TEKNICAL GUIDANCE

Monitoring Wells
Groundwater Monitoring
Version 2.1

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The National Geological Survey of Denmark and Greenland
Ministry of Climate, Energy and Utilities

G E U S

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Content:

1 Introduction

Purpose

The purpose of this technical guideline (TA) is to provide clear instructions for the establishment, maintenance, operation, and possible cancellation of boreholes used in the NOVANA groundwater monitoring in Denmark. The borehole intakes (screen or part of a screen) must form the basis for knowledge about the chemical and quantitative state and trends in the groundwater. In addition, the boreholes contribute with significant metadata to the monitoring in the form of information about the geological layer met in the borehole.

Principle

The fully equipped monitoring boreholes must be able to provide representative data on ground water quality and hydraulic pressure/ water table in the aquifers in which the screens are set. The screen interval where water flows into the borehole is referred to as an intake. This concept is linked to the data structure in Jupiter and is defined in Stockmarr et al. 2001 link (see Figure 1.3 in that report).

The monitoring objectives has implications on the requirements for the technical design of the boreholes. First of all, that the borehole intake is protected against unwanted factors that may affect water sampling and water level data. Optimizing the performance and operation of the intakes will depend on a combination of technical choices, the borehole layout, and the hydraulic properties of the aquifer layers adjacent to each individual intake.

2 Method

Establishment, maintenance, and operation of monitoring wells involve several steps:

- Selection of approximate drilling location according to prioritized monitoring needs.
- Specific (written) agreement for site in the field, established in cooperation with the landowner.
- Selection of drilling method and agreement with the drilling company and supervision tasks (potentially involving a consultant), regarding, among other things, geological sequence description in accordance with GeoVejledning 1 (Ditlefsen et al. 2008).
- Drilling operation, completion with filters, casing, gravel packing, and sealing.
- Storage of all relevant information associated with the drilling operation in the GEUS Jupiter database.
- Finalisation with borehole protection, pumps, and adapter construction.
- Post-drilling tasks: Once drilling is complete, tasks not described in detail in this technical instruction must be addressed, specifically regarding the legal registration of easements (tinglysning) and storage of the collected data.

- Entry into the station network: When it is decided that a borehole intake is to be included in the monitoring network, a legal declaration approved by the landowner is registered as an easement to ensure the future establishment of time series. Registration must ensure access to the borehole and protection of the immediate area without an expiration date. This process is outside the scope of this Technical Guidance.
- During the operation of the borehole, it must be continuously checked and documented that the collected data are valid and that the borehole does not cause contamination (see, e.g., section 2.4).
- General legislation and requirements for boreholes can be found in the overview via: Brønde og boringer - Miljøstyrelsen.

2.1 Time, place, and period

When the location of the borehole is to be determined, a specific inspection of the conditions in the field must be conducted. This applies in particular to:

- Access conditions, including possibilities for staying and working during sampling.
- risk of local flooding in depressions and ditches.
- risk of traffic collision with the borehole installation ore the samplers.

Monitoring boreholes are best placed by a fixed access road, to avoid having to drive to the borehole across fields etc. Otherwise, soft terrain after prolonged rain can cause field damage requiring compensation and unpredictable time consumption after getting stuck and towing.

Establishment, supervision, surveying, and sampling of boreholes can take place at any time of the year, except during periods of extreme frost and heavy snow.

2.2 Drilling technical requirements and methods

Choice of drilling method

The aim must always be to have the least possible impact on the horizontal and vertical surroundings of the well, which is why dry drilling techniques should be preferred as first choice (auger and bucket drilling, lined or hollow auger, respectively. However, these methods will often require the use of a smaller amount of water, which must be of drinking water quality.

It may be necessary to choose a reverse flushing drilling (air lift/suction drilling), where the use of actual drilling fluid/mud must be accepted. This is the case if there is a need for an intake at a greater depth. The same applies in solid rocks such as limestone and on Bornholm. There must always be a specific assessment that justifies the use of drilling methods that involve drilling fluid/mud, including weighing up costs, local geological conditions, and the dimensions of the well.

Direct flushing drilling, where there is a significant overpressure on the drilling fluid/mud, may only be used under very special circumstances (e.g. strongly artesian conditions), where otherwise there is no possible and the risk of permanent impact is minimal.

Material requirements
The boreholes must be established with the aim of obtaining representative samples and measurements of the groundwater in the filtered layer in front of the borehole intake.
Drilling methods must be selected that as far as possible do not introduce foreign substances into the area in and around the borehole, including in particular drilling fluid, carrier substances or stabilizers that can be deposited in the borehole or washed out.

Materials used in the development of the borehole, casing, filter and seals, must be fully documented and to the greatest extent possible be inert, with special focus on the parts that come close to the borehole intake. The introduction of any substance that may increase the risk of contamination must be discussed with the national Topic Centre for Groundwater and Wells.

Drilling mud and drilling fluid
The addition of drilling fluid/mud, which can change the redox conditions and ion exchange conditions in and around the borehole, must be avoided as much as possible. In cases where drilling fluid/mud are indispensable, all additives used in the drilling fluid/mud must be documented.

Where the addition of drilling fluid is necessary, the water must be of drinking water quality.

During the drilling process, is it in any case essential that careful records are kept of the consumption and viscosity of the drilling fluid/mud in relation to the quantities of sediments drilled up from the borehole and the expected volume of the borehole itself. Greater losses of drilling fluid/mud to the formation or dilution of drilling fluid/mud must be prevented in view of possible cavities or highly permeable layers. The amount of drilling fluid/mud used must be limited, which must be documented in the drilling report, so that the impact, especially nearby the borehole intake, can be assessed. The conditions surrounding the use of the drilling fluid/mud (quality and quantity) are an important part of the supervision of the drilling work.

Due to the risk of contamination, it must be checked whether there are parameters that are, or can be, affected by the drilling fluid/mud, for example sulphate, nitrate, sodium, potassium, calcium, magnesium, and chloride in the first years after the establishment of the well. After the first years of sampling, it must be assessed whether these data should be rejected.

At the start of the drilling work
A DGU. no. must be requested from the drilling archive at GEUS immediately after drilling work is initiated. The DGU no. must be used to uniquely

identify all notes about the work on the well. A prerequisite for obtaining a DGU no. is generally that the drilling has begun and that there are approximate coordinates on the well. In this way, it is ensured that all information collected during the drilling work is linked to a correct well.

Completing the borehole
In principle, a filter pipe with a small diameter and short filter length provides the best sample in relation to the monitoring needs in groundwater monitoring, where the focus is on time series. Therefore, the first choice is a short intake of 1 m, and a liner must be established that enables the use of 3' submersible pumps.

The filter should be installed as far as possible in aquifers where sufficient performance can be expected. The goal for the fully established intake is that during pre-pumping and sampling there is a performance of at least 2 litres per minute, with a lowering that does not reach the upper edge of the intake.

Figure 1. Well completion. In this case, there are two casing strings in the same borehole.

To ensure optimal completion around the intake and casing with filter and sealing materials, the pipes must be positioned at a safe distance from the borehole walls. It must be ensured that the sealing materials can be placed so they completely encircle the casing and seal any penetrated, low-permeable layers. Generally, only one filter and casing are placed in a single borehole. However, if special conditions necessitate it, two pipes may be installed in the same borehole, provided that pipe centralizers ensure the correct installation of filter and sealing materials. Exceptionally, multiple intakes may be established if the borehole diameter permits and extreme caution is taken regarding potential leaks.

