the installations costs will be lower. Besides, PE is more environmentally friendly and easy to recycle. In case of complete combustion, only the non-toxic carbon dioxide and water are released. Because of the advantages mentioned above it is recommended to use PE pipes.

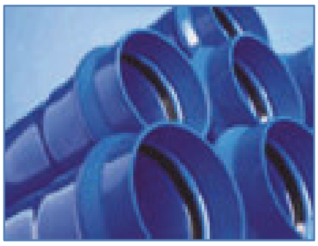


Figure 25 PVC-pipes

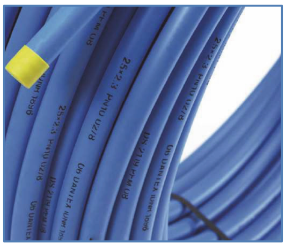


Figure 26 PE-pipes

7.2.2 Well field model

Using software a well field model can be designed. This model allows validating and calculates different parameters of a well field which includes the wells, riser pipes[24] and raw water pipes to the waterworks. uGraph Water Extraction[25] is the software that is used for designing the well field model. In the following chapters the input data and the calculations will be explained.

With uGraph the new well field is schematised, see figure 27 and 28. The figure shows the two new wells connected by a raw water pipe to the waterworks Kolt Skovvej. For the new well field two models are made. In model 1 the two wells are connected to separate pipe lines. In model 2 the water from both wells is transported by one pipe line.

The input data for the model is presented in table 17 and 18. The following rules are used with respect to input data:

- General information about the wells is found in the Jupiter database.
- The transmissivity is calculated according to pump test data provided by the waterworks. The pump data was only available for well 89.1754. Since the wells are situated close to each other and placed in the same aquifer, the transmissivity for both wells are assumed to be the same. (The calculation of the transmissivity is discussed in chapter 7.3).
- For the leakage coefficient and the well efficiency assumptions are made. The values are corresponding to comparable wells.
- The height difference which has to be overcome is the difference between the highest elevation and the lowest elevation. The maximum and minimum elevations are included in the model.

[24] A long tube inside the borehole made of metal or plastic to carry water to the surface.
[25] uGraph Water Extraction is a software developed by Orbicon .

Well name	**W1**	**W2**
Well data		
Well ID	89.1852	89.1754
X-coordinate (m)	568.248	568.193
Y-coordinate (m)	6.219.677	6.219.750
Terrain Level (m)	72,81	72,2
Groundwater Table (m)	22,09	22,2
Well Diameter (mm)	225	225
Well Efficiency (%)	70	70
Storativity (-)	0,005	0,002
Leakage Coefficient (/s)	1,00E-09	1,00E-09
Transmissivity	0,0006	0,004
Pump data		
Pump type	SP 30-14	SP 30-14
Frequency	50	45
Pump Level (m)	15	15
Riser pipe		
Inner Diameter (mm)	150	150
Length (m)	58	56
Roughness (mm)	0,1	0,1
Head Loss Factor (-)	1	1
Raw water pipe		
Material	PE-125 PN6	PE-125 PN6
Inner Diameter (mm)	111	111
Length (m)	1300	1300
Roughness (mm)	0,01	0,01
Head Loss Factor (-)	16	16

Table 17 Input data model 1

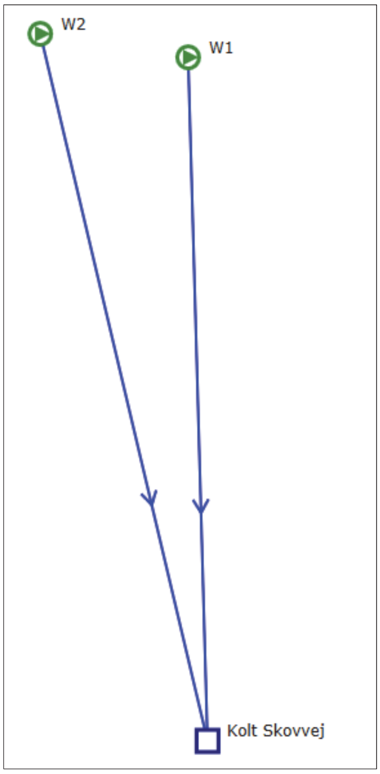


Figure 27 Schematic illustration model 1

Well name	**W1**	**W2**
Well data		
Well ID	89.1852	89.1754
X-coordinate (m)	568.248	568.193
Y-coordinate (m)	6.219.677	6.219.750
Terrain Level (m)	72,81	72,2
Groundwater Table (m)	22,09	22,2
Well Diameter (mm)	225	225
Well Efficiency (%)	70	70
Storativity (-)	0,005	0,002
Leakage Coefficient (/s)	1,00E-09	1,00E-09
Transmissivity	0,0006	0,004
Pump data		
Pump type	SP 30-11	SP 30-11
Frequency	50	45
Pump Level (m)	13	13
Riser pipe		
Inner Diameter (mm)	230	230
Length (m)	58	56
Roughness (mm)	0,1	0,1
Head Loss Factor (-)	1	1
Raw water pipe		
Material	PE-250 PN6	PE-250 PN6
Inner Diameter (mm)	250	250
Length (m)	1300	1300
Roughness (mm)	0,1	0,1
Head Loss Factor (-)	17	17

Table 18 Input data model 2

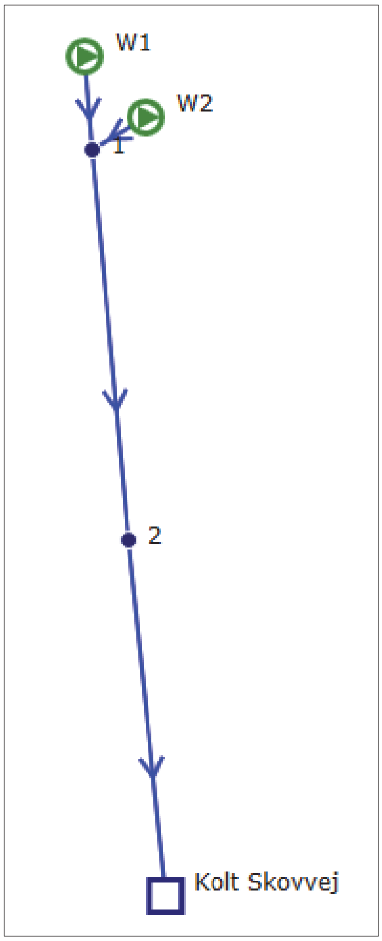


Figure 28 Schematic illustration model 2

7.2.3 Results in well field model

According to defined information for the model, the calculation is performed. A summary of the results is presented in table 3 and 4. For a complete list of results, see annex 2 and 3.

Pump/Well	Flow [m³/h]	Water Velocity [m/s] in raw water pipe	Total Pressure Loss [m]	Pump Type	Power Consumption [kW]	Specific Power Consumption [kWh/m³]
W2	39,60	1,06	15,79	SP 46-8	13,59	0,34
W1	40,04	1,07	15,10	SP 46-8	13,63	0,34
				Total	27,22	0,34

Table 19 Results model 1

Pump/Well	Flow [m³/h]	Water Velocity [m/s] in Raw water pipe	Total Pressure Loss [m]	Pump Type	Power Consumption [kW]	Specific Power Consumption [kWh/m³]
W2	40,82	0,55	4,09	SP 46-7	12,00	0,29
W1	41,64			SP 46-7	12,06	0,29
				Total	24,06	0,29

Table 20 Results model 2

7.2.4 Pressure losses

Using of the program the total pressure loss in the system is calculated. Pressure loss occurs due to resistance in the pipe system. The resistance is caused by the contact of water and the pipes, changes in pipe diameter, bends, valves and the raw water station. Calculating the resistance for each of this element is very time consuming, therefore standard head loss factors are used. Table 21 shows the standard head loss factors for the different elements. Depending on the number of elements the sum is taken of the head loss factors. The sum is used to calculate the total head loss.

Elements	Head loss factor
T-pipe	1
Bends	1
Valve (open)	1
Raw water station	1
Dimension change	10

Table 21 Typical head loss factors

The total lift of the water, called *total dynamic head* (TDH), is calculated as the sum of the vertical lift from the water level in the well to highest elevations in the pipe network (i.e geodetic lift), and the friction losses in the riser pipe and the raw water pipe. The following diagrams show the pressure levels in the system.

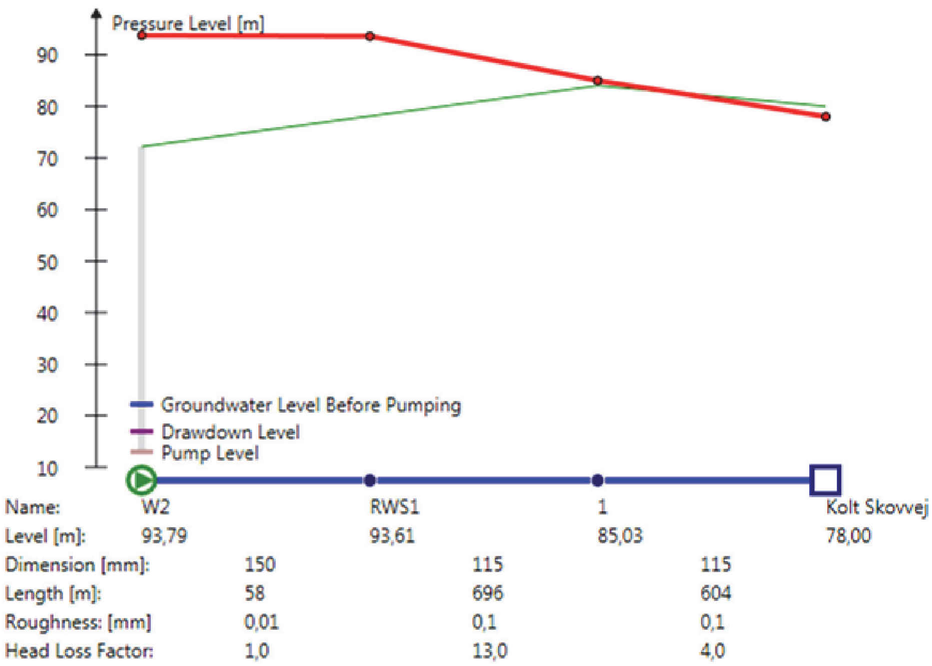


Figure 29 Pressure level diagram model 1, well DGU nr. 89.1754

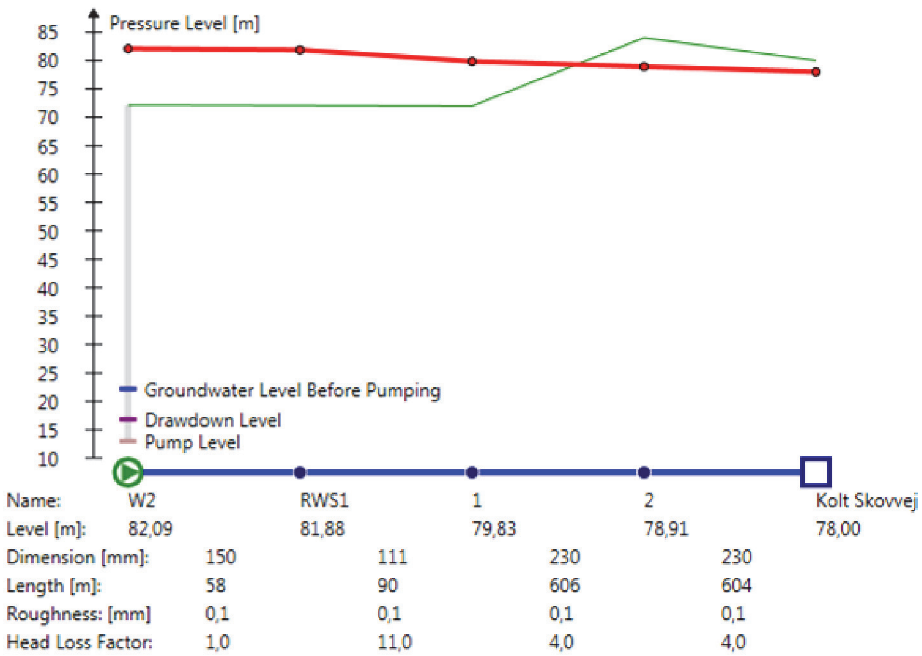


Figure 30 Pressure level diagram model 2, well DGU nr. 89.1754

7.2.5 Pump type

The pumps which are used in the wells should be carefully selected so that water is pumped at minimum costs. The main pump type used for wells is a submersible pump (SP). SP's are multistage centrifugal pumps operating in a vertical position. Water is being subjected to great centrifugal forces caused by the high rotational speed of impellers. The delivered head depends on the number of impellers.

In the new wells Grundfos pumps will be applied. Grundfos is the world's largest pump manufacturer, made in Denmark. A suitable pump can be selected from the pump catalogue of Grundfos. A web application from Grundfos is used to select the most suitable pump. The pumps are categorized by type follow by a number, for example SP 30-11. The first number indicates the pump capacity in m^3/h and the second number indicates the number of impellers or pump chambers.

Figure 31 Multistage submersible pump (Grundfos)

The pump is determined on the basis of the capacity and the head that has to be delivered. The total dynamic head is presented in table 22. The total dynamic head is the value for the pressure that the pump should deliver. In model 1 and 2 the pump should deliver a pressure of respectively 7.6 bar and 6.6 bar. The minimum pump capacity has to be $35m^3/h$. According to the web application of Grundfos the right pump type for model 1 is SP 46-8 and for model 2, the SP 46-7.

Model type	Vertical lift (m)	Geodetic lift (m)	Head loss (m)	Total dynamic head (m)
1	50	12	14	76
2	50	12	4	66

Table 22 Dynamic head well pump

7.2.6 Power consumption versus energy costs

As can be seen in the results table 19 and 20, the power consumption differs in each model because of the different pump types. Each of the two new wells expected to produce 35m³/h, but only one is in operation at any time. The expected operation time will be 18 to 20 hours per day. According to this data the power consumption can and the energy price are calculated (table 23). The energy price is based on the average energy price of 0.30217€ per kWh electricity in Denmark[26] in 2012.

	Pump yield (m3/year)	Total specific power consumption [kWh/m³]	Power consumption (kWh/year)	Costs (€/year)
Model 1	229.950 – 255.500	0,34	78.183 – 99.645	26.582 – 33.879
Model 2	229.950 – 255.500	0,29	66.685 – 74.095	19.339 – 21.486

Table 23 Yearly power consumption. Model 2 will save 7.243€ to 12.393€ per year on energy costs.

7.2.7 Retention time and well yield

The purpose of calculating the retention time is to know how long the water is travelling inside the pipe from the well to the waterworks. With the model the water velocity is determined (see results table 24 and 25). With the velocity and the length of the pipe the residence time is calculated.

Pipe layout	Velocity (m/s)	Length (m)	Residence time (s)	Residence time (min)
Option 1	0.98	1300	1326	22
Option 2	0,98	1300	1326	22
Option 3	0,98	1800	1836	31

Table 24 Residence time model 1

Pipe layout	Velocity (m/s)	Length (m)	Residence time (s)	Residence time (min)
Option 1	0,47	1300	2766	46
Option 2	0,47	1300	2766	46
Option 3	0,47	1800	3830	64

Table 25 Residence time model 2

7.3 Transmissivity calculations by Cooper-Jacob straight line method

Cooper-Jacob straight line method is used to calculate estimation of transmissivity from pumping data. Pump yield and drawdown against time is needed. Time is on logarithmic scale and drawdown on arithmetic scale. Then straight line is drawn and difference in drawdown over one logarithmic cycle is read (Δs).

Transmissivity was calculated with this method in new well, 89.1754. Result was 0,0131 m^2/s. Data is based on graph which is unfavourable to collect right information for calculation. For this reason this result is not used in wellfield model. When T and Q are known, efficiency can be founded on figure 33. Result was 60%.

[26] www.energy.eu. Reference month: November 2012.

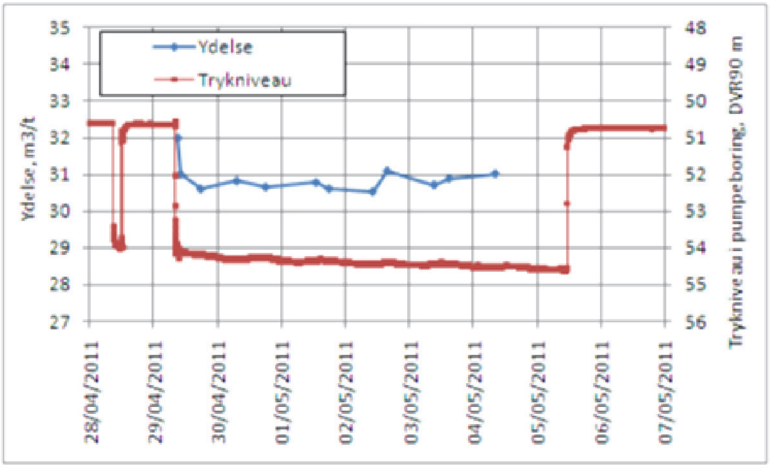


Figure 32 Pump data in well nr. 89.1754

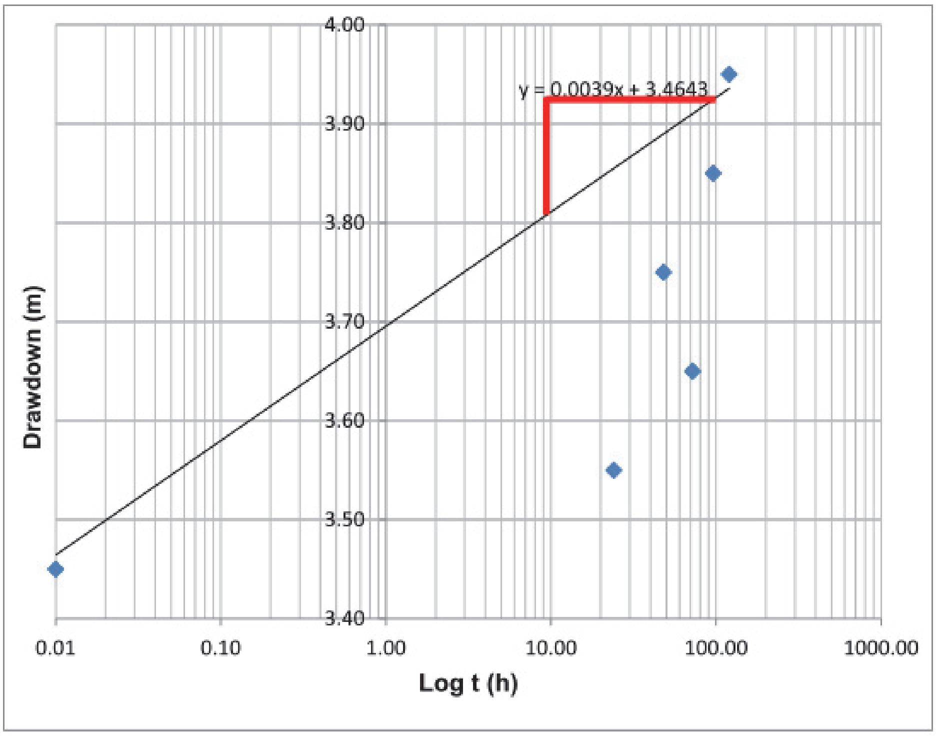


Figure 33 Results of Cooper-Jacob straight line method

The rest of the calculations can be found at the enclosures, nr. 7.

8 Evaluation of potential connection between well fields[27]

As a part of the research to find out are the two new wells connected to old wells. Comparison is made by different methods to have enough information to evaluate potential connection between these wells. There are also more methods which can be used but this information is the only ones suitable at this time. In previous pages of this project there is geological information about well fields. Here is no evaluation of geological conditions because conditions are aprox. the same in new and old wellfield.

27 Optional Part.

Field work was done to collect information for a potentiometric map. Field work was part of optional part and the first step was making a potentiometric map.

Field work was done on the 17th of May 2013 at area of Hasselager-Kolt. Table 26 shows the wells in which the water table was measured. In some of the observation wells there were several rise pipes, as can be seen in figure 34. The water table was measured by a water level meter with tape measure and indicator. Measurements were done from a standardised point on the top of the pipes in the wells. In some wells was more than one pipe. The measured ground water table was sometimes different in these pipes. A reason could be that the screens in the individual rise pipes were placed on different levels.

Figure 34 Observation well at Kolt-Hasselager area. Ewoud 17.05.2013

Due to safety reasons, the wells are locked at all times with heavy metal locks. In some cases a concrete wall has been placed to prevent damage to the well. These safety parameters are very important to protect the water quality. We also noticed that some of the wells are very close to roads. As we know, there is no special protection between road and well if an accident will happen. Especially oil on ground is a serious problem. On the other hand, wells are very deep, which gives much more time to clean after an accident.

Wells have neutral colour, green or grey, making them less disturbing in the landscape. However, the wells are therefore sometimes difficult to detect.

Measurements 17.5.2013		
DGU number	Distance	Date of well contructed
89.1754	49,96	9-1-2010
89.1852	50,72	9-1-2010
89.1420	1) 39,90	18-7-2008
	2) 39,57	
89.1612	1) 50,51	11-6-2004
	2) 50,60	
	3) 50,51	
89.1611	1) 44,29	14-10-2010
	2) 44, 28	
	3) 44,37	
89.1605	1) 45,68	20-1-2012
	2) 45,07	
	3) 45,25	
89.179	14,44	17-12-2012
89.1351	36,04	14-12-2004
89.1419	34,44	19-4-2010

Table 26 Survey data from the wells

8.1 Chemistry

The idea was to find out are two new wells (green colour in table) connectect to old wells. This can be done at one part by comparing chemistry. If wells are at same aquifer, chemistry should be almost same in different locations. Nature and human activities on surface will cause some differenties even the aquifer would be the same. Water is flowing underground and will collect impurities and chemicals from ground on its way from one point to another. The review of the data can be see in table 27.

Wells field data

Wells	89.1632	89.1263	89.1904	89.1088	89.1089	89.1038	89.1754	89.1852
Date	25.10.04	29.05.89	05.12.12	01.06.69	01.06.79	01.01.60	14.10.10	20.01.12
Well depth (m)	72	65	90	84	92	77	136	118
Water table (depth, m)	40,1	39,7	52,2	52,4	52,3	60,6	50,1	49,7
Pump capacity (m3/h)	50	30	25	27	55	25	35	35
Address	Pilegaardsvej	Pilegaardsvej	Buen 24	Buen 24	Buen 24	Koltvej 14	Genvejen	Genvejen
Chemistry	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Sample date	15.11.11	21.05.12	22.01.13	04.02.13	15.10.03	15.12.09	05.05.11	18.10.10
Iron	2,14	2,08	1,55	1,24	1,3	0,002	3,4	3,4
Manganese	0,221	0,317	0,295	0,247	0,25	0,001	0,28	0,32
Ammonium	0,2	0,1	0,38	0,23	0,28	0	0,2	0,18
Phosphorus	0,05	0,05	0,12	0,35	0,13	0	0,1	0,13
Calsium	99,6	108	86,1	82,5	88,1	101	100	100
Chloride	21	23	24	24	19	20	20	21
Magnesium	6,6	8,98	14,4	3,58	12,5	8,86	9,3	8,9
Potassium	1,43	1,69	4,52	3,82	3,8	2,69	2,4	2,4
Sodium	12,4	12,5	25,9	21,1	17,2	15,7	16	16
Sulfate	43	63	19	20	18	32	43	44
Hydrogencarbonate	259	284	357	303	319	305	291	297
NVOC	1,6	1,3	1,4	0,7	0,91	1	2,5	3,1
Fluoride	0,2	0,2	0,2	0,3	0,25	0,2	0,23	0,23
Nitrate	0	0	1,2	0	0	0	0	0
pH	7,6	7,45 (3.10.08)	(ass. 7,3)	7,4 (15.9.12)	7,2	7,44	7,5	7
K (mS/m)	54,8	56	75	56,5	56,1	54	58	no data
Pesticides (sum)	0	0	0	0	0	0	0	0
Calculations								
Hardness	15,44	17,16	15,29	12,35	19,56	16,15	16,11	16,02
	Middle	Middle	Middle	Middle	Hard	Middle	Middle	Middle
Ion excange	0,91	0,84	1,67	1,36	1,40	1,21	1,23	1,18
	Ion ex.(close)	No ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.
Degree of weathering	1,3	1,32	0,94	0,89	1,04	1,15	1,21	1,18
	Normal(close)	Pyrite ox.	No pyr.ox.	No pyr.ox.	Normal	Normal	Normal	Normal
Ion balance	1,5%	1,5%	-3,1%	-11,1%	2,2%	4,5%	4,1%	1,6%
Calsite saturation index	0,61	0,54	0,39	0,4	0,25	0,53	0,56	0,57
	Saturated	Saturated	Saturated	Saturated	Saturated	Saturated	Saturated	Saturated
Redox type	C	C	D	D	X	X	C	C

Table 27 Comparison of the chemical quality at the well fields

New wells in Genvejen have almost same chemical quality than the other wells. This can be very easy seen from table. Only iron and NVOC-levels (red colour in table) are quite different, about double content. The explanation for different iron and NVOC-levels can be found from surface but it's not very likely because wells are very deep, around 100 meters. There is more than 20 meters clay between water table and surface (see at boring reports, enclosures 2.1) which makes impurities infiltration very slow. There might be also impurities deeper in ground from ancient times.