Casings and filters must possess high material density and strength to provide maximum protection against deformation, fractures, or leaks. Furthermore, they must not contain substances that can be released over a very long period. This means, for example, that filters must not be made of metals such as stainless steel, as acidic water can lead to the leaching of trace elements.

Similarly, sealing materials must be inert, mineral-based, and natural to ensure minimal impact on the natural groundwater.

Well Development

The drilling contractor's establishment of a new intake is only complete once the well has undergone thorough and sufficiently prolonged well development (≠ pre-pumping). Development must be performed immediately after the filter is set, but only after the installed clay seals/plugs have fully hydrated, to avoid pulling bentonite from the clay plugs into the filter.

Figure 2 shows a conceptual diagram of well hydrology during pumping. It illustrates that the drawdown inside the well is caused by water resistance in the form of formation loss and well loss. The purpose of well development is to minimize well loss.

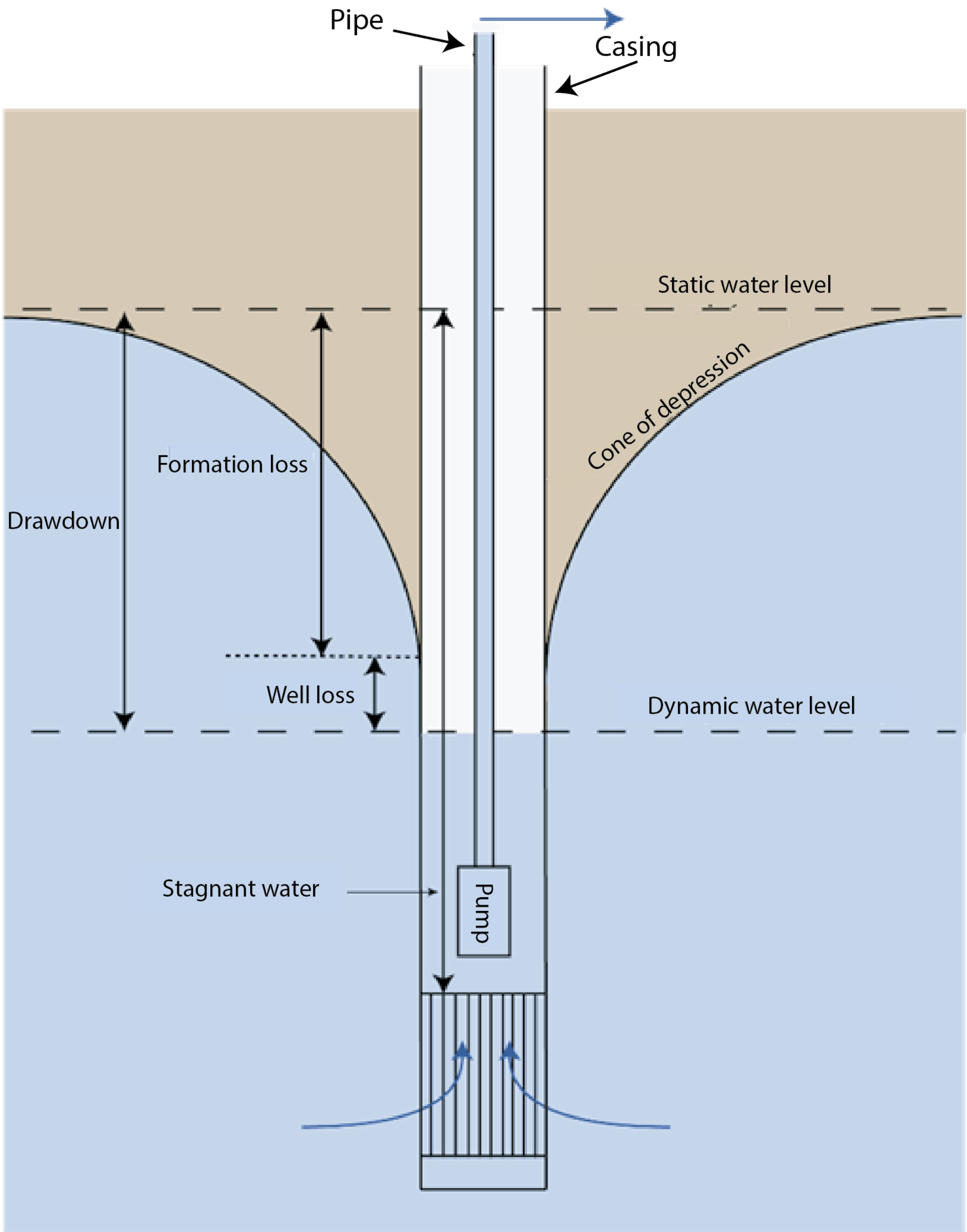

Figure 2. Conceptual diagram of well design with a pump positioned immediately above the intake, showing the cone of depression, well loss, and formation loss.

During well development, the well's performance is optimized by removing fine-grained material around the intake and, in particular, minimizing geochemical impacts on water samples resulting from the drilling process. Well development should be conducted as step-drawdown pumping, typically in three stages, where the yield is doubled for each stage, reaching maximum capacity in the final stage. The duration of the final stage must be at least 4 hours, and the pumped water must be sediment-free after each stage. The screen must not be dewatered during the development process; see technical instructions for groundwater sampling (Thorling, 2012).

Inclusion of other wells for monitoring
In addition to establishing new monitoring wells, existing wells drilled for other purposes may be included in the monitoring station network. First choice must be wells that meet the requirements of this Technical Instruction (TI). Wells that do not meet the requirements for new monitoring wells in this TI may, under extraordinary circumstances, be used for specific selected monitoring needs.

The decision on the extent to which an existing well can be used for monitoring depends on a specific assessment of, for example, the lack of possibility for a landowner agreement to establish a standard monitoring well, as well as the hydrological and chemical conditions of the well.

A well with a long intake (screen), for example, may be suitable for water level soundings. If an existing well with screen lengths > 2-3 m, or with screens crossing low-permeability layers, is used for water level monitoring, there must be a thorough understanding of the vertical pressure conditions. For instance, a flow log can document whether an intake covers layers with differing pressure heads.

The assessment of which chemical parameters are expected to have results affected by leaching from the well installation, requires knowledge of the materials used during the construction and completion of the well to be considered included in the monitoring program.

In exceptional cases, for example, while clarifying the suitability of a long screen for monitoring, packer testing or zone-specific sampling down through the intake may be performed. This can reveal whether there are significant variations in water quality throughout the intake.

It is not possible to provide an exhaustive list of the specific conditions that limit an existing well's suitability for NOVANA (the national groundwater monitoring program); therefore, these must always be discussed with the Topic Centre for Groundwater and Well at GEUS.

Surveying and securing the ground level elevation during drilling
Before drilling commences, a well-defined 'ground level' must be established, which the driller shall use as a reference for depths throughout the drilling process. After the completion of drilling, including well completion and screen installation, this 'ground level' must be surveyed and recorded in relation to the well's permanent reference point (benchmark), see Figure 3.

Lithology, events during drilling, any borehole logs, screen placement, and subsurface completion must all be measured and related via this 'ground level' to the well's permanent benchmark.