Based on chemistry data it can be said that wells might be in same aquifer. Only iron and NVOC levels are very different between well fields which make decision difficult. On the other hand we don't know what is happening between well fields so as a conclusion can be said wells are in same aquifer. Realistic evaluation will need more information than chemical quality.

8.2 Pump data

To evaluate potential connection between new and old wellfield, pump data is very useful. Figure 30 shows changes in pressure levels in different wells. Well 89.1612 is observation well, located 365 meters away from well 89.1754 which is on new wellfield. From this pump data can be seen that starting and stopping pumping in well 89.1754 effects immediately on water table in observation well. This means these two wells are definitely connected via aquifer to each other because effect is direct.

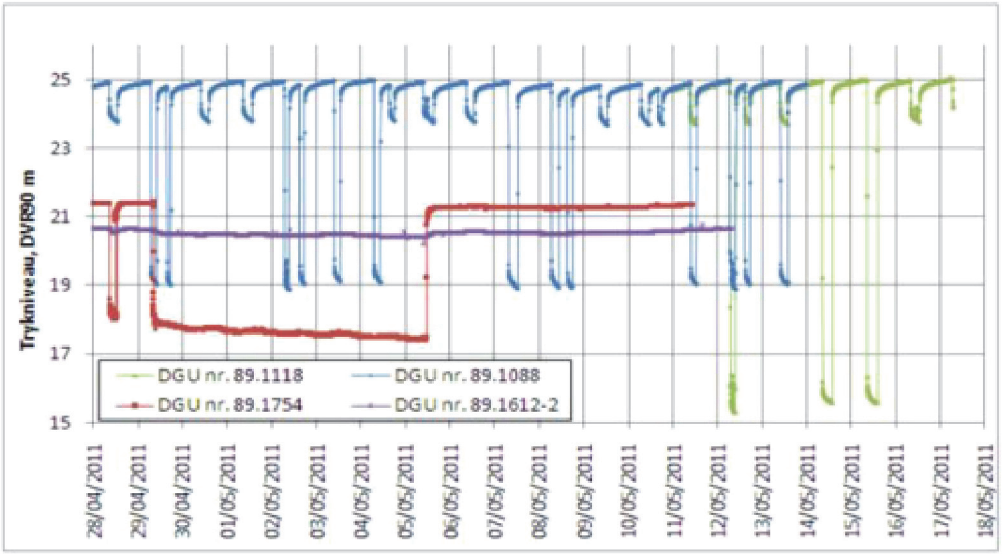


Figure 35 Pump test data shows changes in pressure levels during test pumping in May 2011. Pump capacity in 89.1754 is 40m^3/h during test pumping.

From figure 30 can also been evaluated potential connection between new wellfield and old wellfield. After stopping pumping in well 89.1725, small effect in well 89.1088 can be seen after three days. Distance between these wells is 1083 meters. Because effect can be seen after three days, not immediately, aquifer is probably different. This small effect in well 89.1088 can also came from another source. If these two wells are not in same aquifer, there might be still leakage between them. Small leakage will cause longer perioid between pumping and the effect in another well.

If this effect in well 89.1088 is from pumping in new well, then aquifers are not likely the same. There is still probably leakage between different aquifer if effect after three days is not coming from another source.

8.3 Potentiometric map

A Potentiometric map is a contour map which shows the groundwater table elevation referenced to sea level. Water is flowing from a high elevation/potentional to a lower elevation/potential. From the contour lines can be seen in which way groundwater is flowing. The map is also useful for defining the abstraction area of an aquifer.

For constructing a potentiometric map of the area was done field work. The distance between the well's standardized measurement point and ground water table was measured. The groundwater table is determined by comparing the elevation of this measurement point and the measured distance to the water level in the well. The results are presented in table 28. The elevation of the standardised measurements point in the wells is based on the information in Jupiter.

DGUnr	GWT	GWT2	GWT3
89.1420	-0,6	-0,27	0
89.1419	-0,65	0	0
89.179	-5,14	0	0
89.1611	13,43	13,44	13,35
89.1612	20,98	21,005	21,18
89.1754	22,24	0	0
89.1852	22,09	0	0
89.1605	20,85	-20,76	-20,85
89.1351	-8	0	0
89.1118	26,3	0	0
89.1038	24,93	0	0
89.1263	40,5	0	0

Table 28 Potentional elevation data

Creating a potentiometric map was done by a program called MapInfo. The contour lines showing the groundwater level are projected on a satellite map. Each line has a number which indicates the elevation of the groundwater table in meters. An additional colour gradient is given to the groundwater elevations on the map for high elevations and blue for low elevations. The DGU-numbers of the measured wells are also indicated in map.

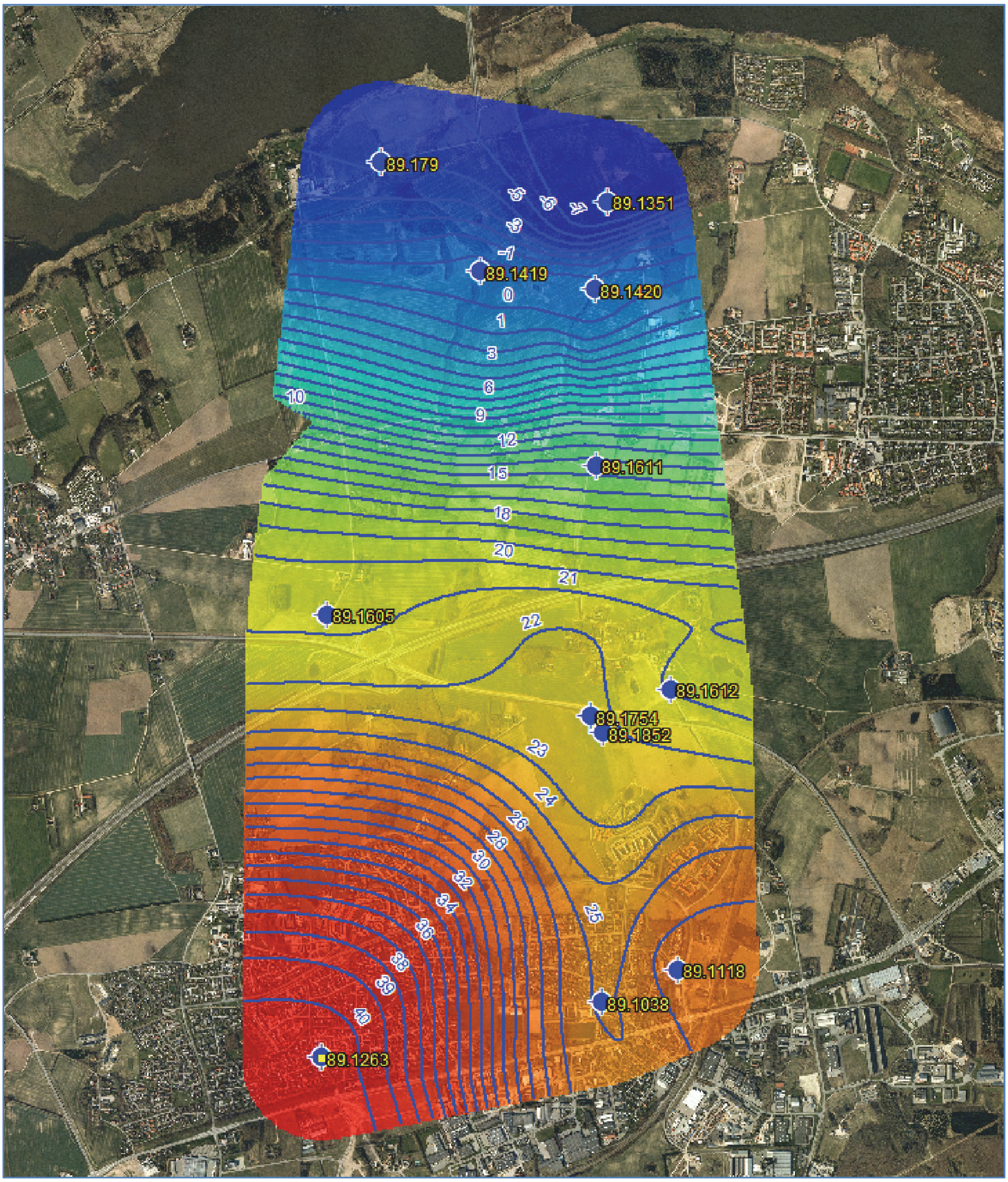


Figure 36 Potentiometric map at the area of Kolt-Hasselager. MapInfo

The wells 89.1754, 89.1852, 89.1118 and 89.1263 are placed in an unconfined aquifer. Only well 89.1118 is placed in a confined aquifer. Despite the old wells are placed in the same aquifer, the ground water table varies a lot, between Pilegaardsvej and Koltskovvej/Koltvej. The water table in the well fields Kolt Skovvej/Koltvej is more or less the same compared to new wellfield while there is huge difference in water level compared towards to the wellfield in Pilegaardsvej. Based on this huge difference in two different places it can't be said that there is a connection between the aquifer in the old wells and the aquifer in the new wells. Further research should reveal whether this statement is true or not.

8.4 Buried valley system

Buried valley is an ancient valley of stream or river. It's filled by sediment which can store and transmit large amounts of ground water in the area.

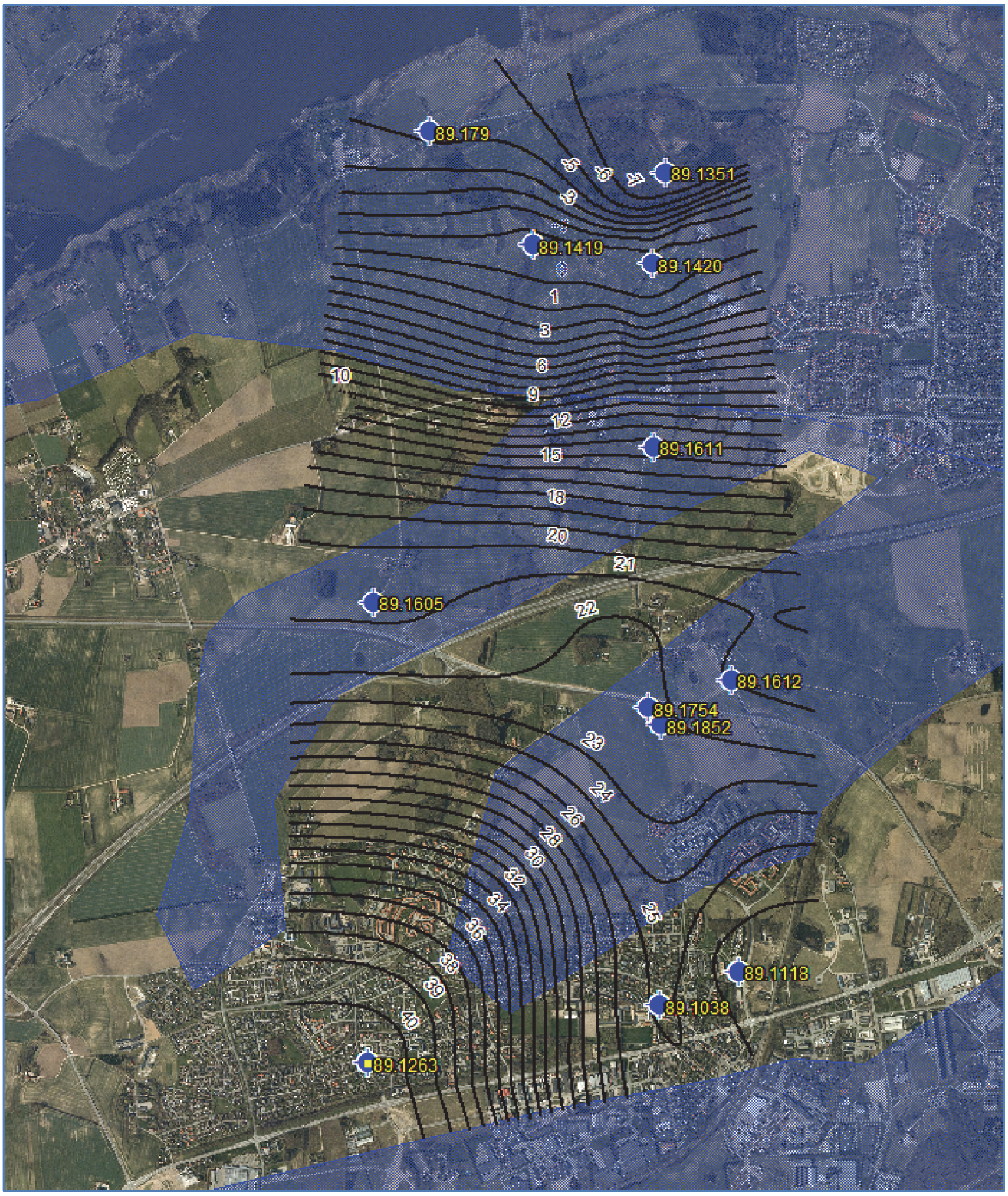


Figure 37 Buried valley represented at Kolt-Hasselager area. MapInfo

This map (figure 37) shows the contour lines from the potentiometric map and the wells with DGU-numbers. The Blue colour indicates the local buried valleys. Wells in Pilegaardsvej, Koltskovvej and Koltvej are not situated in a buried valley while new wells in Genvejen are. Pilegaardsvej waterworks is located in urban area which means that no information is available about the buried valleys because borings can't be made there.

Based on taking the map in consideration, it can be stated that wells at Pilegaardsvej waterworks might be situated in same buried valley as the new wells. If they are in same valley, than the aquifer in the wells might be connected. . More information is needed to have certainly about this issue.

8.5 Conclusion

Based on the chemical quality of the ground water, pump data, the potentiometric map and the buried valley system, is made a conclusion about a potential connection between well field´s aquifers. The results are only based on available data presented in the previous chapters.

The chemical quality of the ground water refers to a connection a the aquifers. Although, iron and NVOC-levels are much higher in the new well field, a connection is most likely. Pump data indicates to a weak connection if the effect between new and old well exists truly. In that part data is not trustworthy because it is not known for sure where the particular effect[28] is coming from.

Potentiometric map instead does not give much information about potential connection. There is notable difference in elevations of water table between Pilegaardsvej and Kolt Skovvej, while the new wells in Kolt Skovvej and new well field has almost same elevation of the water table.

The buried valley system map is very useful to find out whether the aquifers might be connected or not. It should be noted that the buried valleys are not fully investigated because measurements are not done in urban areas. It can be seen that the urban area of Hasselager/Kolt is surrounded by a buried valley. It looks like that the urban area of Kolt-Hasselager is situated in the buried valley. Therefore, it is most likely that the well fields are connected. It could be a weak or strong. However, further research should be done to ensure this.

Due to previous discussion, it is believed that there is a connection between aquifer from the well fields. To find out if this is certainly truth more research is needed.

[28] The effect of decreasing water level in the one observation well (and an old abstraction well) by the abstracting water in the new well.

Enclosures

2 Geology and Hydrogeology data

2.1 Boring reports (Borerapport)

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

GEUS

BORERAPPORT — **DGU arkivnr: 89. 1038**

Borested : Hasselager Vandværk, Kolt
8361 Hasselager
Matr.nr.5r

Kommune : Århus
Region : Midtjylland

Boringsdato : 1/1 1960 — **Boringsdybde** : 77 meter — **Terrænkote** : 89.1 meter o. DNN

Brøndborer : Erik Mortensen, Lund
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget :
- beskrevet :
- antal gemt :

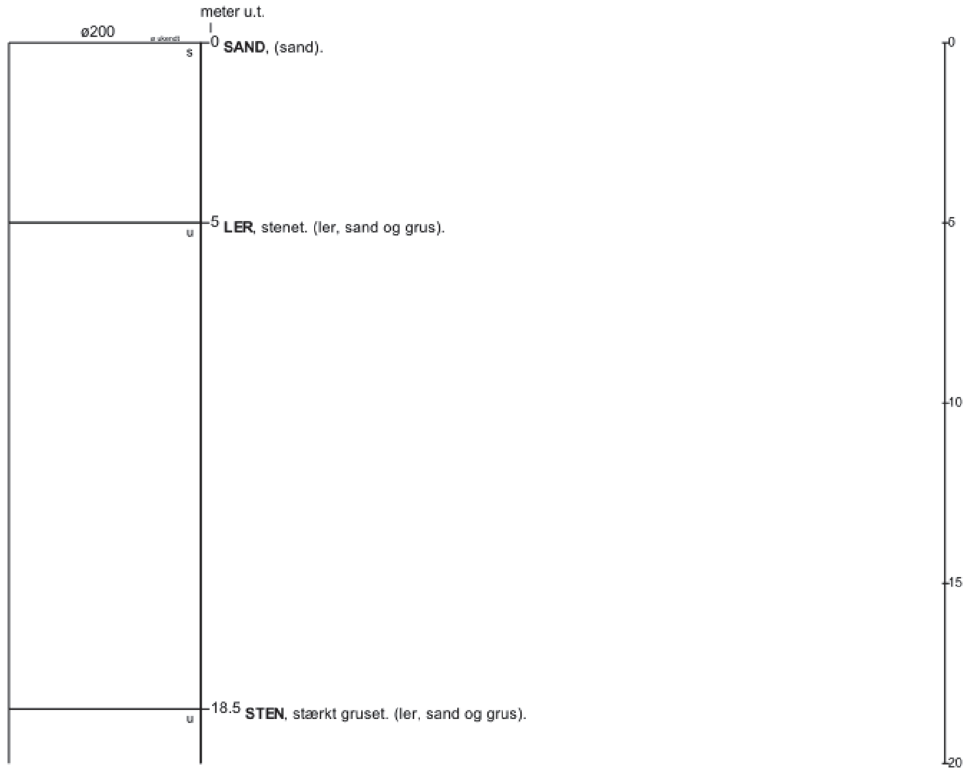
Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Tørboring/slagboring

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 568243, 6218512

Datum : EUREF89
Koordinatkilde : Kommune
Koordinatmetode : Andet

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	60.59 meter u.t.	19/4 2010	25 m³/t	4.5 meter	
	(første)	57 meter u.t.	1/1 1960	25 m³/t	4.5 meter	
				30 m³/t	5.5 meter	
Indtag 2	(seneste)	63 meter u.t.	26/5 1982			

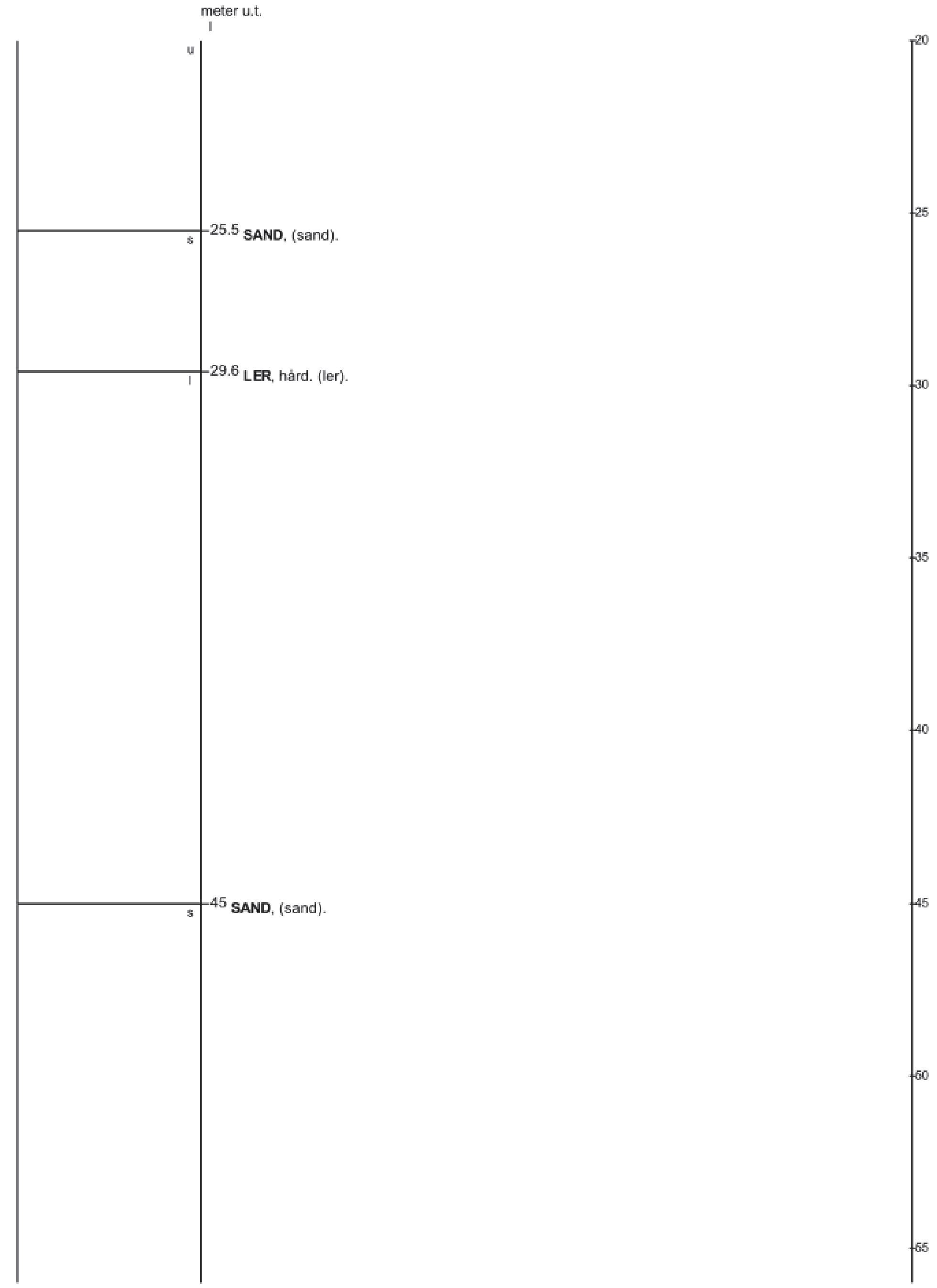
Notater : Århus Kommune: Koord. opdateret fra N&Ms GeoEnviron, okt. 2009



fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland | Udskrevet 20/5 2013 Side 2

BORERAPPORT **DGU arkivnr: 89. 1038**



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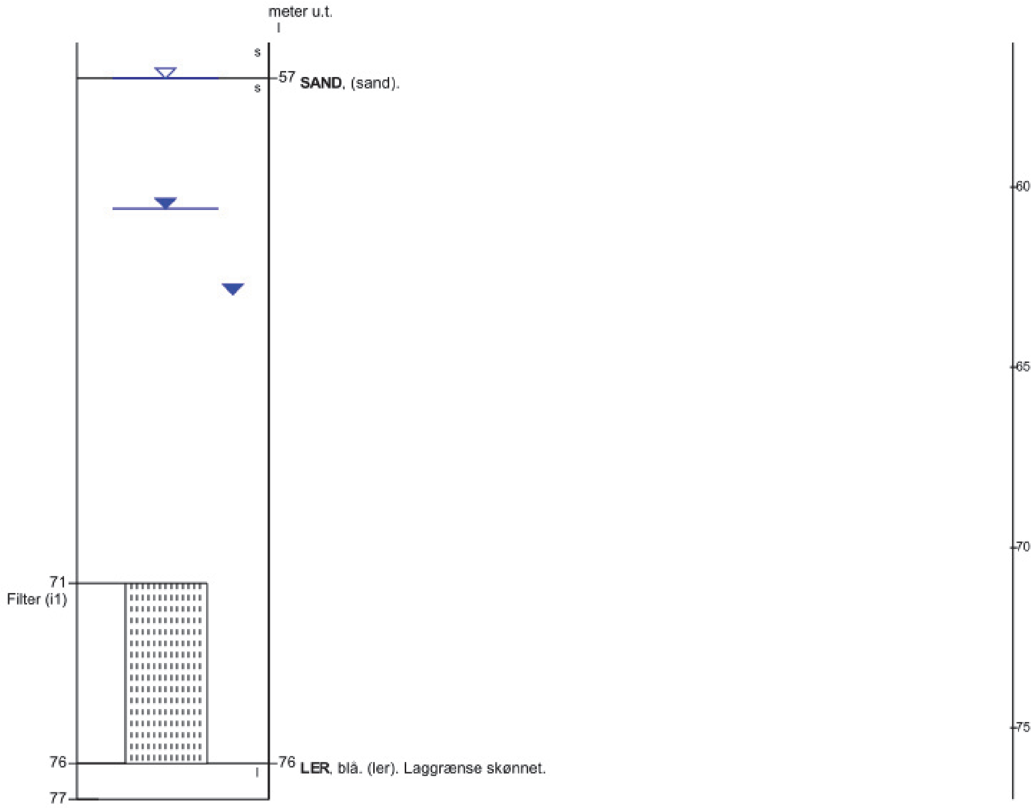
De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 3

BORERAPPORT **DGU arkivnr: 89. 1038**



De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

BORERAPPORT — **DGU arkivnr: 89. 1088**

Boringssted : Hasselager Vandværk
8361 Hasselager

Kommune : Århus
Region : Midtjylland

Boringsdato : 1/1 1969 — **Boringsdybde** : 84 meter — **Terrænkote** : 77.47 meter o. DNN

Brøndborer : Kr. Tøpholm, Lading
MOB-nr :
BB-journr :
BB-bornr : 2

Prøver
- modtaget :
- beskrevet :
- antal gemt :

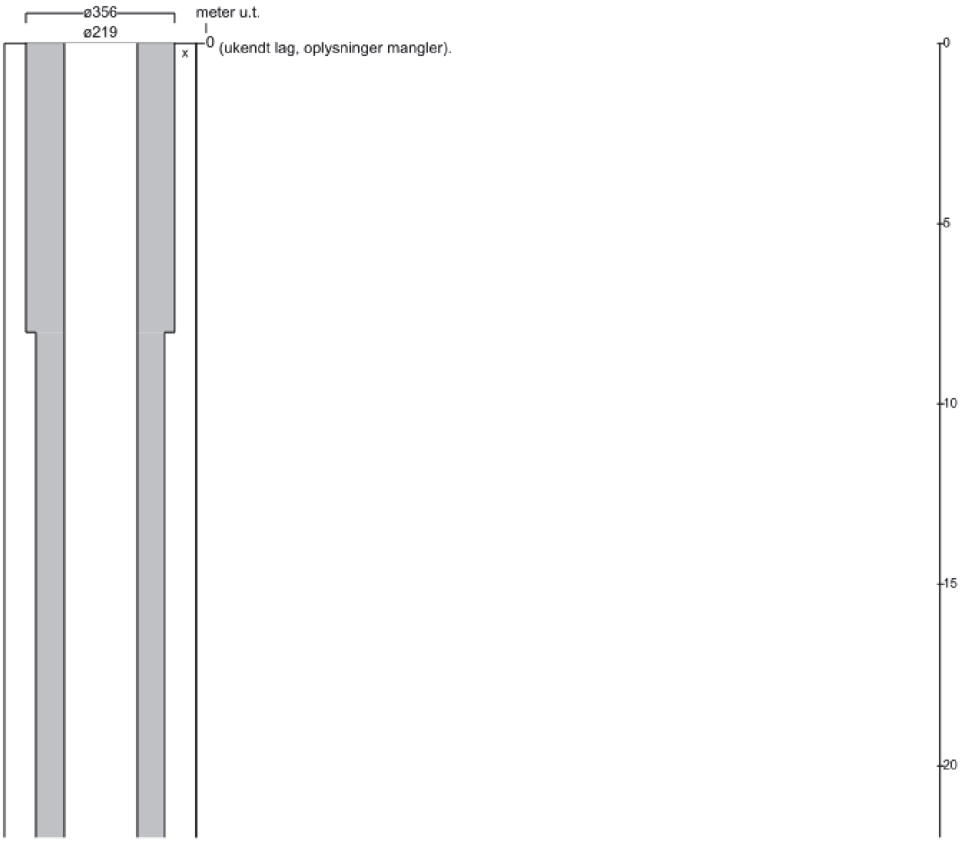
Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Tørboring/slagboring

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 568550, 6218668

Datum : EUREF89
Koordinatkilde : Kommune
Koordinatmetode : Andet

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	52.4 meter u.t.	14/12 2004			
	(første)	51.85 meter u.t.	1/12 1983			

Notater : mangler orig. brøndborerjournal - ingen opl. om vand og jordlag Århus Kommune: Koord. opdateret fra N&Ms GeoEnviron, okt. 2009

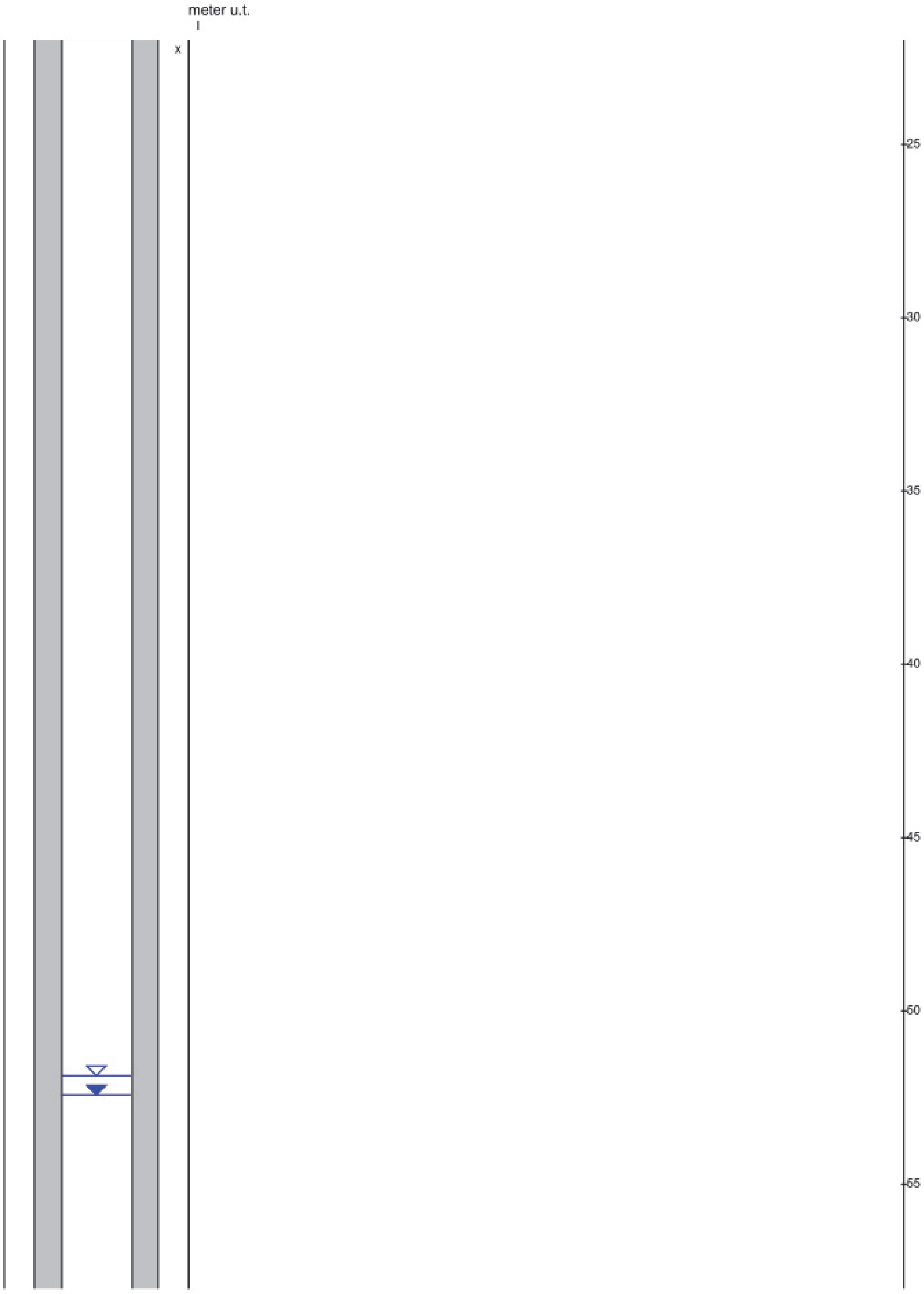


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 2

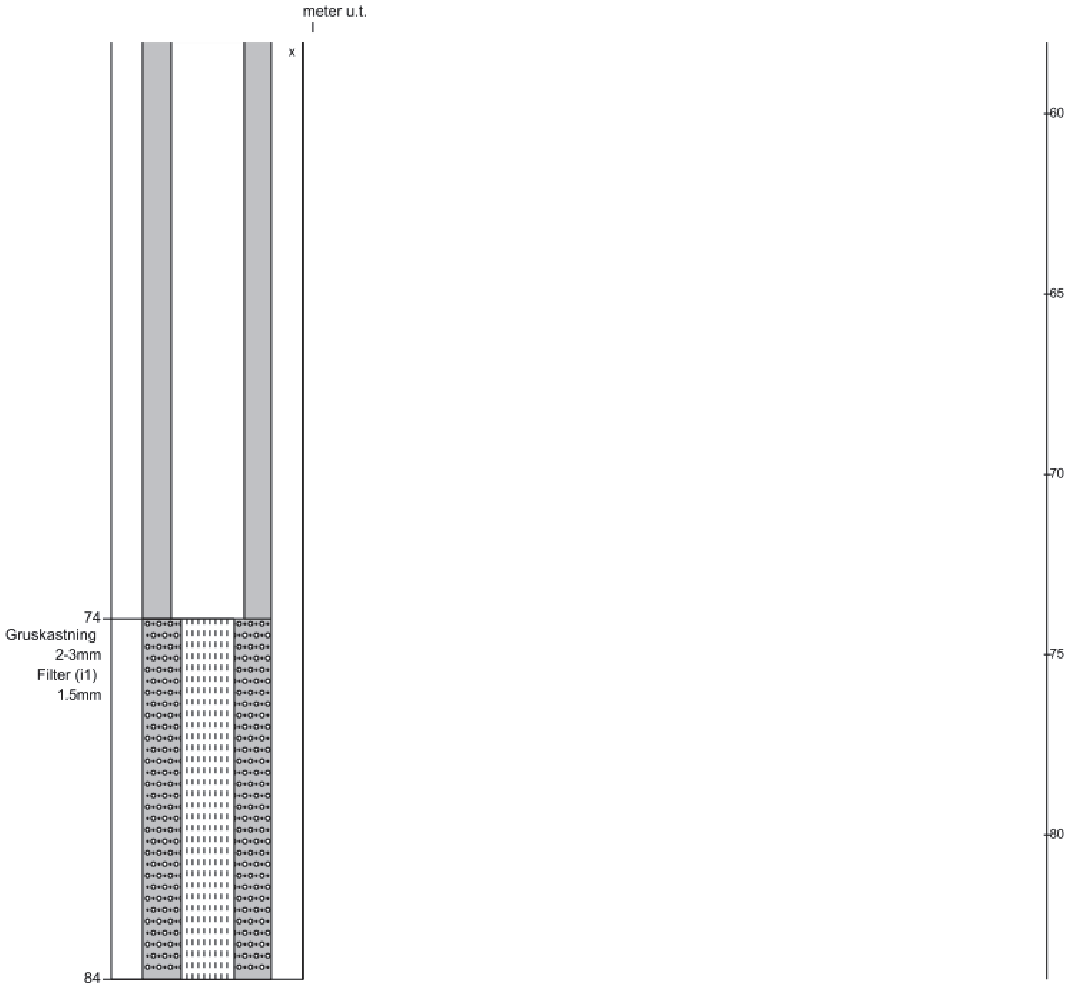
BORERAPPORT **DGU arkivnr: 89. 1088**



fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland Udskrevet 20/5 2013 Side 3

BORERAPPORT **DGU arkivnr: 89. 1088**



De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

GEUS

BORERAPPORT

DGU arkivnr: 89. 1089

Borested : Hasselager Vandværk
8361 Hasselager

Kommune : Århus
Region : Midtjylland

Boringsdato : 1/6 1979 — **Boringsdybde** : 92 meter — **Terrænkote** : 77.39 meter o. DNN

Brøndborer : Aqua Teknik
MOB-nr :
BB-journr :
BB-bornr : 3

Prøver
- modtaget :
- beskrevet : 1/6 1979 **af** : B
- antal gemt :

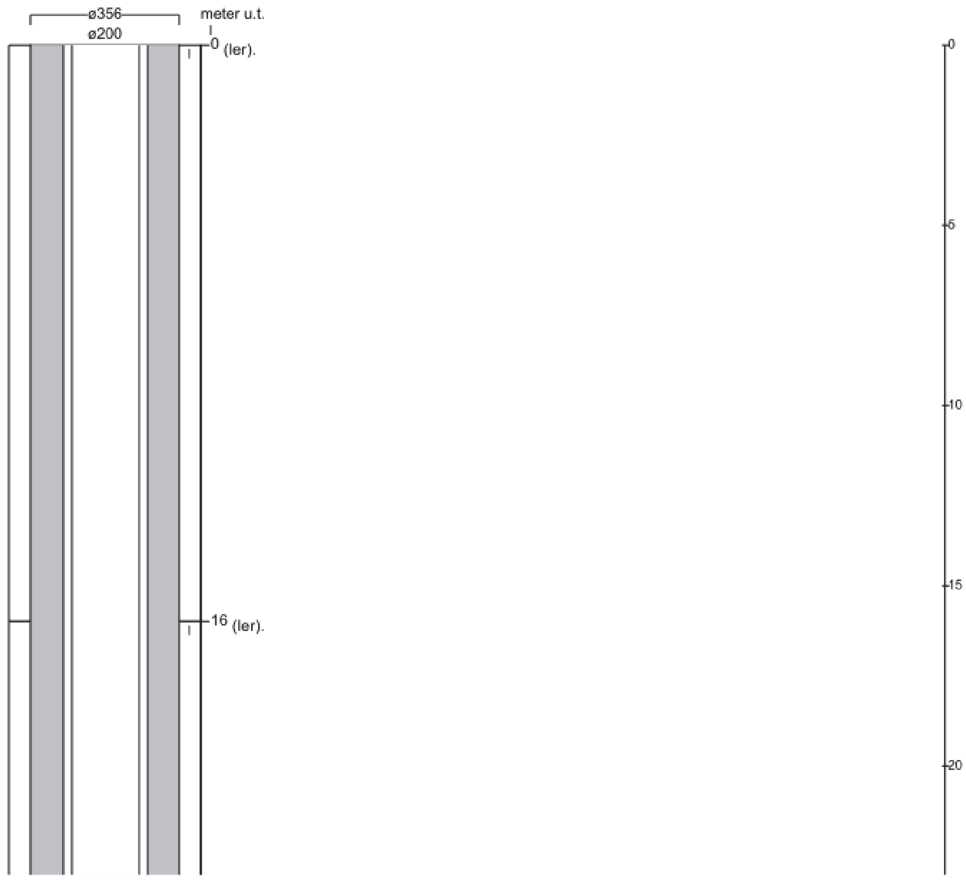
Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Tørboring/slagboring

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 568534, 6218646

Datum : EUREF89
Koordinatkilde : Kommune
Koordinatmetode : Andet

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	52.31 meter u.t.	19/4 2010	55 m³/t	3 meter	
	(første)	50 meter u.t.	1/6 1979			

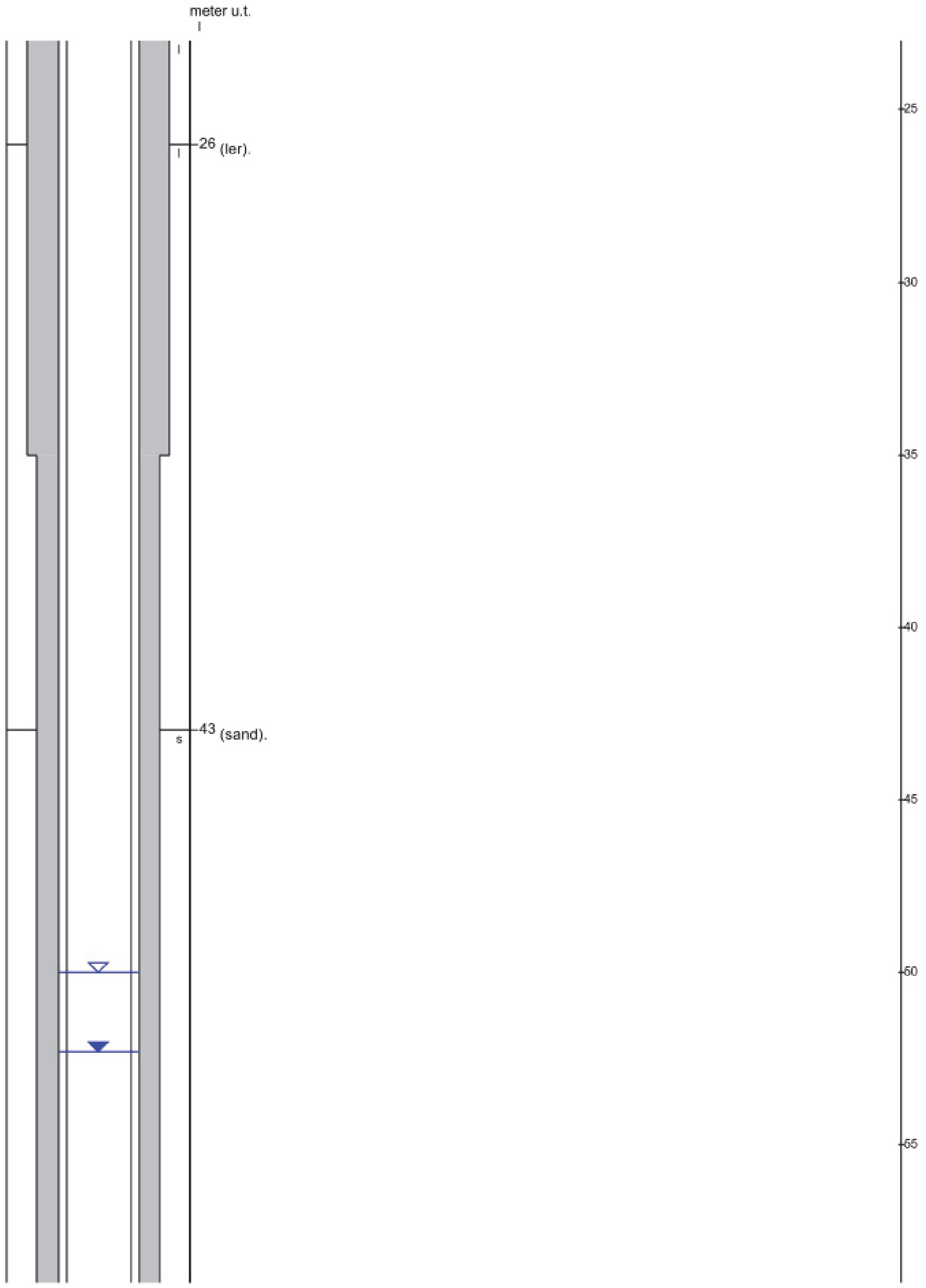
Notater : Århus Kommune: Koord. opdateret fra N&Ms GeoEnviron, okt. 2009



fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 2

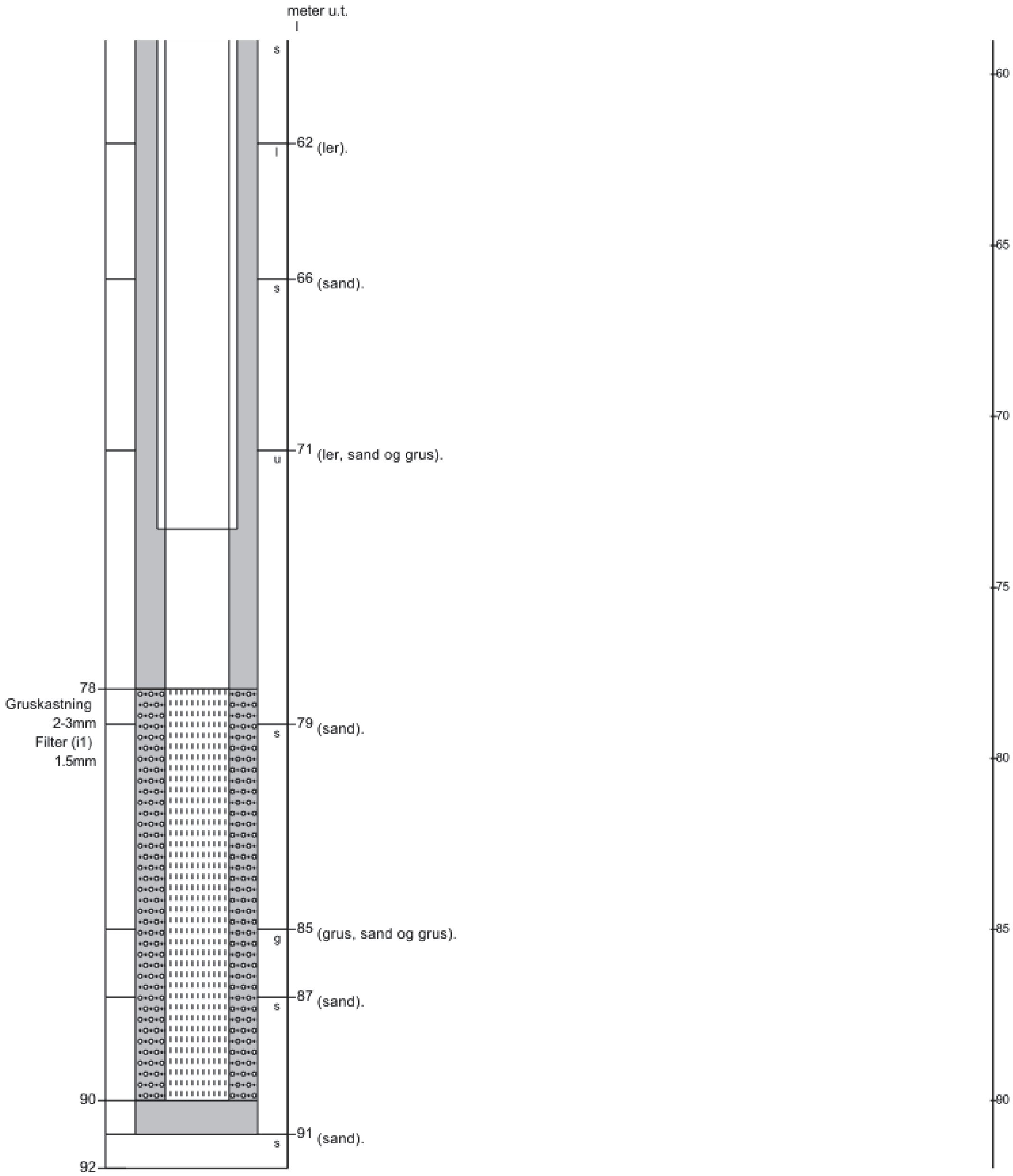
BORERAPPORT — **DGU arkivnr: 89. 1089**



fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland   Udskrevet 20/5 2013 Side 3