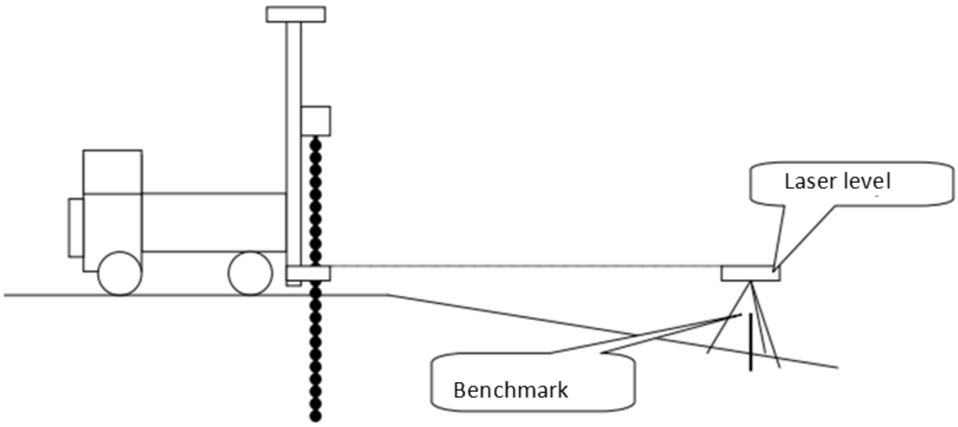

Figure 3. Conceptual diagram for the establishment of a temporary ground reference point during drilling operations. https://www.geus.dk/media/7300/vejledning-dybderegistrering.pdf

Accuracy and Precision
During drilling, the contractor is responsible for correct registration of depths to formation boundaries, intakes, clay seals, etc. while the supervisor ensures the ground reference point remains stable and samples and logs are correctly recorded. If discrepancies are discovered between the driller's depth descriptions and other measurements relative to 'ground level' during drilling, the supervisor is responsible for ensuring any necessary consequential corrections in the overall documentation, including the driller's well report.

All other above-ground measurements of the well must be performed relative to the well's 'benchmark' with a maximum uncertainty of 1 cm. The recorded measurements must be described with sketches and documented with photographs as a crucial part of the well's 'Localization.' This ensures that the collected water table measurements (soundings) possess a data quality suitable for determining groundwater potentiometric conditions, both geographically and between aquifers at the same site.

Drill Samples, Submission, and Storage
During drilling, soil samples must be collected for every meter, and all formation boundaries must be recorded, even if multiple boundaries occur within a single meter.

Immediately after drilling, a sub-sample of all drill samples must be taken and stored in airtight containers, such as plastic bags. The remaining sample material is to be placed on a draining surface and covered with rainproof material. The collected lithological sequence must be photographed continuously throughout the drilling process.

If sediment-chemical analyses or other sample descriptions are required beyond the basic geological sample description at the GEUS core laboratory, the specific project description for the well must specify how the samples are to be collected, handled, and subsequently analysed.

All samples must be delivered to GEUS accompanied by a well report detailing the sample ID (at minimum: DGU no., depth, date and time, and sampler ID), as well as the field registration results, to allow for electronic transfer to the Jupiter database. These procedures are available on the GEUS website link.

Figure 4. Sediment samples from the drilling process laid out so the lithological sequence can be easily followed, ensuring accurate geological description on-site.

Discarding Samples
If there is any doubt regarding the depth from which a sample originates, it must be discarded. The same applies if material from multiple depths has been mixed. It must be noted in the supervision report which samples were discarded and the reason why.

2.3 Surveying and Final Localization of Wells

The purpose of well localization is to obtain an exact, unambiguous description of the well's location in the terrain, a description of its technical design, and a description of the practical access to the well. This information is reported to Jupiter at GEUS.

All surveying data must be linked to the well's permanent benchmark. The benchmark must be placed on the best fixed structure to ensure the elevation does not change over time. This is most easily achieved by placing the mark on the well's innermost (deepest) casing. The well's permanent benchmark must be surveyed with an absolute uncertainty of less than 10 cm according to the Danish coordinate system(DVR90).
A link to the localization form is available on the GEUS website here, along with a guide.

A link to general forms and guides at GEUS for obtaining DGU numbers, abandonment forms, etc., can be found in the bibliography.

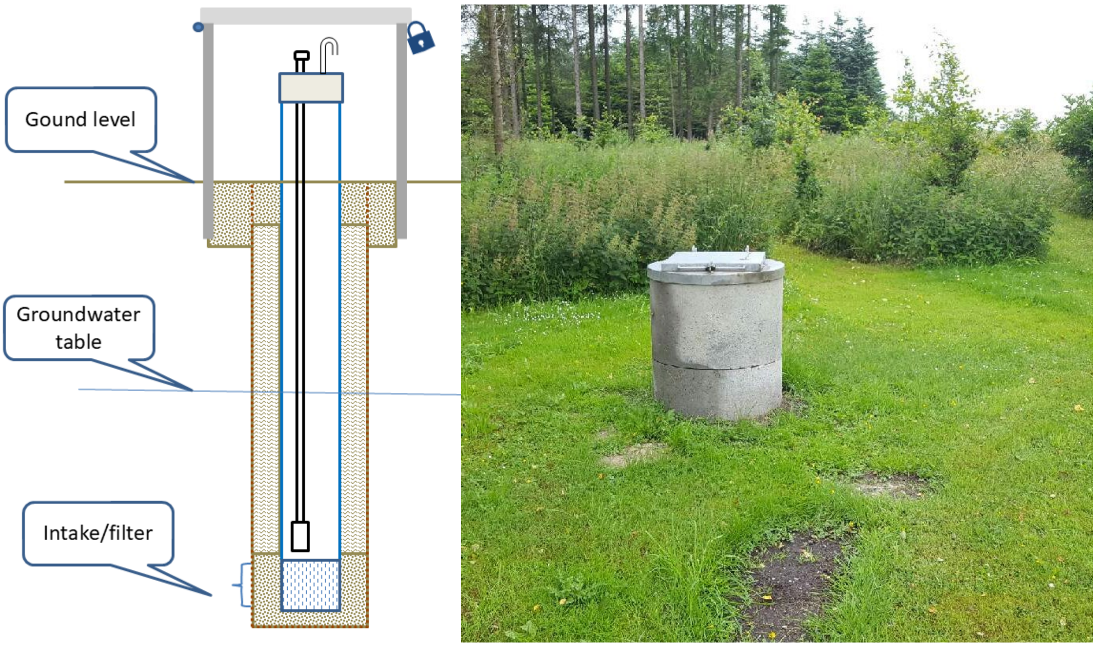

Figure 5. Completed well with locked protection. Note that a secure but lightweight cover is installed. To the left, a conceptual diagram.

Labelling of Well Intakes
All intakes must be labelled with a unique identity (DGU and intake number), and a well sign with a barcode, printed from GEUS.dk, must be mounted: https://data.geus.dk/boringsskilt.

The ID, consisting of the DGU and intake number, must be used during all site visits and must be traceable in notes and records from supervision and monitoring. For further information, please refer to the Data Technical Guidance’s for Groundwater Chemistry and Water Level Measurements (DG-01 & DG-02).

2.4 Equipping and completion of monitoring wells

When a borehole is included in the station network, it must—in addition to general legislative requirements for boreholes—meet a number of specific requirements for groundwater monitoring. These requirements depend on whether water samples are to be collected or if the borehole is used solely for water level monitoring (sounding). The completion must ensure that representative samples and measurements can be obtained from the intake, while ensuring that operations are efficient and can be integrated into the landowner's land use with minimal nuisance.