BORERAPPORT   **DGU arkivnr: 89. 1089**



De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

GEUS

BORERAPPORT

DGU arkivnr: 89. 1263

Borested : I/S Hasselager Kolt Vandværk, Elmetoften 38
8361 Hasselager
Hasselager

Kommune : Århus
Region : Midtjylland

Boringsdato : 29/5 1989 | **Boringsdybde** : 65 meter | **Terrænkote** : 72.76 meter o. DNN

Brøndborer : Poul Christiansen,Højslev
MOB-nr : 11509
BB-journr :
BB-bornr :

Prøver
- modtaget : 17/8 1989 **antal** : 14
- beskrevet : 6/12 1989 **af** : OW
- antal gemt : 0

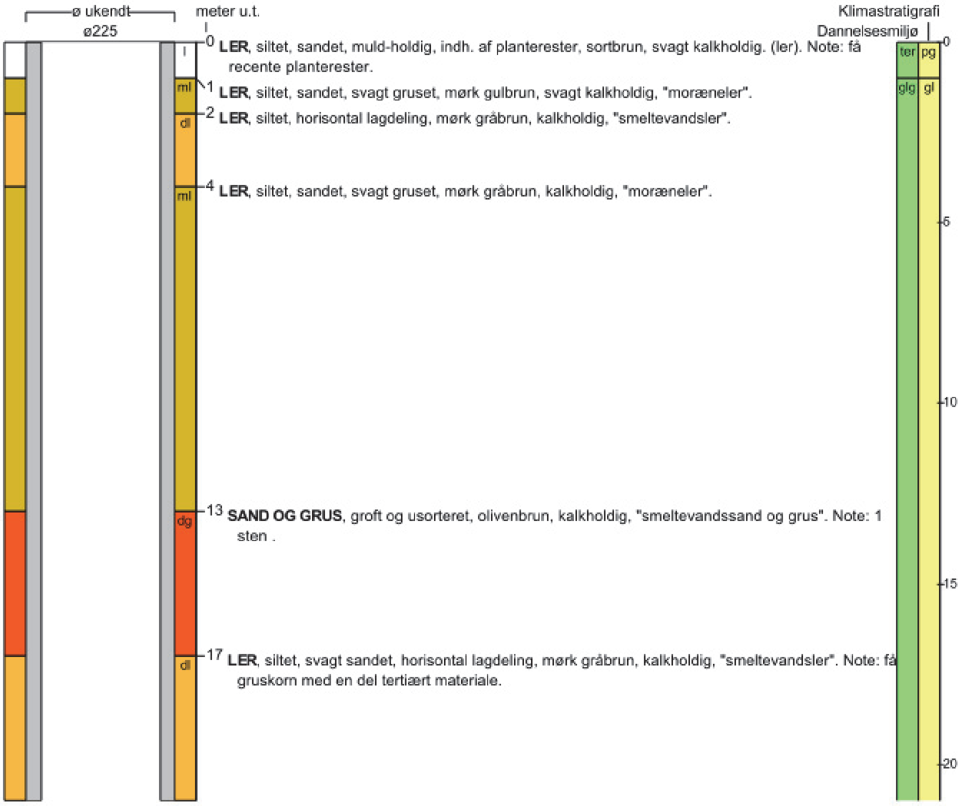
Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Lufthæve

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 567031, 6218278

Datum : EUREF89
Koordinatkilde : Amt
Koordinatmetode : Differential GPS

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	39.65 meter u.t.	19/4 2010	29.4 m³/t	3.3 meter	
	(første)	39.3 meter u.t.	29/5 1989	7 m³/t	1.1 meter	
				14.4 m³/t	1.9 meter	

Notater : Lærspærre: 34-35m, 6-7m. Gruskastning nr. 3. Århus Kommune: Koord. opdateret fra LOPIS database, okt. 2009

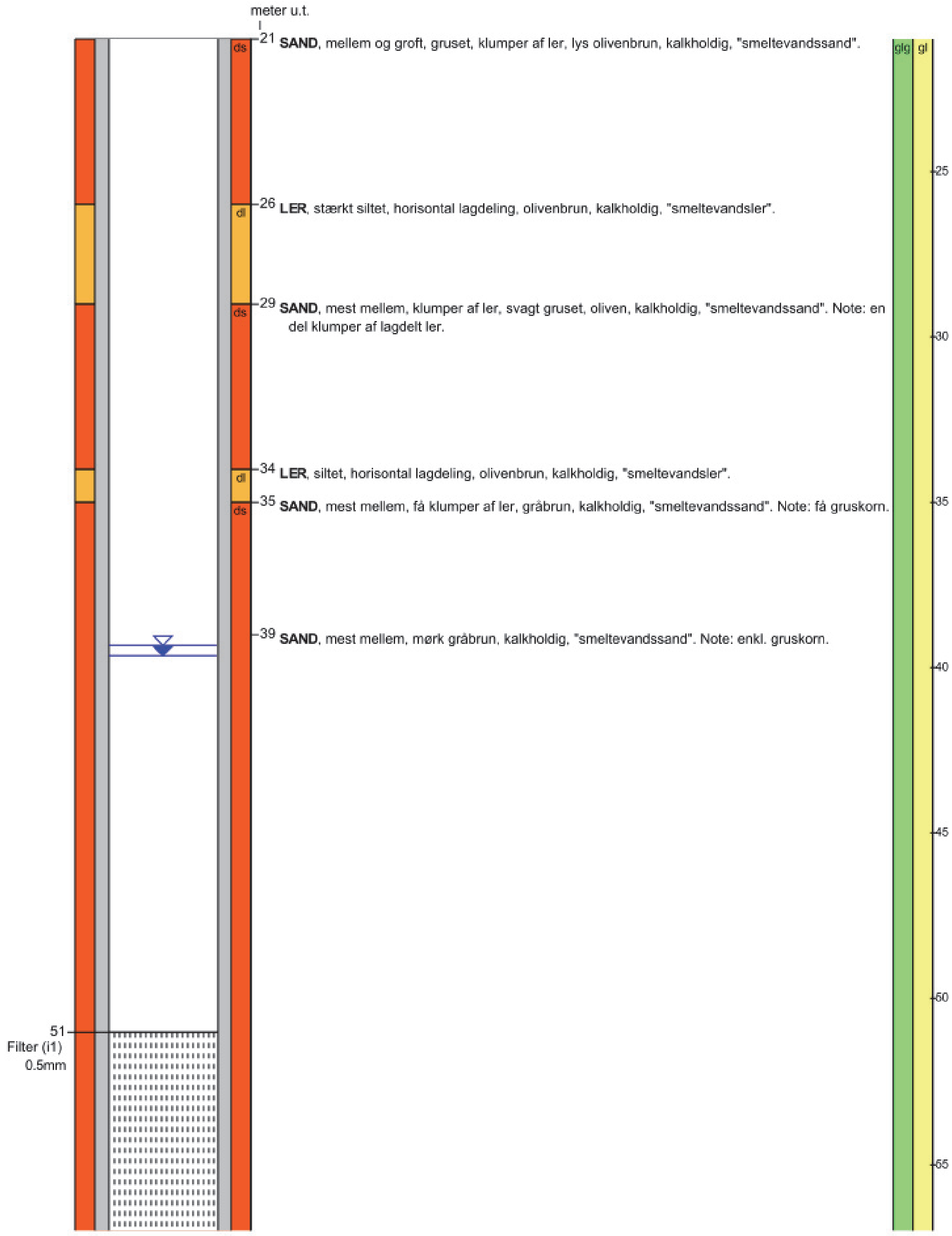


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 2

BORERAPPORT **DGU arkivnr: 89. 1263**

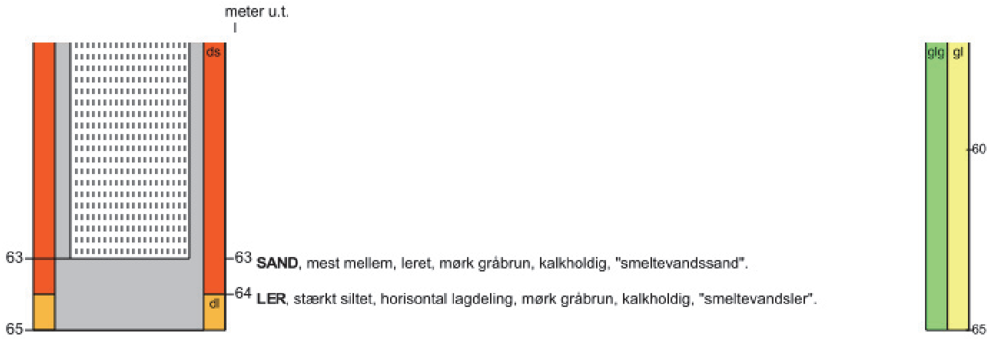


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 3

BORERAPPORT **DGU arkivnr: 89. 1263**



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

meter u.t.	
0 - 1	terrigen - postglacial
1 - 65	glacigen - glacial

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

BORERAPPORT — DGU arkivnr: 89. 1632

Borested : Hasselager-Kolt Vandværk, Pilegårdsvej
8361 Hasselager

Kommune : Århus
Region : Midtjylland

Boringsdato : 25/10 2004 **Boringsdybde** : 72 meter **Terrænkote** : 74.5 meter o. DNN

Brøndborer : SP-Brøndboring, Hammel
MOB-nr :
BB-journr : Pilegårdsvej
BB-bornr :

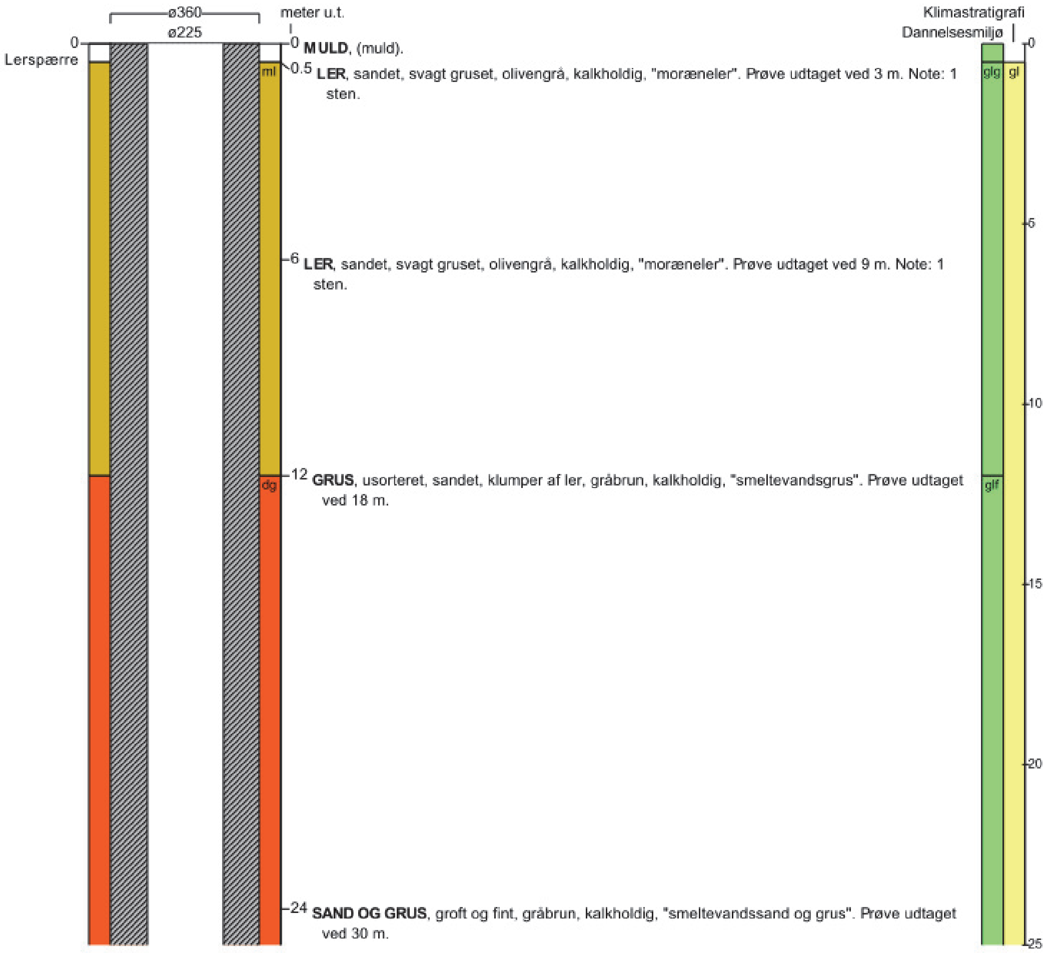
Prøver
- modtaget : 26/9 2005 **antal** : 10
- beskrevet : 24/11 2005 **af** : TC
- antal gemt : 0

Formål : Vandværksboring
Anvendelse : Vandforsyningsboring
Boremetode : Lufthæve

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 567027, 6218266

Datum : EUREF89
Koordinatkilde : Amt
Koordinatmetode : GPS

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	40.07 meter u.t.	11/11 2004	50 m³/t	5.53 meter	



fortsættes..

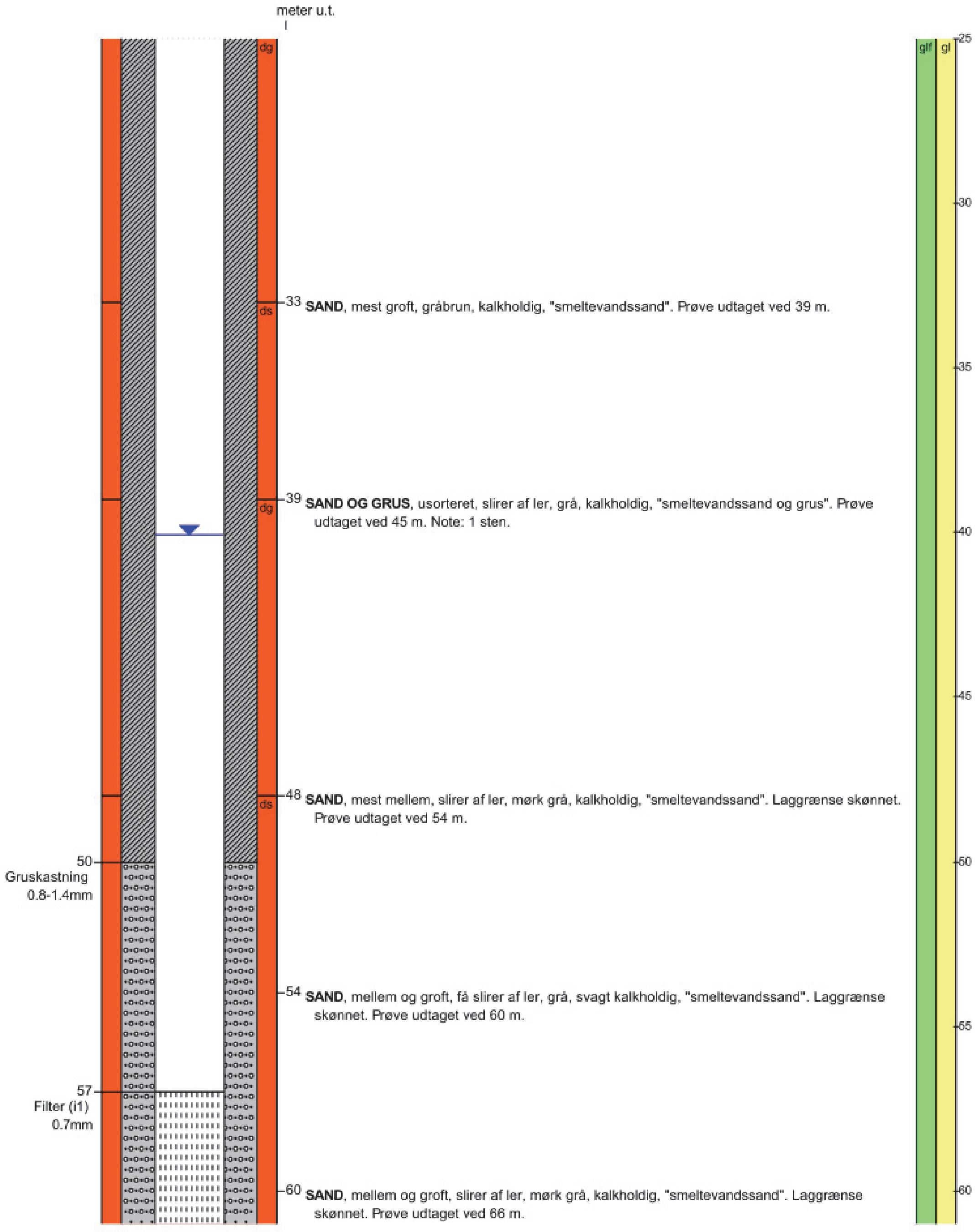
De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 2

GEUS

BORERAPPORT

DGU arkivnr: 89. 1632

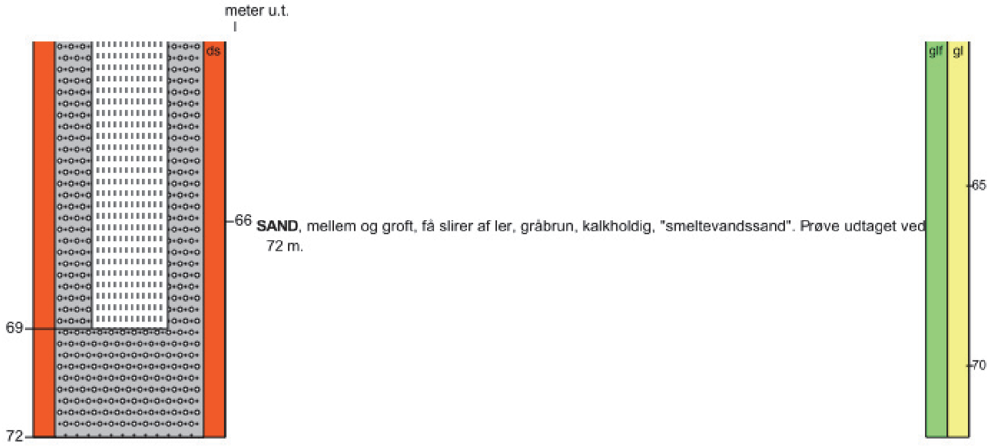


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 3

BORERAPPORT **DGU arkivnr: 89. 1632**



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

meter u.t.		
0	- 0.5	mangler
0.5	- 12	glacigen - glacial
12	- 72	glaciofluvial - glacial

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

GEUS

BORERAPPORT

DGU arkivnr: 89. 1754

Borested : Genvejen
8381 Tilst

Kommune : Århus
Region : Midtjylland

Boringsdato : 14/10 2010 — **Boringsdybde** : 136 meter — **Terrænkote** : 72.2 meter o. DNN

Brøndborer : SP-Brøndboring, Hammel
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget : 15/11 2010 **antal** : 28
- beskrevet : 17/1 2011 **af** : ELL/HJG
- antal gemt : 0

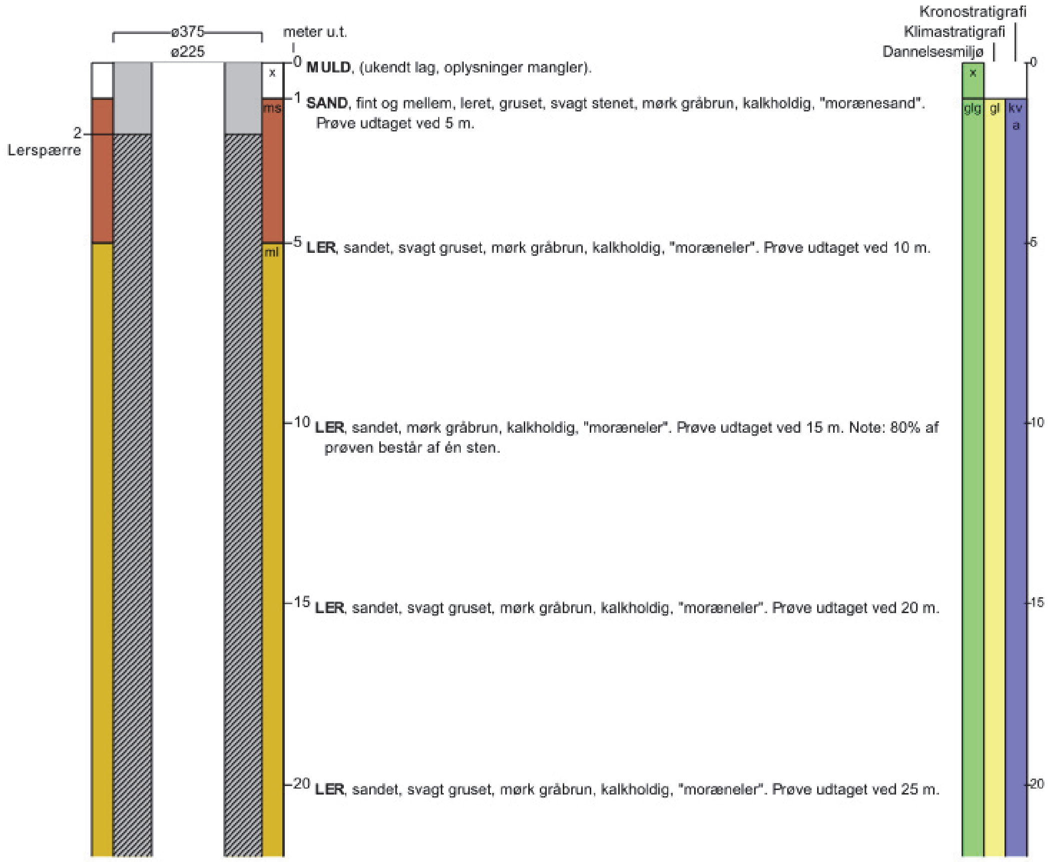
Formål : Vandværksboring
Anvendelse :
Boremetode : Lufthæve

Kortblad : 1314 IVNV
UTM-zone : 32
UTM-koord. : 568193, 6219750

Datum : WGS84
Koordinatkilde : Brøndborer
Koordinatmetode : GPS

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	50.06 meter u.t.	14/10 2010			

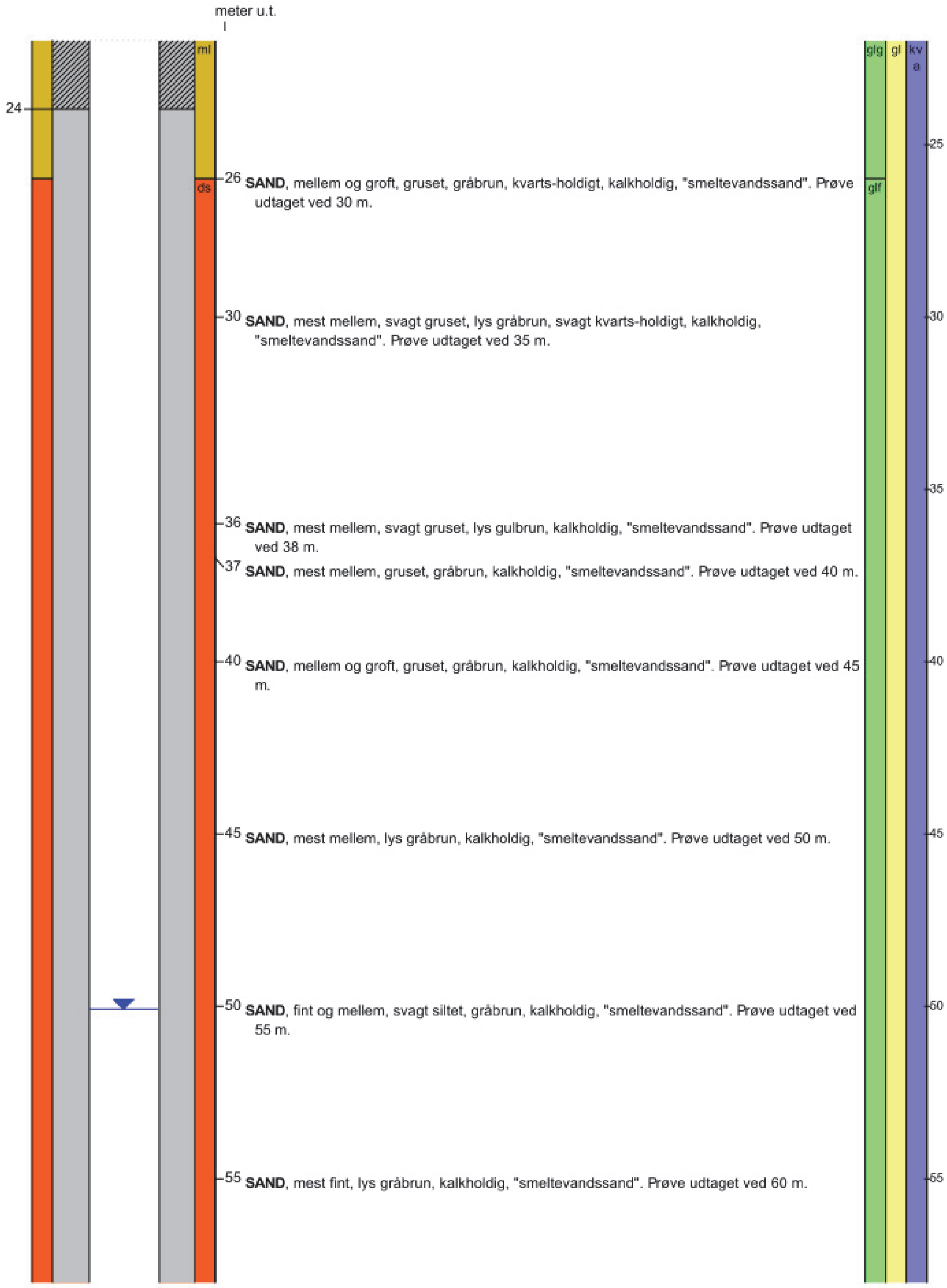
Notater : Pumperesultater indberettes af Orbicon.



fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 2

BORERAPPORT — **DGU arkivnr: 89. 1754**

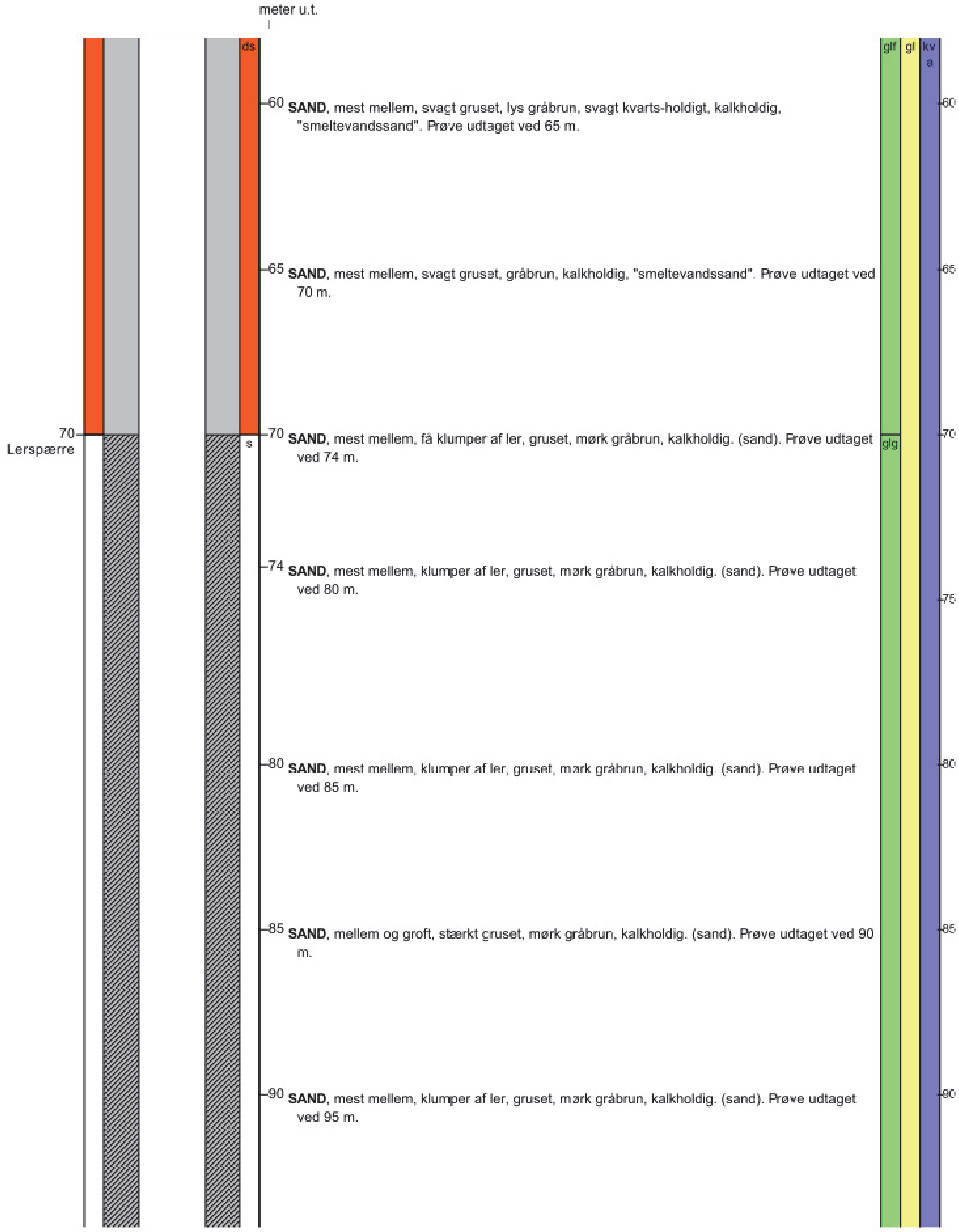


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 3

GEUS

BORERAPPORT — DGU arkivnr: 89. 1754



fortsættes..

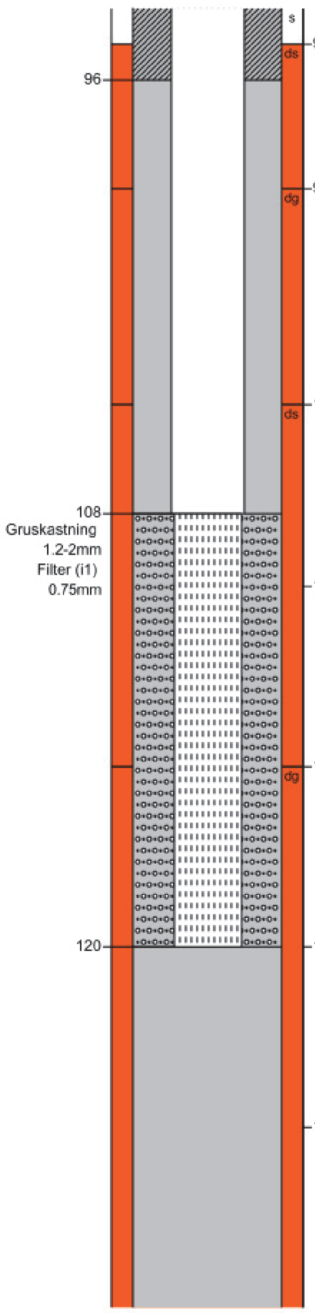
De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 4

BORERAPPORT

DGU arkivnr: 89. 1754

meter u.t.



95 **SAND**, mest mellem, gruset, gråbrun, kalkholdig, "smeltevandssand". Prøve udtaget ved 99 m.

99 **SAND OG GRUS**, usorteret, gråbrun, kalkholdig, "smeltevandsgrus". Prøve udtaget ved 105 m.

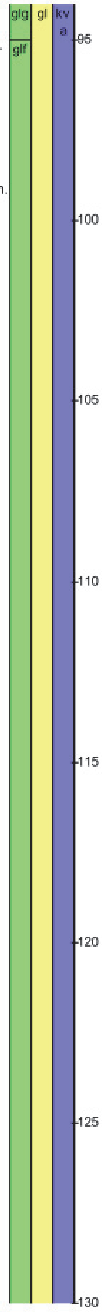
105 **SAND**, mellem og groft, gruset, gråbrun, kalkholdig, "smeltevandssand". Prøve udtaget ved 110 m.

110 **SAND**, mellem og groft, gruset, gråbrun, kalkholdig, "smeltevandssand". Prøve udtaget ved 115 m.

115 **SAND OG GRUS**, usorteret, gråbrun, kalkholdig, "smeltevandsgrus". Prøve udtaget ved 120 m.

120 **SAND OG GRUS**, usorteret, gråbrun, kalkholdig, "smeltevandsgrus". Prøve udtaget ved 125 m.

125 **SAND OG GRUS**, usorteret, gråbrun, kalkholdig, "smeltevandsgrus". Prøve udtaget ved 130 m.



fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

GEUS

BORERAPPORT — DGU arkivnr: 89. 1852

Borested : Genvejen, Lemming
8381 Tilst

Kommune : Århus
Region : Midtjylland

Boringsdato : 20/1 2012 — **Boringsdybde** : 118 meter — **Terrænkote** : 72.81 meter o. DNN

Brøndborer : SP-Brøndboring, Hammel
MOB-nr :
BB-journr :
BB-bornr : B2

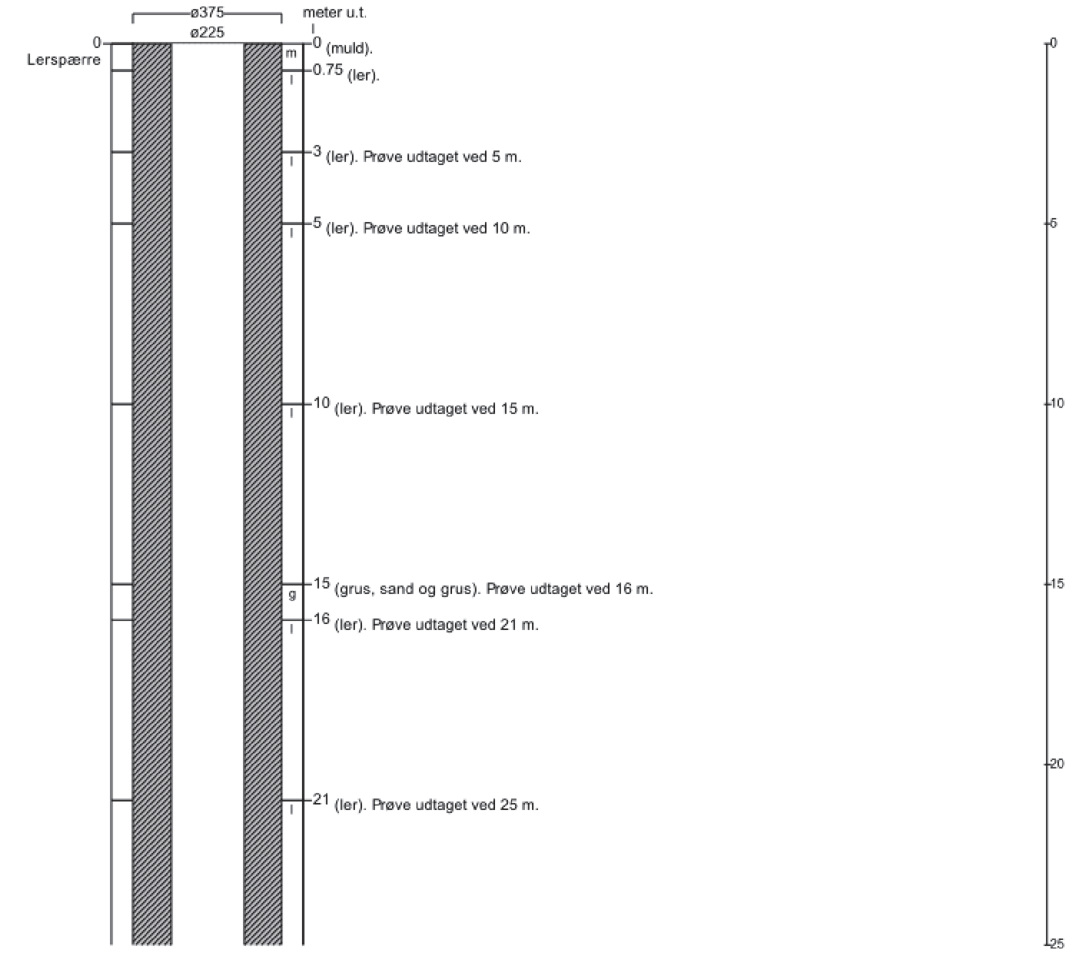
Prøver
- modtaget : 14/8 2012
- beskrevet :
- antal gemt : 0

Formål : Vandværksboring
Anvendelse : Vandværksboring
Boremetode : Lufthæve

Kortblad : 1314 IVNV
UTM-zone : 32
UTM-koord. : 568248, 6219677

Datum : WGS84
Koordinatkilde : Brøndborer
Koordinatmetode : GPS

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	49.7 meter u.t.	20/1 2012	32 m³/t	13.2 meter	



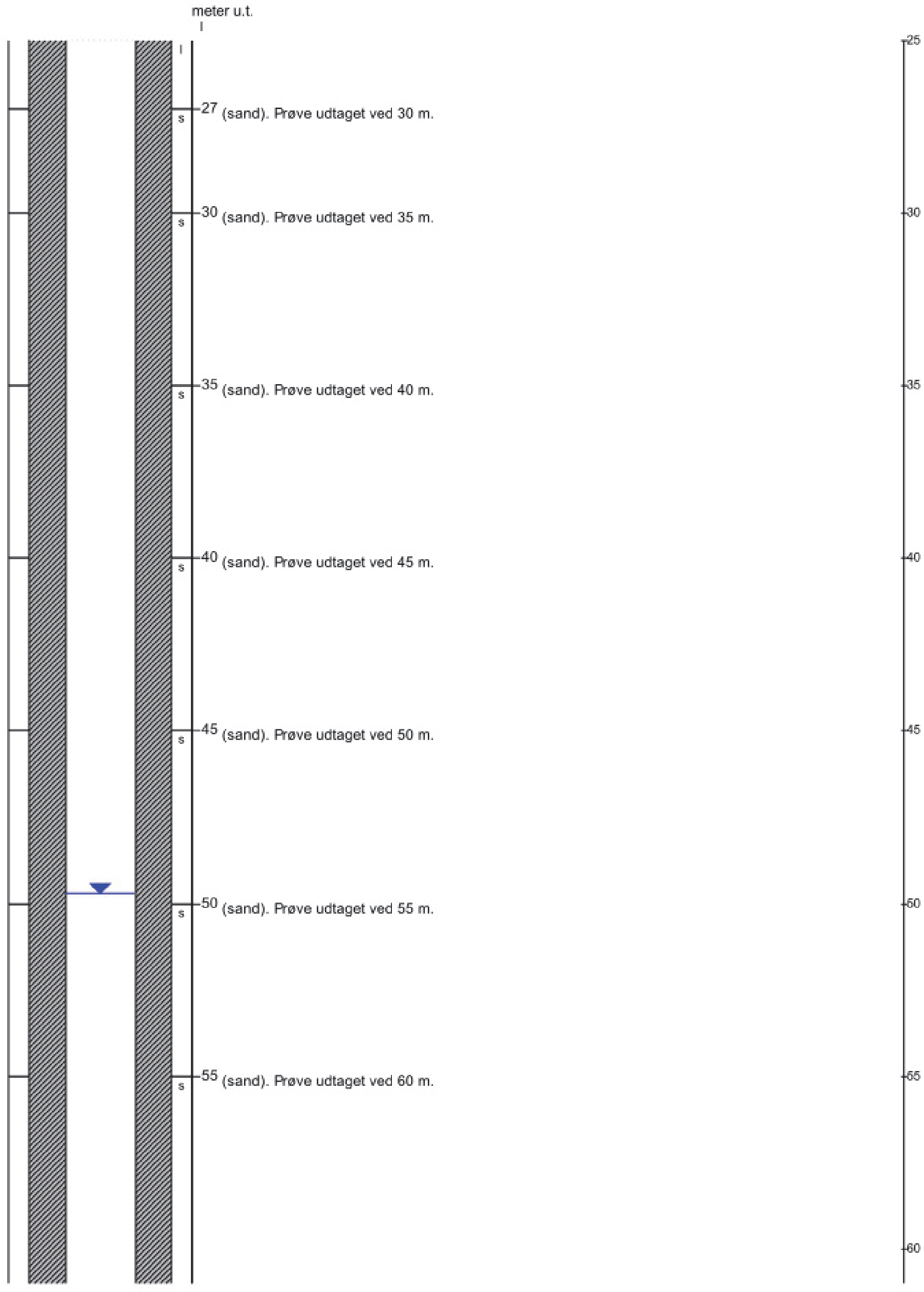
fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 2

BORERAPPORT

DGU arkivnr: 89. 1852

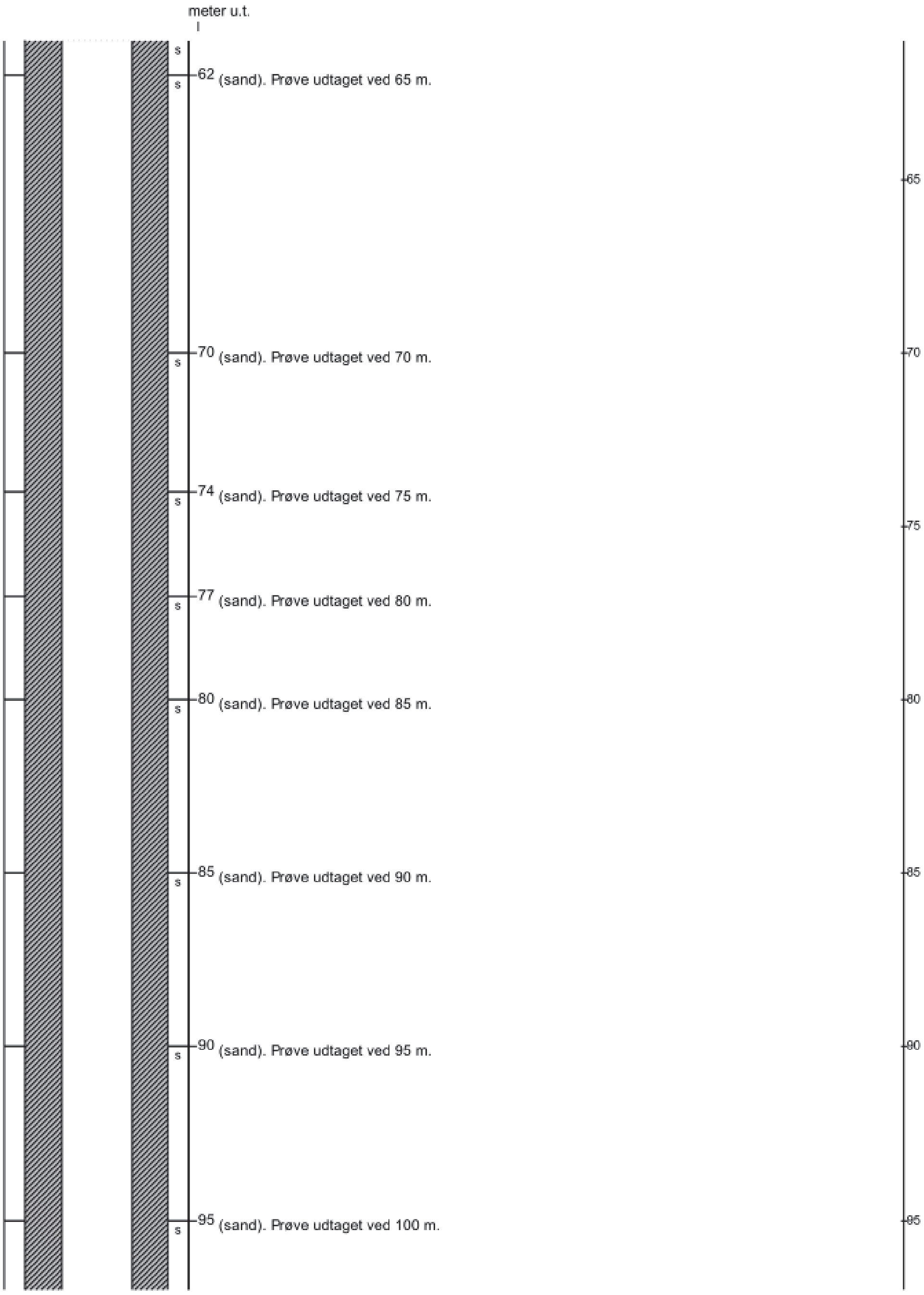


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland — GEUS

Udskrevet 20/5 2013 Side 3

BORERAPPORT **DGU arkivnr: 89. 1852**

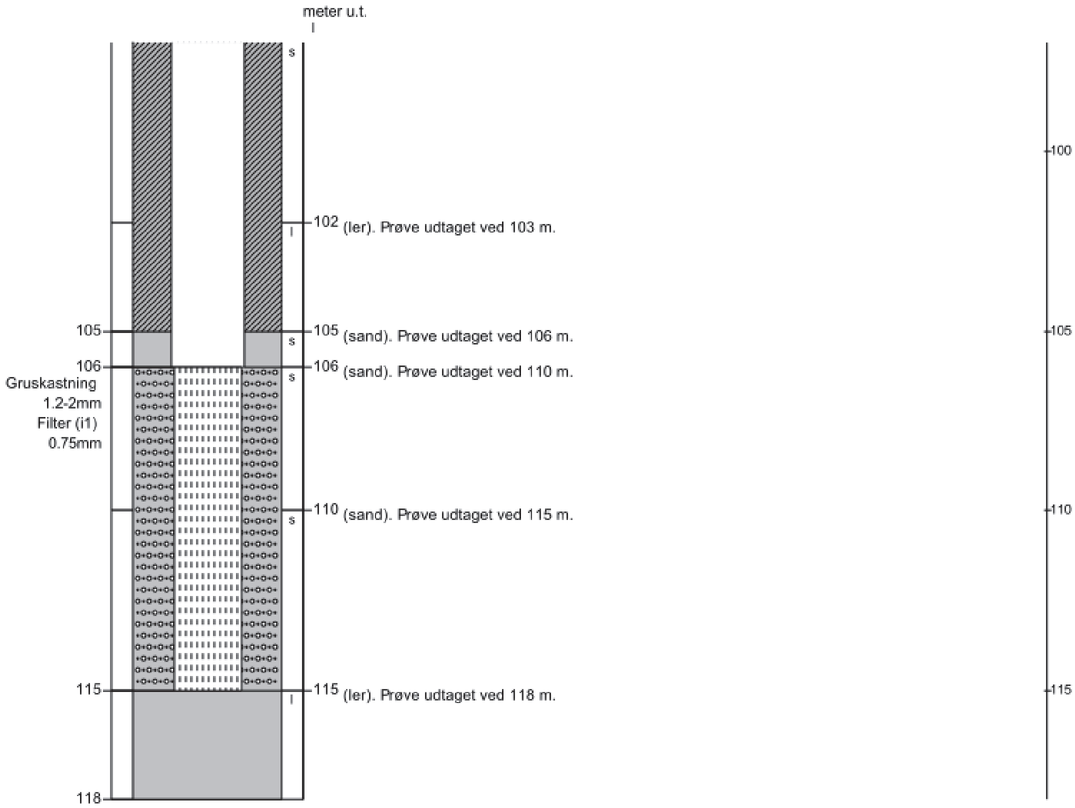


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 4

BORERAPPORT **DGU arkivnr: 89. 1852**



De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 20/5 2013 Side 1

GEUS

BORERAPPORT — DGU arkivnr: 89. 1904

Borested : Ved Kolt Skovej 7
8361 Hasselager

Kommune : Århus
Region : Midtjylland

Boringsdato : 5/12 2012 **Boringsdybde** : 90 meter **Terrænkote** : 76.92 meter o. DNN

Brøndborer : SP-Brøndboring, Hammel
MOB-nr :
BB-journr :
BB-bornr :

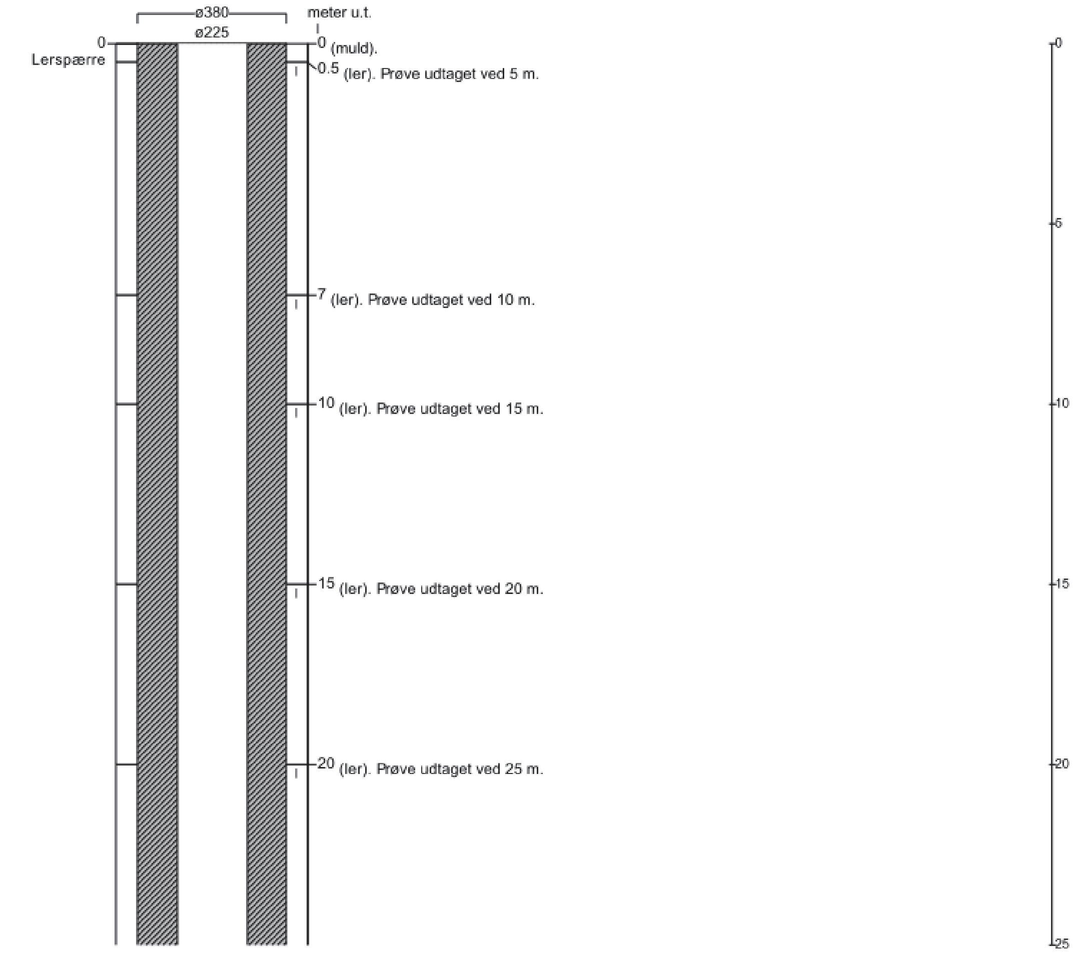
Prøver
- modtaget :
- beskrevet :
- antal gemt : 0

Formål : Vandværksboring
Anvendelse : Vandværksboring
Boremetode : Lufthæve

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 568602, 6218674

Datum : WGS84
Koordinatkilde : Brøndborer
Koordinatmetode : GPS

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	52.2 meter u.t.	17/12 2012	25 m³/t	15 meter	



fortsættes..

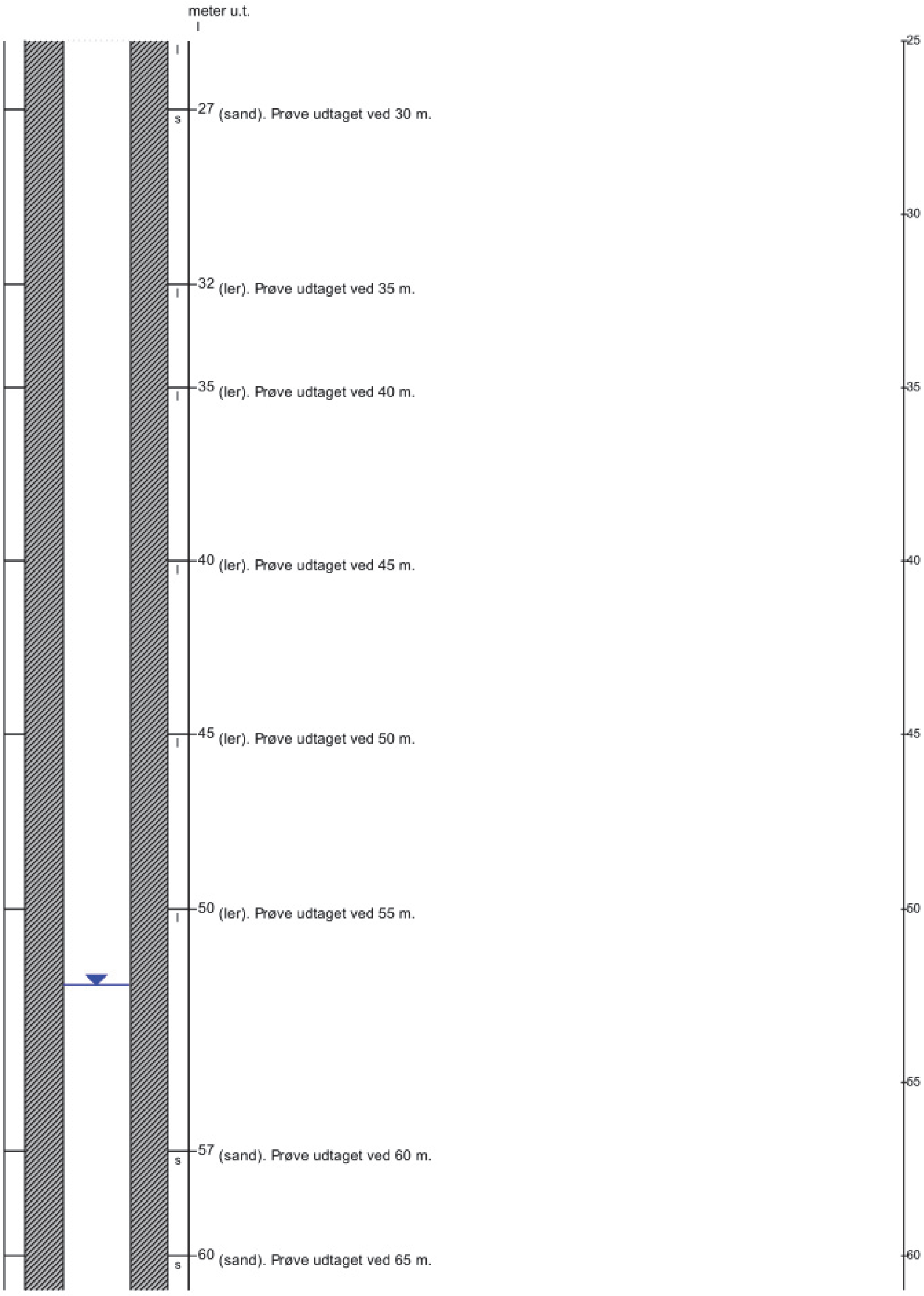
De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 2

GEUS

BORERAPPORT

DGU arkivnr: 89. 1904

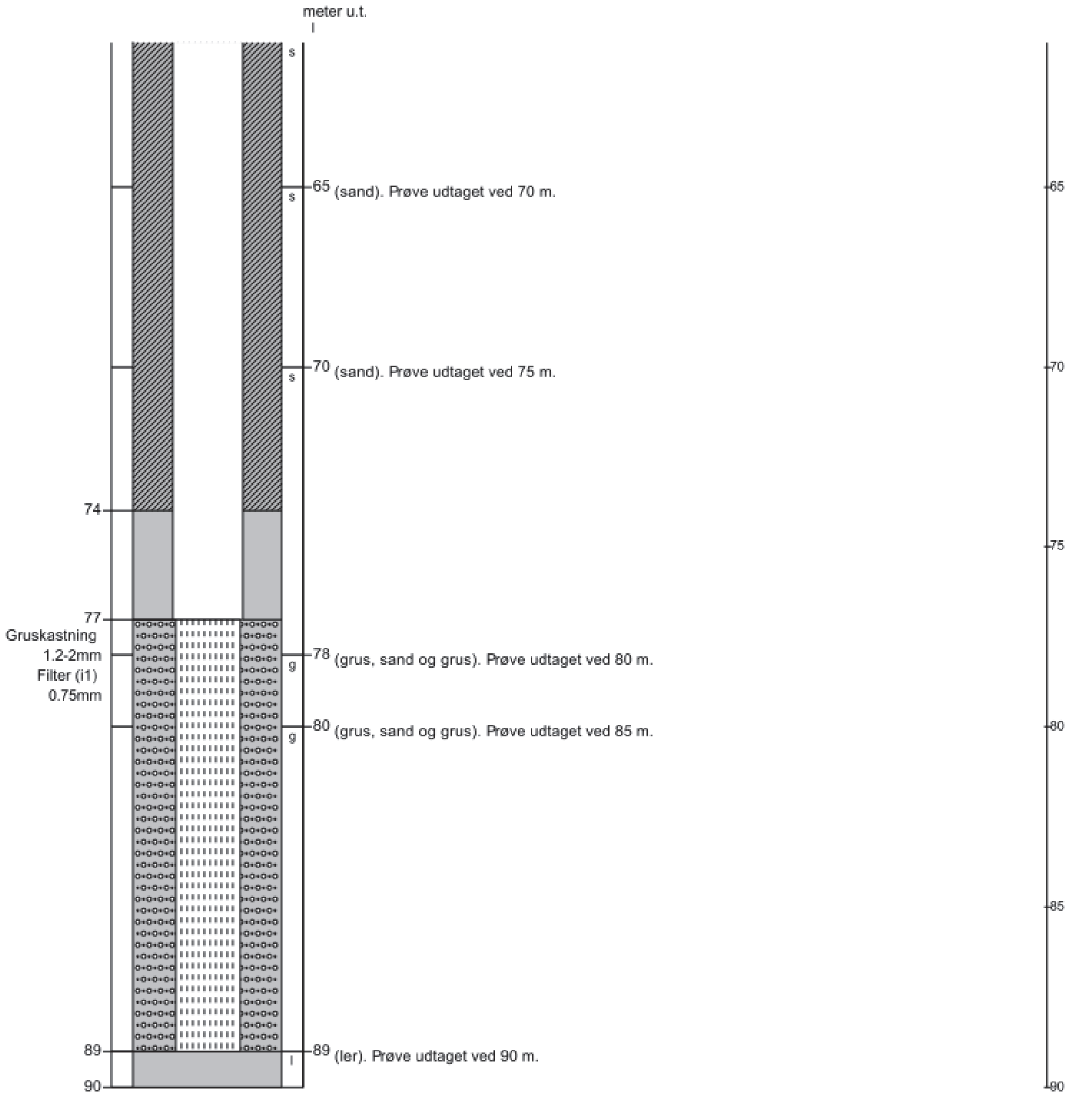


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 20/5 2013 Side 3

BORERAPPORT **DGU arkivnr: 89. 1904**



De Nationale Geologiske Undersøgelser for Danmark og Grønland — Udskrevet 27/5 2013 Side 1

GEUS

BORERAPPORT — DGU arkivnr: 89. 1118

Borested : Buen 24, Hasselager, Hasselager-Kolt Vandværk
8361 Hasselager
erstatningsbor. for B.1

Kommune : Århus
Region : Midtjylland

Boringsdato : 1/8 1984 — **Boringsdybde** : 90 meter — **Terrænkote** : 76.76 meter o. DNN

Brøndborer : Aqua Teknik
MOB-nr :
BB-journr :
BB-bornr :

Prøver
- modtaget : 4/4 1986 **antal** : 11
- beskrevet : 18/3 1994 **af** : PN
- antal gemt :

Formål : Vandforsyningsboring
Anvendelse : Sløjfet/opgivet bor
Boremetode : Tørboring/slagboring

Kortblad : 1314 IVSV
UTM-zone : 32
UTM-koord. : 568574, 6218660

Datum : EUREF89
Koordinatkilde : Kommune
Koordinatmetode : Andet

		Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1	(seneste)	52 meter u.t.	27/11 2012	35 m³/t	12 meter	
	(første)	51 meter u.t.	1/8 1984			

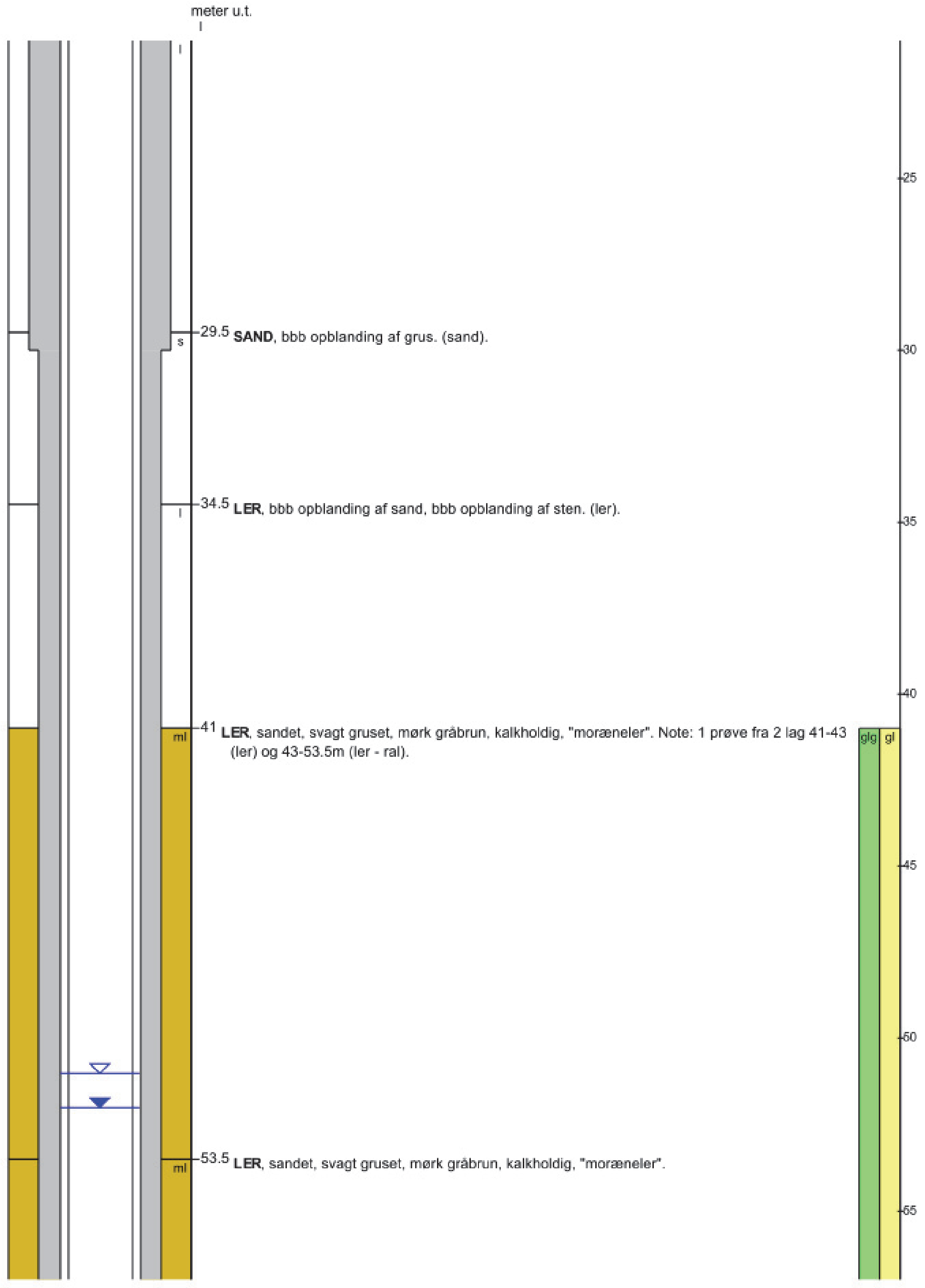
Notater : Gruskastning Lund 6+2. 250mm PVC-forerør til 79.7m.u.t. - 200mm opsrør 77.7-83.7m.u.t. Århus Kommune: Koord. opdateret fra N&Ms GeoEnviron, okt. 2009

fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland

Udskrevet 27/5 2013 Side 2

BORERAPPORT **DGU arkivnr: 89. 1118**

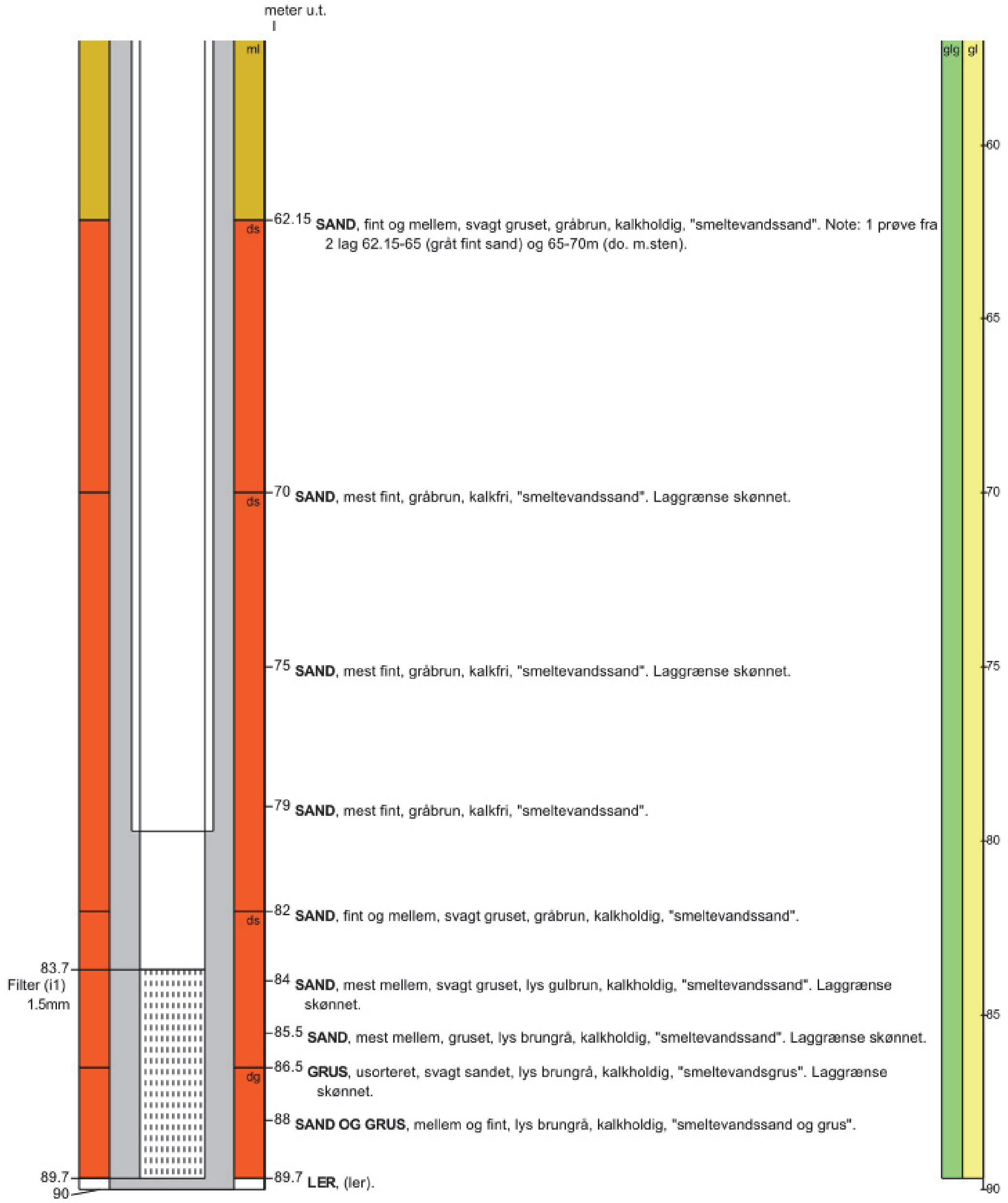


fortsættes..

De Nationale Geologiske Undersøgelser for Danmark og Grønland | Udskrevet 27/5 2013 Side 3

GEUS

BORERAPPORT | **DGU arkivnr: 89. 1118**



3 Chemistry calculations

3.5.1 Ion balance

Calculations are done by following way: laboratory result (mg/l) is divided by molecular weight. Then it's multiplied by charge. The data results of each well are shown in the following tables:

Ion balance	89.1088	04.02.13				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	82,5	40,08	2	4,12		
Mg	3,58	24,31	2	0,29	Cations	5,428
Na	21,1	22,99	1	0,92	Anions	6,07
K	3,82	39,10	1	0,098	Deviation	-11,1%
Anions						
HCO3	303	61,018	1	4,97		
Cl	24	35,45	1	0,68		
SO4	20	96,07	2	0,42		
NO3	0	62,01	1	0		

Ion balance	89.1089	15.10.03				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	88,1	40,08	2	4,4		
Mg	12,5	24,31	2	1,03	Cations	6,28
Na	17,2	22,99	1	0,75	Anions	6,14
K	3,8	39,10	1	0,097	Deviation	2,2%
Anions						
HCO3	319	61,018	1	5,23		
Cl	19	35,45	1	0,54		
SO4	18	96,07	2	0,37		
NO3	0	62,01	1	0		

Ion balance	89.1038	15.12.09				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	101	40,08	2	5,04		
Mg	8,86	24,31	2	0,73	Cations	6,52
Na	15,7	22,99	1	0,68	Anions	6,23
K	2,69	39,10	1	0,069	Deviation	4,5%
Anions						
HCO3	305	61,018	1	5		
Cl	20	35,45	1	0,56		
SO4	32	96,07	2	0,67		
NO3	0	62,01	1	0		

Ion balance	89.1754	05.05.11				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	100	40,08	2	4,99		
Mg	9,3	24,31	2	0,77	Cations	6,52
Na	16	22,99	1	0,7	Anions	6,26
K	2,4	39,10	1	0,06	Deviation	4,1%
Anions						
HCO3	291	61,018	1	4,78		
Cl	20	35,45	1	0,58		
SO4	43	96,07	2	0,9		
NO3	0	62,01	1	0		

Ion balance	89.1852	18.10.10				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	100	40,08	2	4,99		
Mg	8,9	24,31	2	0,73	Cations	6,48
Na	16	22,99	1	0,70	Anions	6,38
K	2,4	39,10	1	0,06	Deviation	1,6%
Anions						
HCO3	297	61,018	1	4,87		
Cl	21	35,45	1	0,59		
SO4	44	96,07	2	0,92		
NO3	0	62,01	1	0		

Ion balance	89.1904	22.01.13				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	86,1	40,08	2	4,3		
Mg	14,4	24,31	2	1,18	Cations	6,73
Na	25,9	22,99	1	1,13	Anions	6,94
K	4,52	39,10	1	0,12	Deviation	-3,10%
Anions						
HCO3	357	61,018	1	5,85		
Cl	24	35,45	1	0,68		
SO4	19	96,07	2	0,39		
NO3	1,2	62,01	1	0,02		

Ion balance	89.1263	21.05.12				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	108	40,08	2	5,39		
Mg	8,98	24,31	2	0,74	Cations	6,71
Na	12,5	22,99	1	0,54	Anions	6,61
K	1,69	39,10	1	0,043	Deviation	1,5%
Anions						
HCO3	284	61,018	1	4,65		
Cl	23	35,45	1	0,65		
SO4	63	96,07	2	1,31		
NO3	0	62,01	1	0		

Ion balance	89.1632	15.11.11				
Cations	Laboratory (mg/l)	M (g/mol)	Charge (eq/mol)	Calc. (meq/l)		
Ca	99,6	40,08	2	4,97		
Mg	6,6	24,31	2	0,27	Cations	5,82
Na	12,4	22,99	1	0,54	Anions	5,73
K	1,43	39,10	1	0,037	Deviation	1,50%
Anions						
HCO3	259	61,018	1	4,24		
Cl	21	35,45	1	0,59		
SO4	43	96,07	2	0,9		
NO3	0	62,01	1	0		