A lockable well protector is installed around the borehole as physical protection against potential collisions or other forceful activities, see Figure 5.

Inside the well protector, a tight seal is fitted on top of the individual liner/casing. This seal can simultaneously integrate an adapter for the pump outlet and a sounding port, see Figure 6.

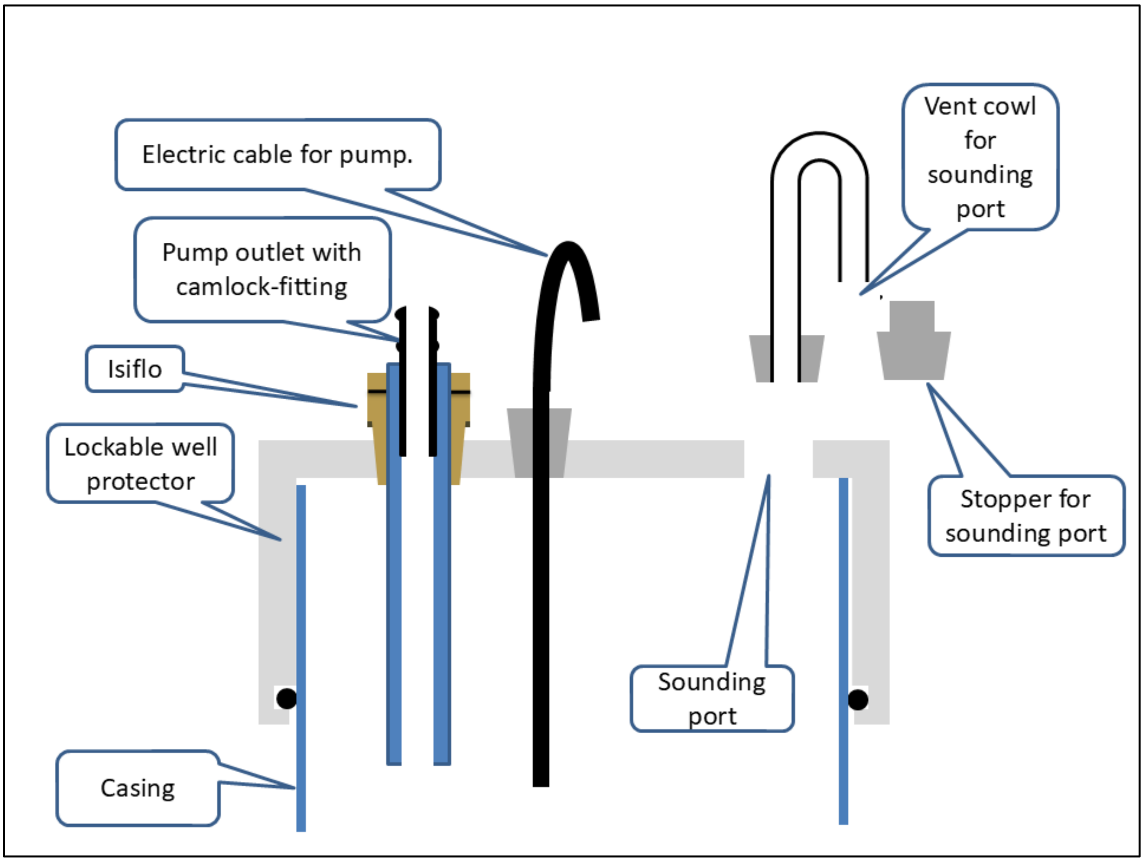

Figure 6. Example of top seal on the well liner/casing with adapter.

Safe, efficient operation of groundwater monitoring requires that the fixed protection of pipes and the well seal interact constructively with various types of related equipment, such as the following:

- The well protector must be capable of being locked and opened without physical strain.
- The protector must shield the borehole, e.g., in the event of a collision.
- The well protector can be a steel pipe, in the form of a so-called 'Aarhus completion' (Århus-afslutning), or a concrete ring with a lightweight, high-strength cover, see Figure 5.
- Heavy concrete manhole covers must not be used.
- The casing top seal must be airtight and protect against aerosols.
- As a general rule, pumps should be permanently installed to mitigate the risk of cross contamination from mobile pumps; additionally, fewer heavy lifts improve the working environment and save time.
- The pump is connected through the casing seal via tight, shielded couplings to an adapter used for purging and sampling.

Borehole installations and connected equipment must, as far as possible, be constructed from inert materials. Certain analytical parameters (e.g., PFAS) are particularly sensitive to contamination. Therefore, reliable knowledge of potential contamination sources is always required.

Pumps
First choice is permanently installed pumps to be used in all intakes.

Pump dimensioning depends on the borehole design, casing diameter, filter lengths, the depth to the static water level (and thus the expected head), and the well yield. Information from the well driller's final development pumping is crucial for selecting the pump for an intake, as it reflects the performance of the specific intake.

A pump should be selected by balancing the well yield and the volume of water to be removed for sufficient purging against time consumption, drawdown, and the amount of suspended solids in the intake. This is described in further detail in the technical instructions for sampling (Thorling, 2012). Whenever possible, the pump is placed immediately above the intake to ensure that the drawdown of the water level during sampling does not fall below the top of the intake. The installation must be designed so that the pump can be easily retrieved and maintained.

Pumps with variable flow rates are advantageous, as they allow for the reduction of heat impact and flow rate after purging and prior to the actual sampling.

Not all pumps are equally suitable for all types of parameters. For instance, a suction pump may be used for 'non-volatile substances,' but it is unsuitable for a large number of parameters as it alters the dissolved gas content of the sample, thereby changing pH and oxygen levels. Furthermore, there is a risk of losing volatile compounds. A suction pump may potentially be used for initial purging or in combination with another pump used for the actual sampling.

As a general rule, the following pump types should be used for sampling:
- Submersible pump, with flow rate control
- Direct air-driven (N_2) 'Montejus pump'
- Indirect air-driven 'bladder pump' (e.g., AP1)
- Various other small 12 V battery-powered submersible pumps (e.g., Whale pumps)
- Peristaltic (suction) pumps
- Where necessary, other motorized or hand-operated suction pumps may be used.

The pumping equipment should, as far as possible, be configured to maintain a slight positive pressure in the pump and hose connections during purging and sampling to prevent air from entering the hoses through leaks.

Figure 7. Preparation for installation of a larger electric submersible pump and hoses. The equipment is pre-assembled in the workshop, where hose lengths are adjusted to the technical completion of the borehole.

Mobile equipment, adapters, hoses, and hose reels

When selecting hoses, it is crucial to use materials that do not leach substances into the samples or adsorb compounds. There is extensive experience-based literature in this field (Sørensen, 2009 and AVJ, 2003). The risk of leaching depends partly on the choice of material and partly on the water's flow rate through the hose. In low-yield boreholes, there is a need for more diffusion-tight hoses to prevent the exchange of gases (e.g., O_2, CO_2, H_2S) with the surroundings, which could alter the chemical balance of the water before the sample is collected.

As a general rule, VA-approved (Water and Waste Approval) hoses made of polyethylene (PE) or uncoloured PE must be used.

Hose reels on wheels must be used in conjunction with mobile pumps to prevent hoses from touching the ground during sampling and to ensure practical and efficient task execution. If soil does get on the exterior of the hoses, they must be cleaned and rinsed with drinking-quality water.