3.5.2 Degree of weathering $F = \frac{2 \cdot (\frac{Ca}{40.1} + \frac{Mg}{24.3})}{\frac{HCO_3}{61.0}}$

Calculations are included in the tables below:

89.1038	mg/l	89.1089	mg/l	89.1088	mg/l
Ca	101	Ca	88,1	Ca	82,5
Mg	8,86	Mg	12,5	Mg	3,58
HCO3	305	HCO3	319	HCO3	303
F	1,15	F	1,04	F	0,89

89.1904	mg/l
Ca	86,1
Mg	14,4
HCO3	357
F	0,94

89.1754	mg/l
Ca	100
Mg	9,3
HCO3	291
F	1,21

89.1852	mg/l
Ca	100
Mg	8,9
HCO3	297
F	1,18

89.1263	mg/l
Ca	108
Mg	8,98
HCO3	284
F	1,32

89.1632	mg/l
Ca	99,6
Mg	6,6
HCO3	259
F	1,30

Interval	Category
<1	no pyrite oxidation
1,0 – 1,3	typical
1,3 – 3,5	pyrite oxidation
>3,5	extreme pyrite oxidation

3.5.3 Ion exchange

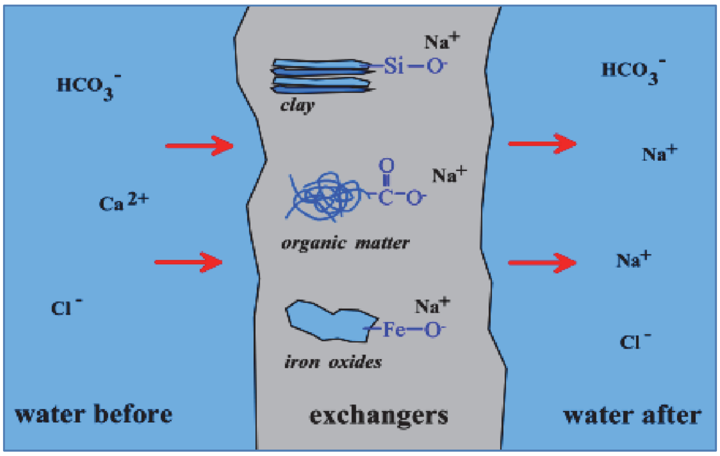


Figure 38 Draft explaining the ion exchange. Figure from chapter 4, Peder Maribo

Calculations are included in the tables below:

89.1089	mg/l
Na	17,2
Cl	19
I	1,4

89.1038	mg/l
Na	15,7
Cl	20
I	1,21

89.1088	mg/l
Na	21,1
Cl	24
I	1,36

89.1852	mg/l
Na	16
Cl	21
I	1,18

89.1904	mg/l
Na	25,9
Cl	24
I	1,67

89.1754	mg/l
Na	16
Cl	20
I	1,23

89.1263	mg/l
Na	12,5
Cl	23
I	0,84

89.1632	mg/l
Na	12,4
Cl	21
I	0,91

Interval	Category
<0,6	reverse ion exchange
0,6 – 0,9	no ion exchange
0,9 – 2,0	ion exchange
>2,0	strong ion exchange

3.5.4 Hardness

$$dH = 5{,}6\cdot\left(\frac{Ca}{40{,}1} + \frac{Mg}{24{,}3}\right)$$

Calculations are included in the tables below:

89.1088	mg/l	mmol/l
Ca	82,5	2,058
Mg	3,58	0,147
dH	12,35	Middle

89.1089	mg/l	mmol/l
Ca	88,1	2,198
Mg	12,5	0,514
dH	19,56	Hard

89.1632	mg/l	mmol/l
Ca	99,6	2,49
Mg	6,6	0,27
dH	15,44	Middle

89.1263	mg/l	mmol/l
Ca	108	2,69
Mg	8,98	0,37
dH	17,16	Middle

89.1852	mg/l	mmol/l
Ca	100	2,5
Mg	8,9	0,37
dH	16,02	Middle

89.1754	mg/l	mmol/l
Ca	100	2,495
Mg	9,3	0,383
dH	16,11	Middle

89.1904	mg/l	mmol/l
Ca	86,1	2,14
Mg	14,4	0,59
dH	15,29	Middle

89.1038	mg/l	mmol/l
Ca	101	2,52
Mg	8,86	0,365
dH	16,15	Middle

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

3.5.5 Calcite saturation index

$$LogSi = pH - 11{,}4 + \log(Ca^{2+}\cdot HCO_3)$$

Calculations are included in the tables below:

89.1088	mg/l
Ca	82,5
HCO3	303
pH	7,4
SI	0,4
	Saturated

89.1038	mg/l
Ca	101
HCO3	305
pH	7,44
SI	0,53
	Saturated

89.1089	mg/l
Ca	88,1
HCO3	319
pH	7,2
SI	0,25
	Saturated

89.1754	mg/l
Ca	100
HCO3	291
pH	7,5
SI	0,56
	Saturated

89.1904	mg/l
Ca	86,1
HCO3	357
pH	7,3
SI	0,39
	Saturated

89.1852	mg/l
Ca	100
HCO3	297
pH	7,5
SI	0,57
	Saturated

89.1263	mg/l
Ca	108
HCO3	284
pH	7,45
SI	0,54
	Saturated

89.1632	mg/l
Ca	99,6
HCO3	259
pH	7,6
SI	0,61
	Saturated

Interval	Category
<0	unsaturated
>0	saturated

3.5.6 Redox water type

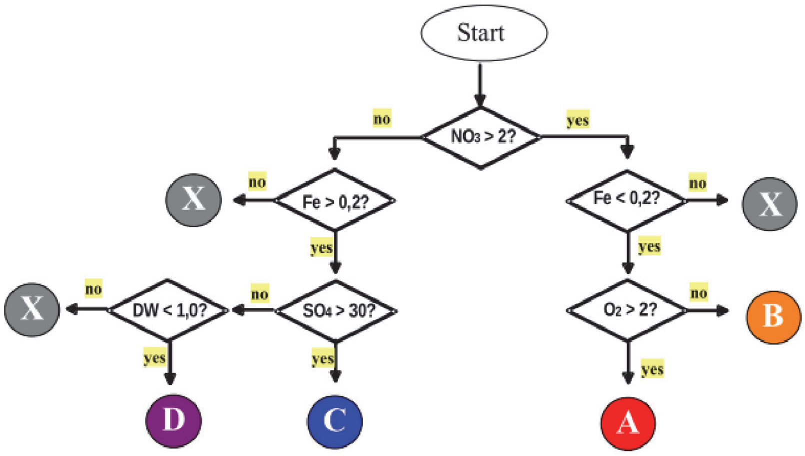


Figure 39 Diagram of redox water classification. From BTWSPL course material

3.5.7 Conductivity

Interval	Category
<30	low salt content
30 – 130	typical
>130	elevated salt content

3.5.8 pH conditions

Interval	Category
<4,5	acidic
4,5 -7,0	aggressive
7,0 – 8,5	buffered
>8,5	alkaline

3.5.9 NVOC

NVOC –non volatile organic carbon. It shows the rank of values in water chemistry:

Interval	Category
<1	low
1 – 4	typical
4 – 10	elevated
>10	brown water

4 Filters details

The company Silhorko has placed two Multiple-media filters from the brand “Eurowater”. Depending of the type of water quality to obtain, the same watertight steel pressure vessel is able to be configured. The driving force for the filtration process inside is the water pressure applied on the filter bed, which can be so high that almost any desired length of filter run is obtainable. See at the following pictures one of the pressurise filters installed at the waterworks:

Figure 40 Multiple-media filters from the brand “Eurowater” at Pilegaardsvej waterworks. Scheme from Eurowater - description of pressure filter. Curtsey of Silhorko

The dimensions of the filters are: circumference: 9.1 metre height with cylindrical part: 2m. The filter bottom is filled with course gravel. Both filters are the same with 6-7 layers of sand. Here there is a table resume:

Hydraulic parameters of pressurised filters

Parameter	Reference	Unit
Area	6.59	m^2
Capacity	100	m^3/h
Circumference	9.1	m
Height	2	m
Running time	12	h
Sand porosity	0.4	-
Volume	18.2	m^3
Inlet pressure	0.8	bar

Table 29 Filter characteristic. Data acquisition provided by Pilegaardsvej waterworks management

4.1 In filtering calculations is necessary to know

$$V_f = \frac{Q}{A}$$

Where:
V_f [m/h]: *Filtration velocity*
Q [m^3/h]: *Maximum hourly flow*
A [m^2]: *Area of the filter*

$$EBCT = \frac{V}{Q} \cdot 60$$

Where:
EBCT [min]: *Empty bed contact time*
V [m3]: *Volume of the filter*
Q [m^3/h]: *Maximum hourly flow*

$$Tres = EBCT \cdot \mathcal{E}$$

Where:
EBCT [min]: *Empty bed contact time*
T_{res} [min]: *Residence time*
$\mathcal{E}$: *Sand porosity*

4.2 Backwash calculations

Used formulas :

$$Fe_{load} = \frac{Fe \cdot Q}{A} \; [\frac{\frac{kgFe}{m^2}}{h}]$$

$$Period = \frac{Run\ length}{Fe_{load}} \; [day]$$

$$Period = \frac{Run\ length}{\frac{Fe}{1000}} \cdot A \; [m^3]$$

Data

Fe [mg/l]	Area [m^2]	Flow [m^3/h]	Fe load [kg Fe/m^2/h]	Run length [kg Fe/m^2/h]	Period [d]	Period [m^3]
2.1	6.59	50	0.0016	0.5	1.3	1569

Table 30 Necessary data for backwash

Water needed for backwash per session: 10m/h * (7min + 3min) * 6.59m^2 * 1/60 = 10.98m^3
Annual water needed for backwash:

$$\frac{365 \text{ days}}{1{,}3} \cdot 10{,}98 = 3082{,}84 \text{ m}^3$$

$$\frac{365 \text{ days}}{2{,}6} \cdot 10{,}98 = 1541{,}42 \text{ m}^3$$

$$3082{,}84 + 1541{,}42 = 4624{,}26 \text{ m}^3$$

At Pilegaardsvej waterworks the filters are made of seven layers of sand with additional protection of gravel at the bottom part. As additional information, the next table shows the possible combinations of filter materials to customise the filtration processes:

Impurities	Problems	Solutions	Filter media
Aggressive CO_2	Aggressive carbon dioxide corrodes concrete, piping, and hot-water tanks of black steel. The corrosion products make the water turbid and the water becomes red with rust and ochre. The carbon dioxide is often present in raw water in earth strata deficient in calcium.	Aggressive carbon dioxide can be neutralized in a pressure filter employing a calcium-containing filter medium. In special cases, aggressive carbon dioxide can be removed by degassing.	Magno-Dol 
Iron and manganese	Often, the worst problems of waterworks are iron and manganese because of discolouration of washing and sanitary appliances in buildings. Typical signs of elevated contents or iron and manganese in water are that the water becomes ochre-coloured or black with a metallic taste.	After oxidation, iron and manganese can be filtered off in a pressure filter. The filter medium can be quartz sand, Nevtraco®, or Hydrolit-MN.	Gravel 
Ammonium and nitrite	The presence of ammonium indicates microbiological activity in the water, possibly resulting from fertilization, contamination, or from geology. Nitrite in raw water is often present as a residual product of an incomplete ammonium conversion. Nitrite also indicates contamination and microbiological activity.	Ammonium is converted into nitrite and afterwards nitrate through biological nitrification. Nitrification requires much oxygen and sufficient filter medium.	Nevtraco® 
Pesticides and chlorine	Contamination from pesticides is primarily a result of the use of the herbicides Caseron G and Prefix G for weed control. The decomposition product 2.6 dichlorobenzamide – BAM – comes from dichlorobenil and chlorthiamid, which are the active substances of Caseron and Prefix.	BAM can be reduced in a pressure filter with a filter medium of activated carbon. Activated carbon is a natural product made from pit coal, wood, or coconut shells. Among other things, an activated carbon filter can remove free chlorine, pesticides, and organic solvents.	Activated carbon 
Arsenic	Arsenic is a natural element and related to certain geochemical environments. Arsenic is found in two forms, As(III) and As(V) of which As(III) is more poisonous and harder to remove from the water. According to WHO, arsenic poses serious health hazards when ingested and has been associated with skin cancer and various organ diseases.	Arsenic combines with iron and can be removed through co-precipitation with iron. If insufficient iron is available in the raw water for this process, the iron content in the water can be increased by addition of iron chloride. Another approach is to remove arsenic by adsorption in a pressure filter with a special filter medium containing iron hydroxide.	Iron granulate 
Adjustment of hardness	Calcium and magnesium mainly determine the total hardness in the water. A large content results in hard water, a small content in soft water. The hardness of the water is measured in German degrees of Hardness (°GH).	A recarbonation filter with various calcium-containing filter media is employed for hardening of the water hardness, for example minerals have to be added to demineralized water before use.	Hydrolit CA 
Suspended solids	If the water contains much suspended matter (high turbidity) such as surface water, there will be an increased need for frequent filter washing when traditional sand filters are employed.	A depth filter is also known as a multimedia filter because the solution combines surface and depth filtration in one pressure filter. The advantage is that a large volume of suspended matter and particles can be removed in one filter. The filter media quartz sand and hydro-anthracite are used for this purpose.	Hydro-anthracite 

Table 31 The table gives a survey of problems caused by selected impurities in the water. Source: EUROWATER Catalogue

4.3 Treatment in the new waterworks at Kolt Skovvej

Wells	89.1904	89.1118	89.1088	89.1089	89.1038	89.1754	89.1852	
Date	05.12.12	Closed	01.06.69	01.06.79	01.01.60	14.10.10	20.01.12	
Well depth (m)	90	90	84	92	77	136	118	
Water table (depth, m)	52,2	52	52,4	52,3	60,6	50,1	49,7	
Pump capacity (m3/h)	25	35	27	55	25	35	35	
Address	Buen 24	Buen 24	Buen 24	Buen 24	Koltvej 14	Genvejen	Genvejen	
Chemistry	mg/l	89.1118	mg/l	mg/l	mg/l	mg/l	mg/l	Standards
Sample date	22.01.13	21.05.12	04.02.13	15.10.03	15.12.09	05.05.11	18.10.10	
Iron	1,55	1,6	1,24	1,3	0,002	3,4	3,4	0,1
Manganese	0,295	0,262	0,247	0,25	0,001	0,28	0,32	0,02
Ammonium	0,38	0,44	0,23	0,28	0	0,2	0,18	0,05
Phosphorus	0,12		0,35	0,13	0	0,1	0,13	0,15
Calsium	86,1		82,5	88,1	101	100	100	-
Chloride	24		24	19	20	20	21	250
Magnesium	14,4		3,58	12,5	8,86	9,3	8,9	50
Potassium	4,52		3,82	3,8	2,69	2,4	2,4	10
Sodium	25,9		21,1	17,2	15,7	16	16	175
Sulfate	19		20	18	32	43	44	250
Hydrogencarbonate	357		303	319	305	291	297	-
NVOC	1,4		0,7	0,91	1	2,5	3,1	4
Fluoride	0,2		0,3	0,25	0,2	0,23	0,23	1,5
Nitrate	1,2		0	0	0	0	0	50
pH	(ass. 7,3)	7,3	7,4 (15.9.12)	7,2	7,44	7,5	7	7-8,5
K (mS/m)	75		56,5	56,1	54	58	no data	30
Pesticides (sum)	0		0	0	0	0	0	0,0005
Calculations								
Hardness	15,29		12,35	19,56	16,15	16,11	16,02	
	Middle		Middle	Hard	Middle	Middle	Middle	
Ion excange	1,67		1,36	1,40	1,21	1,23	1,18	
	Ion ex.		Ion ex.	Ion ex.	Ion ex.	Ion ex.	Ion ex.	
Degree of weathering	0,94		0,89	1,04	1,15	1,21	1,18	
	No pyr.ox.		No pyr.ox.	Normal	Normal	Normal	Normal	
Ion balance	-3,1%		-11,1%	2,2%	4,5%	4,1%	1,6%	
Calsite saturation index	0,39		0,4	0,25	0,53	0,56	0,57	
	Saturated		Saturated	Saturated	Saturated	Saturated	Saturated	
Redox type	D		D	X	X	C	C	

Table 32 Water quality for the treatment

4.4 Aeration in new filters

well	capacity	% of all	iron (mg/l)	manganese (mg/l)	ammonium (mg/l)
89.1118	35	25	1,6	0,262	0,44
89.1088	27	19	1,24	0,247	0,23
89.1089	55	39	1,3	0,25	0,28
89.1038	25	17	0,002	0,001	0
Average			1,14	0,21	0,26

Table 33 Calculations of the impurities average in the raw water

4.5 Filters PI diagram in new waterworks

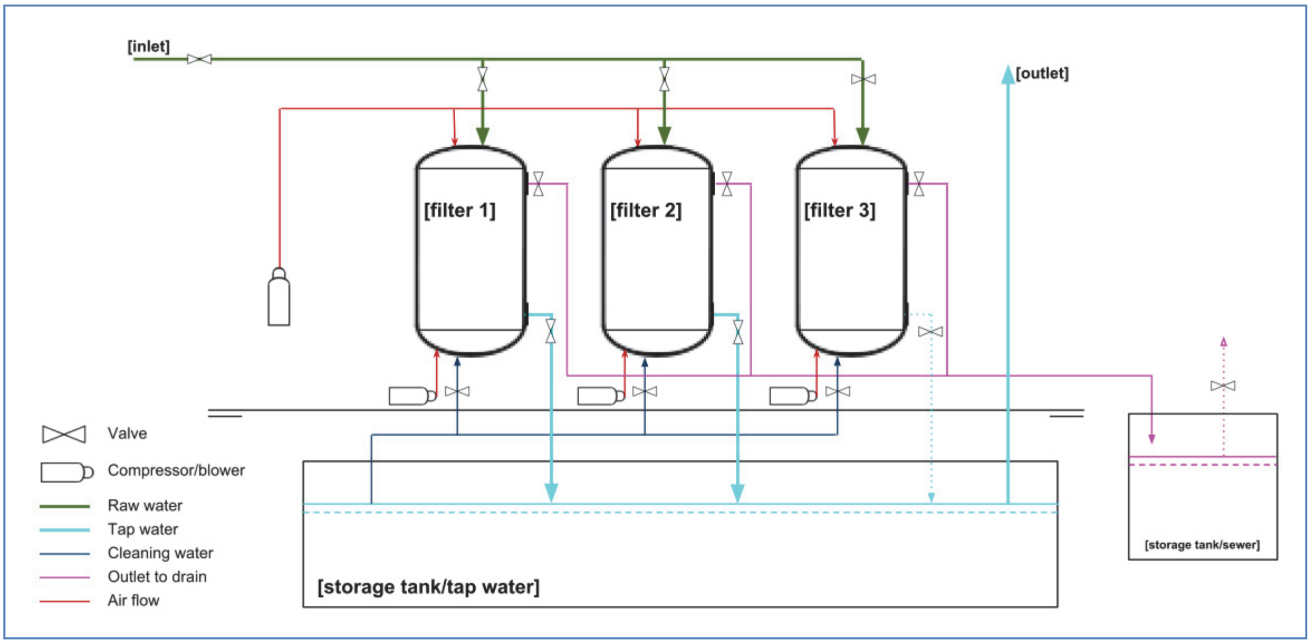


Figure 41 Three filters working in parallel, Lines 1,2 and 3, nr. 3 is in standby

4.6 Backwash estimation in new waterworks

Air + water (10m/h water + 60m/h air)

10 m/h*4.9m2*10 min= 8.167m^3 (water)
60 m/h*4.9m2= 4,9 m3/min * 60 = 294 m^3/h (air)

Annual consumption of water:

filter 1: 365*8,167m3= 2981 m3
filter 2: 365/2*8,167m3= 1490 m3
TOTAL: 4471m^3

Water and air speed are typical. Time was selected to be 10 minutes.

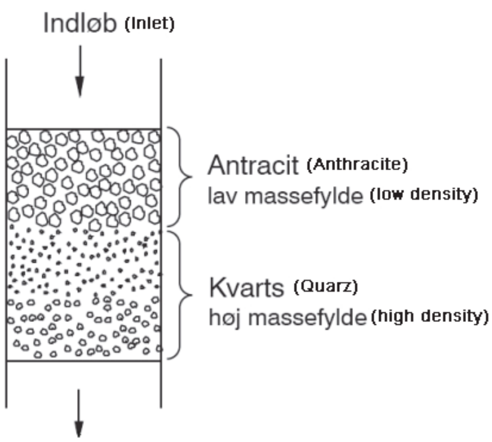


Figure 42 2-media filter bed. Picture from BTWSPL course material

4.7 Optimizing the network supply pumps

Hour	Pilegardsvej	Kolt Skovvej	CONSUM AVE	CONSUM FUTURE	SUM AVE	SUM AVE FUTURE
0	13.063	0.223	13.286	17.671	13.286	17.671
1	10.138	0.225	10.363	13.783	23.649	31.453
2	14.397	0.207	14.604	19.423	38.253	50.876
3	14.842	0.225	15.067	20.039	53.319	70.915
4	15.585	0.226	15.811	21.029	69.131	91.944
5	27.042	0.229	27.271	36.271	96.402	128.214
6	45.814	23.592	69.406	92.310	165.808	220.524
7	0.282	84.673	84.956	112.991	250.764	333.516
8	0.067	48.500	48.567	64.595	299.331	398.110
9	0.048	47.561	47.609	63.319	346.940	461.430
10	0.050	44.458	44.508	59.195	391.447	520.625
11	0.044	42.763	42.806	56.933	434.254	577.558
12	0.023	42.858	42.881	57.032	477.135	634.590
13	0.147	60.878	61.025	81.163	538.160	715.753
14	0.049	42.635	42.684	56.769	580.844	772.522
15	0.041	44.087	44.128	58.690	624.972	831.212
16	0.075	45.632	45.707	60.790	670.678	892.002
17	29.934	8.185	38.120	50.699	708.798	942.701
18	58.048	0.245	58.294	77.530	767.091	1020.232
19	32.537	12.404	44.941	59.772	812.033	1080.003
20	-0.027	29.688	29.661	39.449	841.694	1119.453
21	0.031	27.467	27.498	36.572	869.192	1156.025
22	0.057	26.288	26.346	35.040	895.537	1191.065
23	0.041	36.121	36.161	48.095	931.699	1239.159

SUM MAX	SUM MAX FUTURE	Pump1	Pump1 sum	Pump2	Pump2 sum	Pump4	Pump4 sum	Pump 3	Pump 3 sum
23.25079167	30.92355292	0	450	0	700	0	700	0	400
41.38572083	55.04300871	0	450	0	700	0	700	0	400
66.94238542	89.0333726	0	450	0	700	0	700	0	400
93.30906667	124.1010587	0	450	0	700	0	700	0	400
120.9787396	160.9017236	0	450	0	700	0	700	96	496
168.7032083	224.3752671	0	450	0	700	96	796	96	592
290.1638046	385.9178601	0	450	0	700	96	892	96	688
438.8365042	583.6525505	64	514	0	700	96	988	96	784
523.829472	696.6931977	64	578	0	700	96	1084	96	880
607.1444111	807.5020668	64	642	0	700	96	1180	96	976
685.033018	911.0939139	64	706	0	700	96	1276	96	1072
759.9442757	1010.725887	64	770	64	764	96	1372	96	1168
834.9867403	1110.532365	64	834	64	828	96	1468	96	1264
941.7802657	1252.567753	64	898	64	892	96	1564	96	1360
1016.476674	1351.913976	64	962	64	956	96	1660	96	1456
1093.700228	1454.621303	64	1026	64	1020	96	1756	96	1552
1173.686906	1561.003585	64	1090	64	1084	96	1852	96	1648
1240.396168	1649.726904	64	1154	64	1148	96	1948	96	1744
1342.409924	1785.405199	64	1218	64	1212	96	2044	96	1840
1421.056893	1890.005668	64	1282	64	1276	96	2140	96	1936
1472.964066	1959.042208	0	1282	0	1276	96	2236	96	2032
1521.08542	2023.043609	0	1282	0	1276	0	2236	96	2128
1567.19029	2084.363086	0	1282	0	1276	0	2236	96	2224
1630.472809	2168.528836	0	1282	0	1276	0	2236	0	2224

5 Consumption details

Dimensioning flow is calculated by Q_{max} * hour factor/24. Hour factor is average from this table:

Category	Day factor	Hour factor
Holiday homes, caravan parks	2.0 – 4.0	2.0 – 3.0
Scattered houses or villages, primarily sustained by farming	2.0 – 3.0	2.0 – 2.5
Villages, primarily sustained by small industries and shops	1.5 – 2.0	1.7 – 2.0
Larger cities with a varied mix of industries, offices etc.	1.3 – 1.5	1.5 – 1.7
	Data from Vandforsyningsteknik 5. udg.	

Table 34 Day/Hour factor

6 Water supply network

Annex 1

Pressure loss in pipes (I) can be calculated with the Darcy- Weisbach formula; I = f * V2/2*g*Rh. The pressure loss is calculated by multiplying the friction factor (0,01) with the kinetic energy (V2/2*g) and the hydraulic radius of the pipe (Rh). The velocity and kinetic energy are related, so the pressure will increase simultaneously to the velocity. This is exactly what happens when the demand increases.

Annex 2

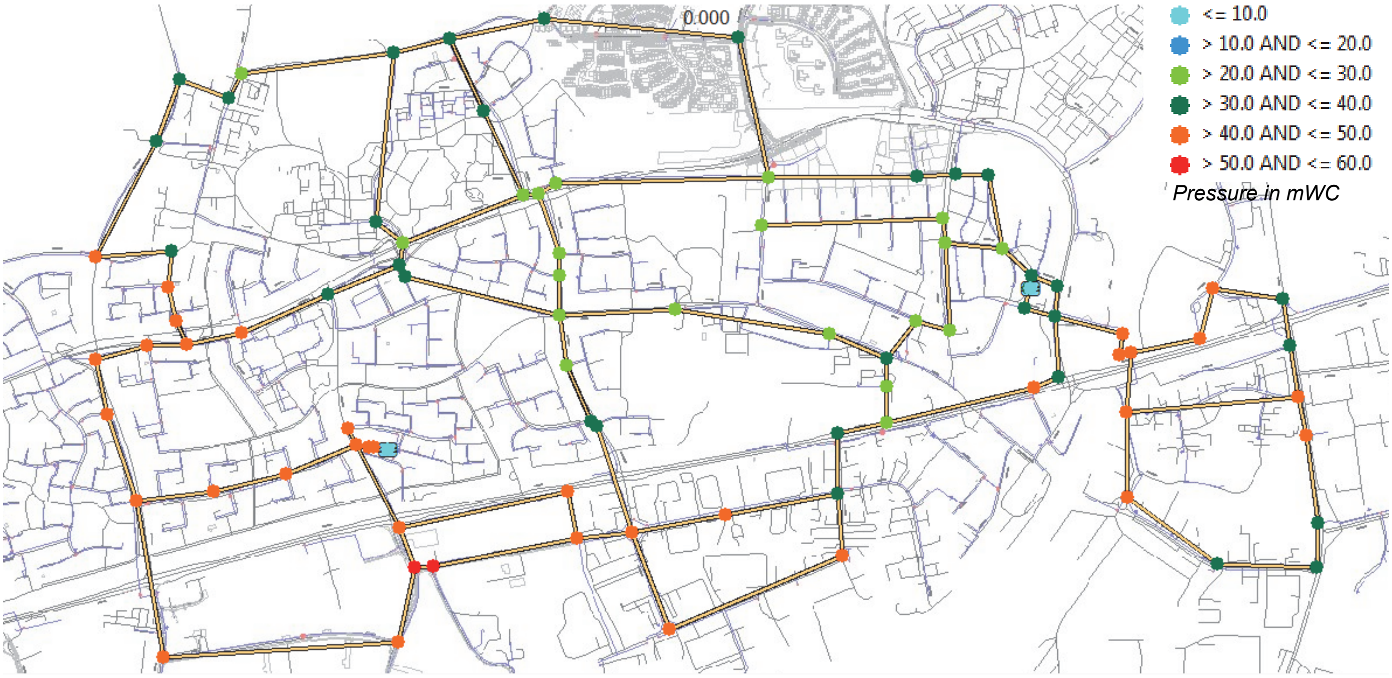


Figure 43: Pressure in junctions for average scenario - Pilegaardsvej waterworks in operation

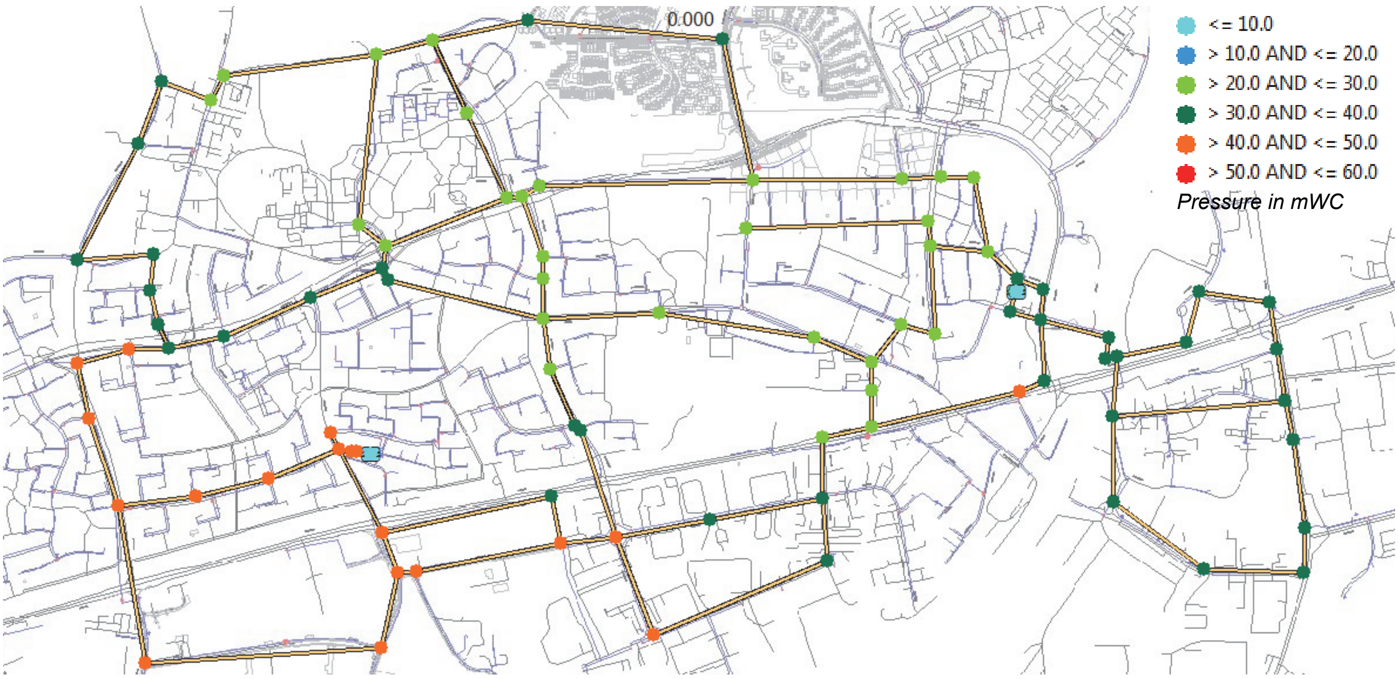


Figure 44: Pressure in junctions for maximum scenario - Pilegaardsvej waterworks in operation

Annex 3

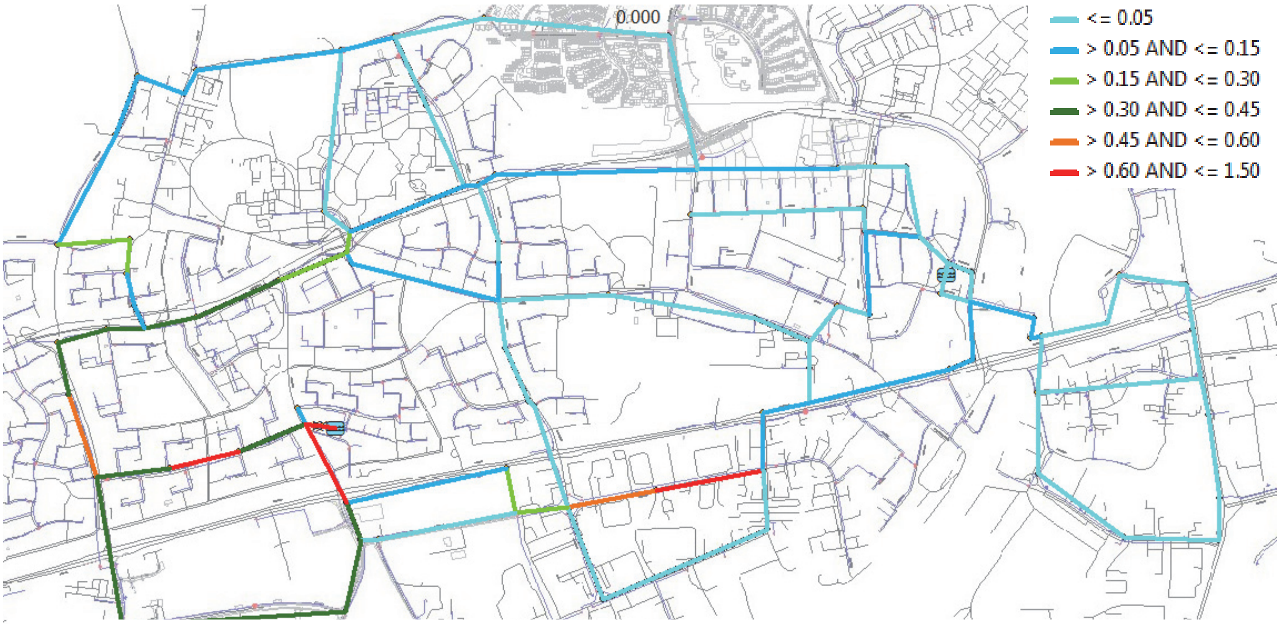


Figure 45 Results velocities for maximum scenario, Pilegaardsvej waterworks in operation

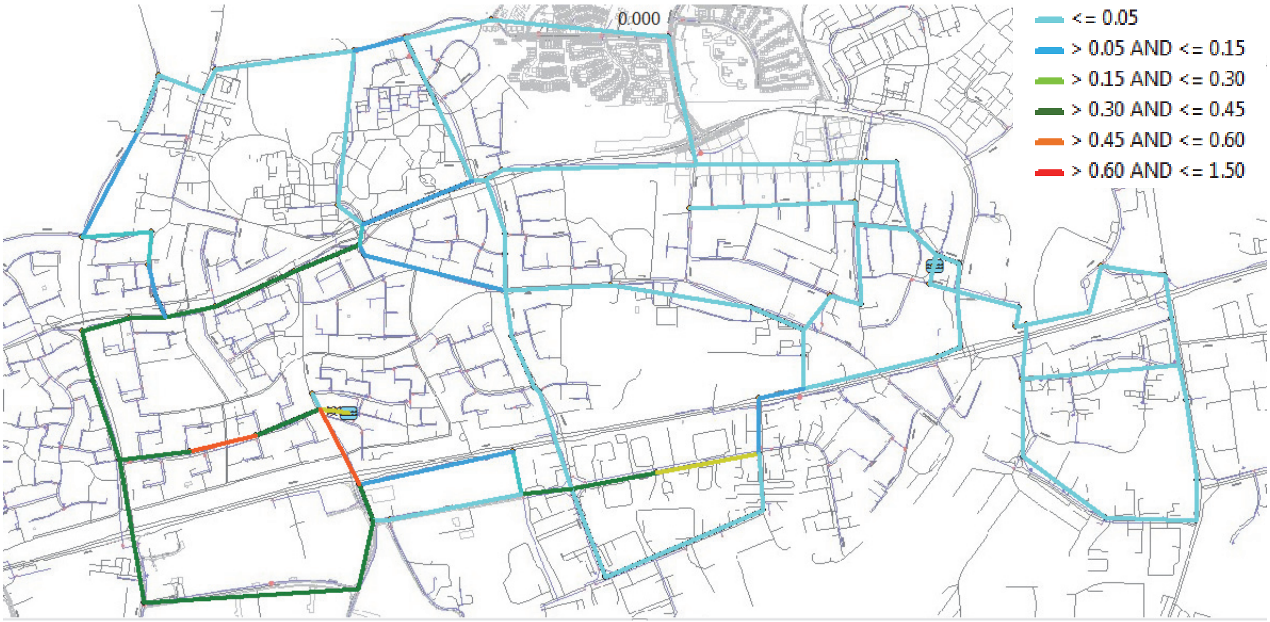


Figure 46 Results velocities for average scenario, Pilegaardsvej waterworks in operation

Annex 4

Calculation flow velocity

According to the data from the waterworks the diameters of the new raw water pipes will be either two separated pipes of 125 mm or one pipe of 250 mm. The pump capacity of the well pumps is 35m³/h. With this data the flow velocity is calculated. The flow velocity in the 125mm pipes will be 1,0 m/s and in the 250 mm pipe.

Pipe flow: 35 m³/h = 0 00972 m³/s

Material: PE-125 PN4
Outer diameter: 125 mm
Inner diameter: 115.4 mm
Inner surface: $0{,}25 * \pi * 0{,}1154^2 \approx 0{,}01046\, m^2$

Velocity: $\frac{0{,}00972}{0{,}01046} \approx 0{,}93\, ms^{-1}$

Material: PE-250 PN4
Outer diameter: 250 mm
Inner diameter: 230.7 mm
Inner surface: $0{,}25 * \pi * 0{,}2307^2 = 0{,}0418\, m^2$

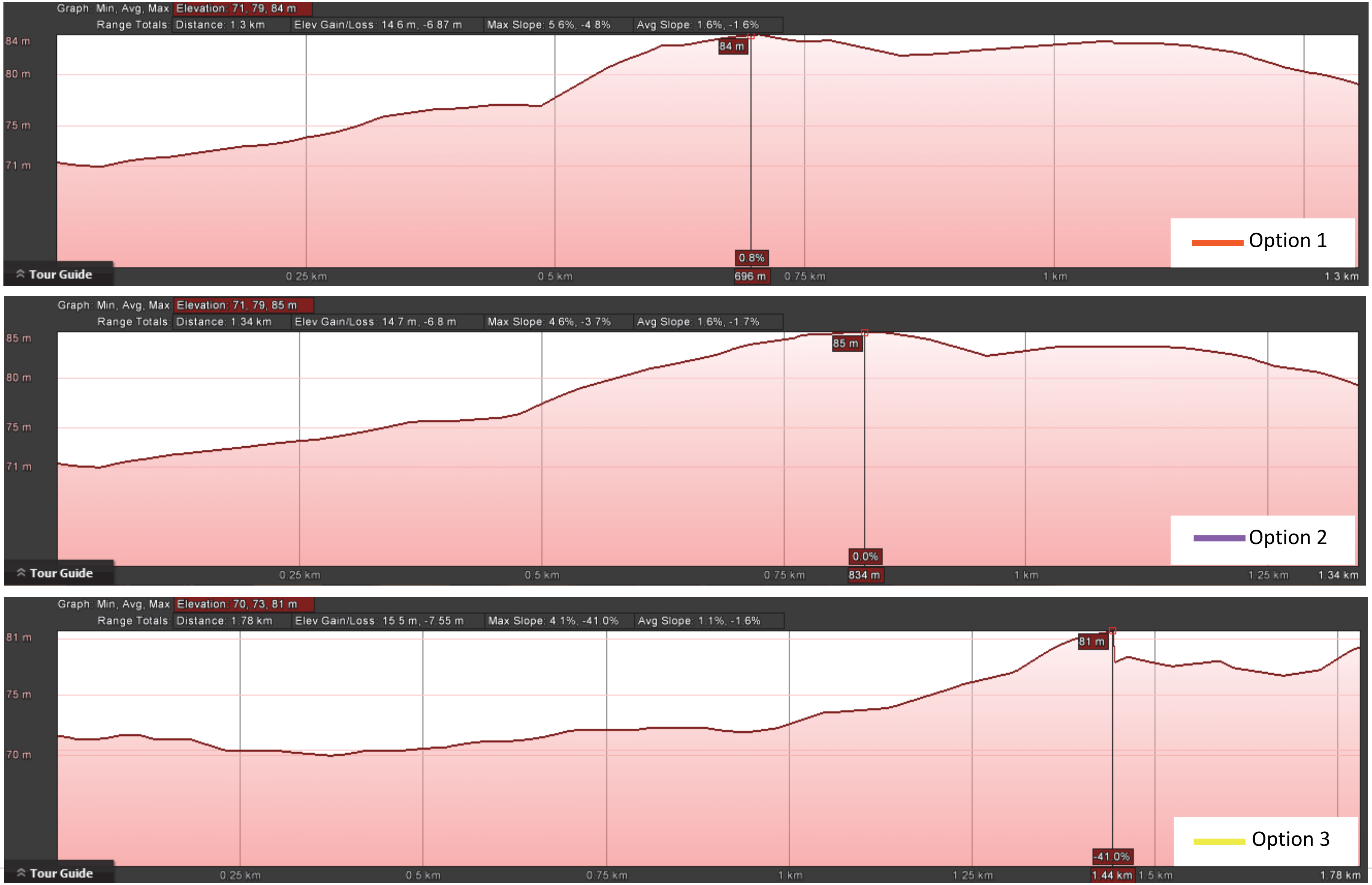
Velocity: $\frac{0{,}00972}{0{,}0418} \approx 0{,}23\, ms^{-1}$

Annex 5

Figure 47 Overview map infrastructure by Hasselager-Kolt waterworks, 15-07-2011

Colour	Elements
Blue	**Water supply network**
Grey	**Road infrastructure**
Red	**Houses and utility buildings**
Green	**Green areas**

Annex 6


Graph: Min, Avg, Max Elevation: 71, 79, 84 m
Range Totals: Distance: 1.3 km Elev Gain/Loss: 14.6 m, -6.87 m Max Slope: 5.6%, -4.8% Avg Slope: 1.6%, -1.6%
84 m
80 m
75 m
71 m
0.8%
696 m
0.25 km
0.5 km
0.75 km
1 km
1.3 km
Option 1
Tour Guide
Graph: Min, Avg, Max Elevation: 71, 79, 85 m
Range Totals: Distance: 1.34 km Elev Gain/Loss: 14.7 m, -6.8 m Max Slope: 4.6%, -3.7% Avg Slope: 1.6%, -1.7%
85 m
80 m
75 m
71 m
0.0%
834 m
0.25 km
0.5 km
0.75 km
1 km
1.25 km
1.34 km
Option 2
Tour Guide
Graph: Min, Avg, Max Elevation: 70, 73, 81 m
Range Totals: Distance: 1.78 km Elev Gain/Loss: 15.5 m, -7.55 m Max Slope: 4.1%, -41.0% Avg Slope: 1.1%, -1.6%
81 m
75 m
70 m
-41.0%
1.44 km
0.25 km
0.5 km
0.75 km
1 km
1.25 km
1.5 km
1.78 km
Option 3
Tour Guide

Annex 7

Customer:	*Ewoud*	Number Of Wells :	2
Wellfield Name:	Koltskovvej	Calculation Pump Time:	1 hours
Model Description:	Wellfield model 1	Date/Time:	25-5-2013 / 19:16

Pump Expenses

Pump/Well	Flow [m³/h]	Pump Type	Pump Frequency [Hz]	Pump Efficiency [%]	Power Consumption [kW]	Specific Power Consumption [kWh/m³]
W2	39,60	SP 46-8	50	60,95	13,59	0,34
W1	40,04	SP 46-8	50	61,06	13,63	0,34
Total	79,64				27,22	0,34

Pumps/Wells

Pump/Well	Flow [m³/h]	Drawdown [m]	Drawdown Level [m]	Pump Level [m]	Pump Status	Plant Discharge Pressure [m]	Total Pressure Loss [m]	Pump Discharge Pressure [m]
W2	39,60	5,22	16,98	13,00	On	61,02	15,79	76,80
W1	40,04	5,27	16,82	13,00	On	61,18	15,10	76,27

Nodes

Node	Terrain Level [m]	Pressure Head [m]	Pressure Level [m]	Flow [m³/h]
W2	72,20	21,59	93,79	39,60
RWS1	72,20	21,41	93,61	
1	84,00	1,03	85,03	
W1	72,81	20,29	93,10	40,04
RWS3	72,81	20,10	92,91	
2	84,00	1,18	85,18	
Kolt Skovvej	80,00	-2,00	78,00	

Pipes

Pipe	From Node	To Node	Flow [m³/h]	Water Velocity [m/s]	Gradient [‰]	Friction Loss [m]	Transition Loss [m]	Total Pressure Loss [m]
W2 - RWS1	W2	RWS1	39,60	0,62	3,07	0,16	0,02	0,18
RWS1 - 1	RWS1	1	39,60	1,06	12,33	7,84	0,74	8,58
1 - Kolt Skovvej	1	Kolt Skovvej	39,60	1,06	11,64	6,80	0,23	7,03
W1 - RWS3	W1	RWS3	40,04	0,63	3,42	0,17	0,02	0,19
RWS3 - 2	RWS3	2	40,04	1,07	12,75	6,97	0,76	7,73
2 - Kolt Skovvej	2	Kolt Skovvej	40,04	1,07	11,89	6,95	0,23	7,18

Annex 8

Customer:	*Ewoud*	Number Of Wells :	2
Wellfield Name:	Koltskovvej	Calculation Pump Time:	1 hours
Model Description:	Copy of Wellfield model 2	Date/Time:	25-5-2013 / 16:56

Pump Expenses

Pump/Well	Flow [m³/h]	Pump Type	Pump Frequency [Hz]	Pump Efficiency [%]	Power Consumption [kW]	Specific Power Consumption [kWh/m³]
W2	40,82	SP 46-7	50	60,46	12,00	0,29
W1	41,64	SP 46-7	50	60,60	12,06	0,29
Total	82,46				24,06	0,29

Pumps/Wells

Pump/Well	Flow [m³/h]	Drawdown [m]	Drawdown Level [m]	Pump Level [m]	Pump Status	Plant Discharge Pressure [m]	Total Pressure Loss [m]	Pump Discharge Pressure [m]
W2	40,82	5,38	16,82	13,00	On	61,18	4,09	65,26
W1	41,64	5,48	16,61	13,00	On	61,39	3,01	64,41

Nodes

Node	Terrain Level [m]	Pressure Head [m]	Pressure Level [m]	Flow [m³/h]
W2	72,20	9,89	82,09	40,82
RWS1	72,20	9,68	81,88	
1	72,00	7,83	79,83	
2	84,00	-5,09	78,91	
W1	72,81	8,20	81,01	41,64
RWS3	72,81	8,00	80,81	
Kolt Skovvej	80,00	-2,00	78,00	

Pipes

Pipe	From Node	To Node	Flow [m³/h]	Water Velocity [m/s]	Gradient [‰]	Friction Loss [m]	Transition Loss [m]	Total Pressure Loss [m]
W2 - RWS1	W2	RWS1	40,82	0,64	3,53	0,18	0,02	0,20
RWS1 - 1	RWS1	1	40,82	1,17	22,80	1,28	0,77	2,05
1 - 2	1	2	82,47	0,55	1,51	0,85	0,06	0,92
2 - Kolt Skovvej	2	Kolt Skovvej	82,47	0,55	1,51	0,85	0,06	0,91
W1 - RWS3	W1	RWS3	41,64	0,65	3,68	0,18	0,02	0,21
RWS3 - 1	RWS3	1	41,64	1,20	488,39	0,03	0,95	0,98

7 Well fields additional data

Graph is read over one log cycle because of formula: $T = \frac{0,183 \cdot Q}{\Delta s}$

$\Delta s = 0,12$m

$Q_{average} = 31,03\ m^3/h \rightarrow 0,0086\ m^3/s$

$T = 0,0131\ m^2/s$

Time (h)	Pump yield (m3/h)	Draw down (m)
0,01	32,00	3,45
24	30,75	3,55
72	30,80	3,65
48	30,60	3,75
96	31,00	3,85
120	31,00	3,95

Table 35 Data estimated from the pump test

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