Hoses must not be stored with volatile substances such as gasoline, etc., as experience shows that hoses can adsorb fuel vapours and later release them into water samples—for example, if a fuel canister is stored alongside hoses in a field vehicle.

Cleaning the pump

If a mobile pump is used, it must be thoroughly cleaned before being moved and submerged into another intake. The pump must be flushed with groundwater in which no organic substances have been detected at concentrations exceeding the drinking water limit. The pump must not have been previously used in a borehole used for monitoring or mapping contaminated soil or waste sites. In very low-yield boreholes (with yields below approx. 2 l/min), mobile pumps should generally be avoided entirely. However, for pilot studies or short-term monitoring programs, mobile pumps may be the most practical option.

After installing the mobile pump, it must be flushed before sampling using one of the following methods, depending on the pump and the borehole yield:

- The pump runs for at least 30 minutes (yields > 2 l/min).
- At least 100 litres are pumped through the hoses.
- In very low-yield boreholes (yields below 2 l/min), the hoses are flushed with at least 10 times the total hose volume.

Method to calculate stagnant water volume in hoses:

$$\boldsymbol{V = L \times \pi \times (d/2)^2}$$

where:
V: volume [m^3]
L: length of hose [m]
d: internal diameter of hose [m]
V [litres] = V [m^3] \times 1000

Example of calculating water volume in hoses:
L = 50 m hose, d = 4 cm internal diameter: V ≈ 63 litres.
L = 100 m hose, d = 2 cm internal diameter: V ≈ 31 litres.
L = 10 m hose, d = 1 cm internal diameter: V ≈ 0.8 litres.

Note: This flushing procedure protects against cross-contamination from highly soluble substances at concentrations below drinking water criteria, but it does not protect against the risk of cross-contamination if the pump and hoses have been used in a heavily contaminated borehole.

Power sources for pumps
Wherever possible, battery and inverter-powered solutions should be used for electric pumps. A motor generator may be used, though it requires additional measures to minimize contamination risk. The choice of power source depends on energy requirements, as high heads or high flow rates require high power output. Battery and frequency converter technologies are now so advanced that they are expected to replace gasoline/diesel generators in the future.
When a motor generator is necessary, the field work environment must be considered, as this may involve many heavy lifts. Lifting can be reduced by using a lift/hoist in the sampling vehicle.

Sampling vehicles with the engine and generator running must be positioned so that the wind carries exhaust away from the borehole during sampling, as exhaust gases can contaminate samples with organic micro-pollutants, among other things.

Several pumps rely on propellants such as compressed air from a compressor or a nitrogen pressurised cylinder. It is critical that any propellant gas coming into direct contact with the water during sampling is of high purity, e.g., at least Nitrogen 4.6 (< 5 ppm O_2, purity > 99.996%).

Field vehicle (Sampling vehicle)
As groundwater monitoring is equipment-intensive, efficient organization requires that field vehicles are equipped to transport propellants, hoses, filtration equipment, and field analysis gear. Collected samples must be kept cold, and the field vehicle must contain either a refrigerator or facilities for the secure transport of coolers and ice packs. A selection of spare parts for pumps and boreholes, pipes, sand, and bentonite must be carried to allow for on-site repair of minor damage or equipment failure. The vehicle layout must ensure that the risk of contaminating sampling equipment and collected samples is minimized.

For instance, fuel for generators must be kept well-separated from hoses and sample bottles. There must also be facilities for the ongoing cleaning of hoses, filtration equipment, and measuring tools.
A lightweight folding table must be part of the vehicle's equipment to ensure optimal setup during sampling, allowing sample bottles to be placed on a table rather than in mud, which risks contaminating the sample during handling in the field and subsequently in the laboratory. This is particularly relevant when many sub-samples are to be collected.

The specific layout of field vehicles is otherwise outside the scope of this technical manual.

Safety
A safe workplace setup goes hand-in-hand with efficient work organization and must be integrated into the overall planning of field work. Heavy equipment (> 20–30 kg), high-voltage electricity in damp environments, pressure cylinders, and high-pressure pumping systems are frequently used. Boreholes located inside deep wells (manholes) should be modified whenever possible so that the sampler does not have to climb down into them.

In all cases, it is necessary to address occupational safety to avoid accidents. Guidelines from the Danish Working Environment Authority (Arbejdstilsynet) should be used when establishing workplace instructions. A review of safety regulations is outside the scope of this technical manual; see AVJ, 2003, for further information.

2.5 Repairs and modifications to boreholes
Situations may arise requiring repairs or changes to the technical completion of boreholes. This may result in changes to the borehole's reference

point (datum), measuring points, intake top and bottom, pipe diameters, etc.

All such changes must be reported to the Well Archive at GEUS, and a new location form (lokaliseringsskema) will often be required.

If an intake is modified such that the depth to the top or bottom of the intake changes, the intake must be given a "closing date" in the Jupiter database. Going forward, the intake must have a new Intake ID and Intake Number in Jupiter. Additionally, a new GRUMO number must be created through the Well Archive. For practical reasons, the lowest available intake number not previously used for the borehole in question is chosen.

2.6 Cancellation of boreholes

If a borehole is no longer to be used—typically because it is damaged or can no longer meet monitoring needs—it must be cancellated (decommissioned). During cancellation, the borehole is completely removed from the surface and upper soil layers so that future land use is no longer disturbed. This means that any easements or land registrations must be discharged.

To ensure compliance with the Executive Order on the Execution and cancellation of Boreholes on Land, an initial assessment must be made to determine if the casing is correctly sealed. Over-drilling and sealing the entire old borehole and casing may be necessary if the alternative leaves leaks.

If a borehole is correctly sealed around the liner, cancellation can be carried out just by sealing the inside of the casing with grout (a sealant typically consisting of a mixture of bentonite and cement), pellets, or other types of seals that can be reliably placed without leaving underground voids. The filling process must be monitored from the bottom up, and it must be continuously verified that the quantity of sealant added corresponds to the filled volume. When using grout, it must be pumped into the borehole from the bottom via a hose (tremie pipe method) to ensure the mixture does not dilute or undergo sedimentation through the water column.

Finally, the casing must be cut at least one meter below ground level, and the cancellation must be reported in the correct form by the well driller to the Well Archive at GEUS.

2.7 Ongoing Inspection of Boreholes

Every visit to a borehole must, at a minimum, include an inspection to follow up on notes from previous visits. Results are recorded on a standard pumping log or a specific inspection form.

An inspection must include the following activities:

- Examine whether the borehole appears undisturbed and has not been damaged by collisions or other destructive activities. Observations must be noted in the pumping log.

- Mow grass and remove brush around the borehole to the extent necessary for future sampling. The extent of vegetation clearing, including any outstanding needs, is noted in the pumping log.
- Note any signs of pesticide spraying in the immediate vicinity of or on the borehole.
- Unlock the borehole and check if hinges or the lock requires lubrication or replacement. If so, lubricate the lock or replace it with a new one. Use the same key for all completions.
- Verify the borehole and intake IDs on the tags. Missing or damaged tags must be replaced. A template for borehole tags can be found on the GEUS Well Archive website: www.geus.dk/borearkiv.
- Measure the water level (sounding) and record the measurement in the pumping log.
- Inspect the interior of the well completion, checking if the casing is damaged, if a hissing sound from leaks can be heard in the casing, and if pests are present in the wellhead (mice, snails, etc.). Signs of standing water or water backup around the casing must be noted.
- If repairs are carried out (e.g., replacing rusted screws), this must be noted in the pumping log.
- If a need for repairs is identified that cannot be performed immediately during the inspection, this must be noted in the pumping log for follow-up.
- Information must be transferred to the relevant registries no later than upon return from the field.

- All equipment in the borehole must be maintained regularly. An equipment logbook must be kept, where all observations are continuously recorded Brønde og boringer - Miljøstyrelsen.

2.8 Maintenance of Fixed Equipment

Pumps and other electrical equipment require ongoing maintenance. All mobile field equipment must be inspected at least once a year, typically in connection with sampling. Fixed pumps must be tested and, if necessary, inspected at least every 5 years. Pump durability varies, and pumps may require replacement or maintenance if, for example, there is excessive sand infiltration, as suspended sand wears down the moving parts of the pumps.

Some maintenance work can be performed while purging the boreholes. Other maintenance requires workshop facilities and potentially additional competencies regarding high-voltage electricity or similar.

2.9 Special Precautions - Pitfalls

Access conditions to a borehole can deteriorate when landowners, for example, merge fields or abandon field roads, which can lead to extra time spent on planning or potentially make sampling impossible.

Frost does not usually challenge monitoring wells, which are designed as far as possible so that no water remains in hoses or other components above ground level. Therefore, only very severe frost would challenge sampling. However, it is worth noting that certain types of plastic (e.g., PVC) become very brittle in freezing temperatures and can be more easily damaged by impacts, etc.

Be aware that during the development (purging) of newly established boreholes, relatively large volumes of water may run off onto frozen ground into surface water, potentially discharging ochre or thawing the discharge area, making the frozen ground too soft for driving.

Very specific conditions apply to artesian boreholes—not only during establishment, which is handled by the well driller. In boreholes where the water cannot be kept below the frost-free depth between samplings, special precautions must be taken to prevent frost bursting. A dry well may be the ultimate solution to protect against frost damage in artesian boreholes, along with the specific measures that requires.

The solution will depend on local conditions, where it is generally preferred to insulate an area around and up the casing. This requires a larger well protector, potentially a so-called raw water station.

Pump dimensioning, particularly regarding flow rate (yield), is crucial to ensure the quality and efficiency of the monitoring task. A pump with too low a capacity leads to unnecessary time consumption. A pump that is too large can heat the water and compromise the integrity of the samples for analysis, as the pump placement must always ensure that the water level is not drawn down into the filter/screen interval.

4 Quality Assurance

4.1 Quality Assurance of Methods

Quality assurance of the work performed depends on whether the borehole is newly constructed or whether an existing borehole, previously used for a different purpose, is incorporated into the program.

When incorporating an existing borehole, all information regarding the borehole must be reviewed, and it must be assessed whether the available documentation of location, chemistry, and intake satisfies the technical requirements for monitoring.
Quality assurance of the well completion and documentation during the establishment of a new borehole depends largely on the cooperation with the parts (e.g., consultant) specifically supervising the drilling work, particularly how the supervision is conducted. Careful supervision of screen placement and sealing must always be carried out in cooperation with the well driller to achieve, among other things, optimal intake placement and maximum yield

without sand or fines infiltration, while ensuring that the seal provides sufficient integrity. The construction of a borehole always involves development pumping of the intake, which is carried out as soon as the curing of the seals allows.

The ongoing quality control of monitoring wells is conducted through the application of technical instructions for water level measurement, inspection, and sampling.

The following classification is used when evaluating geological and other information from existing boreholes:

Quality	Sampling Density	Scope of Description	Boundaries for Aquifers and Aquitards Known
1	One per 1-2 m	FGD, including all relevant info; stated as sealed with approved materials	Yes
2	One per 2-5 m and one per layer	FGD, including screen interval; stated as sealed with approved materials	Yes
3	One per 2-5 m and one per layer	WD, including screen interval; stated as sealed with drilled material	Yes
4	Fewer than one per 5 m	WD and/or geophysical log and screen interval; no information on sealing	Yes
5	Fewer than one per 5 m		No

Table 1: Quality assessment of geological information regarding the stratigraphy at a gauging station. FGD: Full Geological Description. WD: General Well Driller's Description.

In other Technical Instructions (TA) and Data Technical Instructions (dTA) for Groundwater, guidelines are provided for water level measurement, sampling, data processing, and quality assurance. The quality-assured data ultimately uploaded to the national borehole database, Jupiter, provide a picture of how water levels and chemistry vary within the individual borehole intake.

In the national gauging network, the primary objective is to obtain data that are not directly affected by the cone of depression immediately surrounding abstraction wells. In an overall quality assessment of a monitoring well, it is therefore important to evaluate whether there are individual or recurring signs of nearby water abstractions that locally affect the water level.

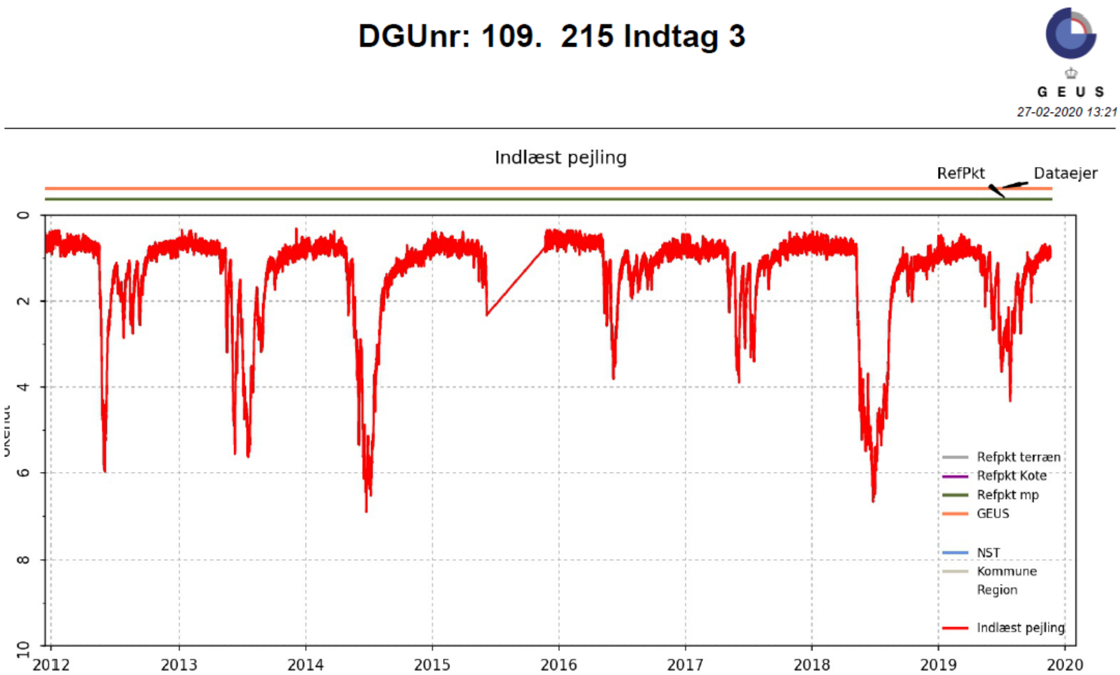

Figure 8. Water level affected by nearby recurring pumping. Upon pump start-up, a relatively rapid drawdown of up to 5 m is observed, and upon pump shutdown, an asymptotic recovery to the unaffected static water level is seen.

4.2 Quality Assurance of Data and Data Submission

Once the well driller has reported the borehole to the Jupiter database, it must be verified that the borehole log and location forms are completed correctly and that all information, including any remarks from the drilling process, has been reported and is retrievable in Jupiter.

Furthermore, there must be consistency between the descriptions of the colours and lithology of the drilled layers from the field and those from the core sample laboratory. It must also be ensured that all information regarding well completion and development pumping (and, if applicable, test pumping) is available.

Be aware that the Intake Number and Intake ID may differ. The measuring point (datum) must be described correctly and must correspond to the borehole's signage. If the measuring point is changed, it must be registered in Jupiter, and a new sign must be installed based on a printout of the information in Jupiter: https://jupiter.geus.dk/boringsskilt/.

5 References

(Most of which is in Danish)

Legislation and Guidelines

MIM 2005: Bekendtgørelse om udførelse og sløjfning af boringer og brønde på land. BEK nr. 1260 af 28/10/2013.

Dansk Standard DS/EN ISO 5667-3, Vandundersøgelse Prøvetagning Del 3: Retningslinjer for konservering og transport af prøver.

Dansk Standard DS 2214, Vandundersøgelse Prøvetagning af vand til analyse for spormetaller.

Ditlefsen, C., Sørensen, J., Pallesen, T.M., Pedersen, D., Nilsen, O.B., Christiansen, C., Hansen, B., Gravesen G., 2008: Jordprøver fra grundvandsboringer. Vejledning i udtagning, beskrivelse og geologisk tolkning i felten. Geovejledning 1. GEUS Teknisk rapport. http://gk.geus.info/xpdf/geo-vejledning_1_final.pdf

Europæisk standard EN ISO/IEC-17025 om generelle krav til prøvnings- og kalibreringslaboratoriers kompetence rummer egnede internationale standarder for validering af de benyttede analysemetoder

EU, 2009: Analysekvalitetsdirektivet, 2009/90/EF af 31. juli 2009 om tekniske specifikationer for kemisk analyse og kontrol af vandets tilstand som omhandlet i Europa-Parlamentets og Rådets direktiv 2000/60/EF.

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Sørensen I., ed., 2009, Environmental Samling- Groundwater. Leonardo da Vinci. EU rapport. Udgivet af VIA University College, Horsens.

U.S. Environmental Protection Agency, 2002: Groundwater Sampling Guidelines for Superfund and PCRA Project Managers

Referencelaboratoriets metodedatablade, se nedenfor under links.

Technical literature

Århus Amt, Miljøkontoret, oktober 1991: Grundvandsboringer, Teknisk rapport.

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Elberling, B., Thorling, L. & Misser P., 1997: Det kan være surt at måle pH. Vand og jord, vol 4, nr. 4, aug. 1997, pp150-152.

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Hansen B., og Thorling, L. 2008: Interkalibrering af grundvandsprøvetagningen 2007, NOVANA. GEUS-rapport. link

Stockmarr, J. (red) 2001: Grundvandsovervågning 2001, Teknisk rapport, GEUS 2001. https://www.geus.dk/Media/7/6/g-o-2001.pdf

AVJ, Amternes Videnscenter for Jordforurening, 2003: Håndbog i prøvetagning af jord og grundvand. link til AVJ-rapport

Miljøstyrelsen, 2001 (Gravesen, P., Kelstrup, N.): Grundlæggende geologi og grundvand. https://www2.mst.dk/udgiv/publikationer/2001/87-7944-818-6/pdf/87-7944-819-4.pdf

Miljøstyrelsen, 2013: Vejledninger om boringer på land. Red: Bastrup, B., og Baumann J., GEO, & Villumsen, B., COWI A/S. https://naturstyrelsen.dk/media/nst/89680/Boringsvejledning.pdf

Best Practice – Forsegling af boringer og sonderinger udgives i starten af 2022, som et TUP-projekt på Miljøstyrelsen hjemmeside

Projektering og konstruktion af borehul DSF/prEN 17522 (Forslag): https://webshop.ds.dk/da-dk/standarder/standard/dsf-pren-17522

Relevant link

Generelt om overvågning af natur og miljø findes på dette link på Miljøstyrelsens hjemmeside: Link til NOVANA

Metodedatablade fra referencelaboratoriet findes på dette link: link til Metodedatablade

Jupiters hjemmeside findes under dette link til Jupiter

Borearkivets hjemmeside findes under dette link: Link til Borearkivet

www.grundvandsovervaagning.dk

https://miljoeogressourcer.dk

GEUS: Lokaliseringsskema: https://www.geus.dk/media/7304/formular-lok_skema-valgfrit.pdf

GEUS: Vejledning i lokalisering og indmåling : https://www.geus.dk/media/7299/lokvejledning-dk.pdf

GEUS: Generering af boringsskilt: https://www.geus.dk/produkter-ydelser-og-faciliteter/arkiver/borearkivet/indberetning-af-boringer-skemaer-og-vejledninger

GEUS: Bestilling af DGU nr, sløjfningsskemaer mv: https://www.geus.dk/produkter-ydelser-og-faciliteter/arkiver/borearkivet/indberetning-af-boringer-skemaer-og-vejledninger

6 Appendix

List of related Technical Guidance

G02- Groundwater sampling Technical Guidance, NOVANA, Denmark.
G03- Groundwater sounding, Technical Guidance, NOVANA, Denmark.

Alle Technical Guidance can be found on the homepage of the groundwater monitoring at GEUS Monitoring homepage, GEUS

Appendix 6.1 Example of borehole log and location form.

PDFs of these borehole logs can be downloaded separately from the GEUS website, where they are stored alongside the borehole data. Here an example of borehole data and geological sequence.

GEUS | De Nationale Geologiske Undersøgelser for Danmark og Grønland | Udskrevet 20/1 2022 Side 1

BORERAPPORT **DGU arkivnr: 106. 1517**

Boringssted : Tyrstingvej 38
8765 Klovborg
Erstatter 106.451, 0,5m ved siden af

Kommune : Ikast-Brande
Region : Midtjylland

Boringsdato : 9/5 2011 | **Boringsdybde** : 23,1 meter | **Terrænkote** : 68,3 meter o. DNN

Brøndborer : Brandevejens Vandteknik
MOB-nr :
BB-journr :
BB-bornr :

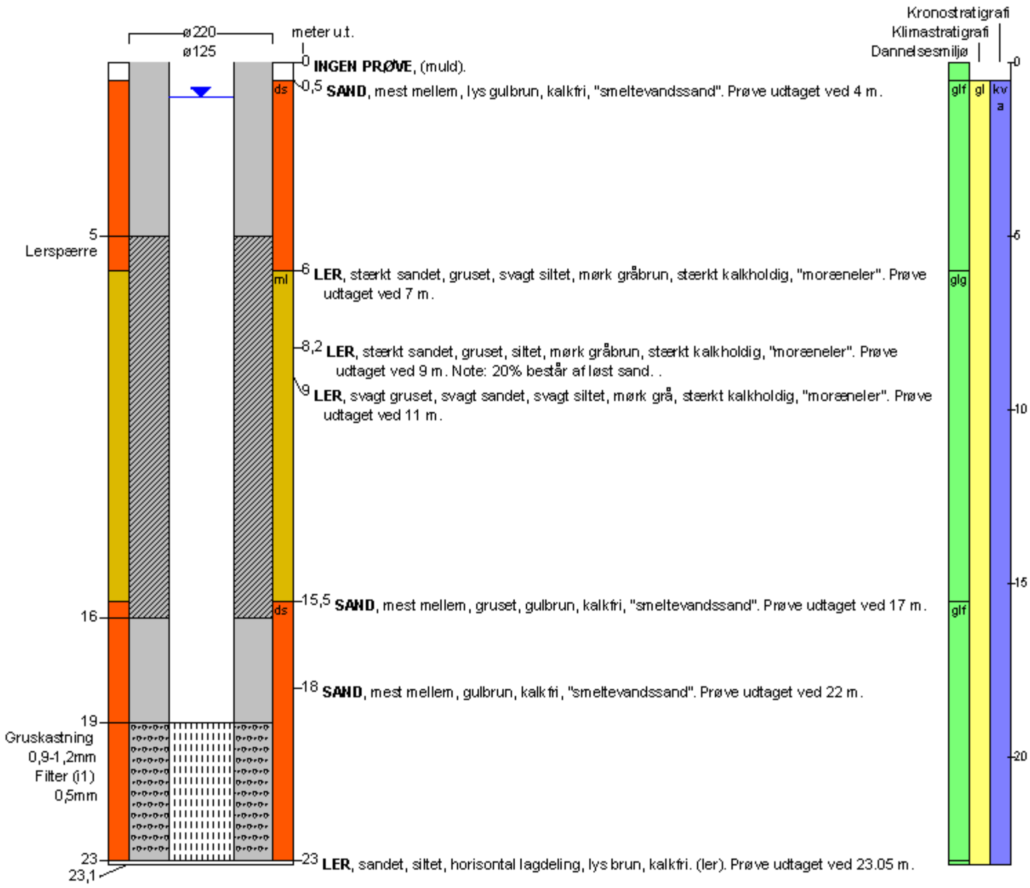
Prøver
- **modtaget** : 11/10 2011 **antal** : 7
- **beskrevet** : 27/6 2012 **af** : SHB/HJG
- **antal gemt** : 0

Formål : Vandforsyningsboring
Anvendelse : Vandforsyningsboring
Boremetode : Tørboring/slagboring

Kortblad : 1214 IINV
UTM-zone : 32
UTM-koord. : 531992, 6199472

Datum : EUREF89
Koordinatkilde : GEUS
Koordinatmetode : Andet

	Ro-vandstand	Pejledato	Ydelse	Sænkning	Pumpetid
Indtag 1 (seneste)	1 meter u.t.	9/5 2011	20 m³/t	8 meter	1,5 time(r)



LOKALISERINGSSKEMA

Lokaliseret af
Firmanavn:
Geo
Subsurface Expertise

Lokaliseringsdato	Modtaget GEUS d.	DGU ark.nr
12/06/2015	18-12-2015	83.1991

Lokaliseret af, initialer	Brøndborerjournaliseringsnr.	Borerapport nr. (MOB)	Indtagsnr.
JMJ			2

Internt registrerings - eller journaliseringsnr: 37943

Lokaliseringsskemaet sendes i udfyldt stand til geusborearkiv@geus.dk

GEUS
De Nationale Geologiske Undersøgelser for Danmark og Grønland
Øster Voldgade 10
1350 København K
Telefon: 38 14 20 00
Telefax: 38 14 20 50

Borestedets adresse

- Vejnavn og nr, nærmeste by eller lokalitetsnavn(e): Lervangvej 7, Ølstrup
- Postnr. og by: 6950 Ringkøbing
- Kommune: Ringkøbing - Skjern
- Ejendomsnavn / firma / matr.: 16k, Degneboligen, Ølstrup
- Region: Midtjylland

Borings-oplysninger

- Brøndborer: Boregruppen A/S
- udført den: 31/03/2015
- Forerørsdiameter: 200 mm
- Største dybde: 25 m
- Oplysninger ifølge borerapport: [X]
- Oplysninger givet på stedet - ingen borerapport: [ ]
- Lokalt boringsnummer: NST vest 20

Borestedets lokalisering

- Borestedet forevist af:
- Boringens ejer på lokaliseringstidspunktet: NST Ringkøbing
- Boringens tilgængelighed: I pumpehus [ ] I gammel brønd [ ] Kun brønd [ ] Fritliggende installationsbrønd, tørbrønd [X] Borerør står frit [ ] Andet:
- Pejlbarhed: Ja [X] Nej [ ]
- Indvendig diameter i pejlestuds:
- Øvrige oplysninger om boringen, f.eks. ejer: Boringsfixpunkt: Top forerør 1.

Beliggenhedsskitse

Anlæggets indretning

Boringsfikspunktskote: Top forerør (Beskrivelse)	a	32,49
Terræn i m under Boringsfikspunkt	b	0,2
Terrænkote	c = a - b	32,29
Pejlepunktsbeskrivelse: Overkant forerør		
Pejlepunkt m under boringsfikspunkt	e	- 0,07
Pejlepunktskote	f = a - e	32,56
Pejling af vandspejl under pejlepunkt	g	3,06
Vandspejlskote	h = f - g	29,50
Vandspejl m under terræn	i = c - h	2,79

Datum: ED50 [ ] ETRS89/WGS84/EUREF89 [X] UTM Zone 32

Boringsfikspunkts koordinater UTM

- X: 462944 99
- Y: 6216620 31
- Målt med DGPS [X] GPS [ ] KMS digitale kortsæt [ ]
- Dig. Luftfoto [ ] Andet: afvigelse x,y: 1 cm
- GPS afvigelse på X,Y:

Boringsfikspunktskote

- Koten er højden over havniveau regnet med fortegn: 32 49 m
- DGPS [X] GPS [ ] Nivelleret [ ] Aflæst på kort [ ] Andet:
- GPS afvigelse på Z: System DNN [ ] DVR90 [X] Andet: afvigelse z: 1 cm

Anvendelse: Vandværk [ ] Markvanding [ ] Husholdning [ ] Industri [ ] Dambrug [ ] Andet: Overvågning

Example of a location form (lokaliseringsskema) from the Jupiter database

Appendix 6.2 Equipment for the sampling vehicle.

The following tools and equipment must be available in a field vehicle:

- Hoses for pumps, discharge hoses, adapters, etc.
- Mobile pumps, potentially mounted on hose reels on wheels for boreholes without fixed pumps.
- Fittings and adapters for various discharge taps on water supply systems.
- Field measurement equipment, etc., in accordance with Technical Instruction (TA) for groundwater sampling (TA G02).
- Filtration equipment.
- Cooling unit for samples.
- Sufficient power supply for pump operation.
- Pressure cylinders for sampling with air-driven pumps (e.g., Montejus pumps).
- Manual water level meters (dip meters/sounders).
- Spare batteries, spare parts, gaskets, and bolts/screws for equipment.
- Optional oil-free compressor.
- Wipes/towels.
- Deionized water.
- Extra filter sand and bentonite for minor repairs of collapses, etc.
- Rubber gloves in various sizes.
- Hand tools: Screwdrivers, wrenches, wire cutters, etc.
- Shovel, scythe, loppers, saw, etc., for maintenance of the borehole's immediate surroundings.

Appendix 6.3. Overview of regulations for reporting borehole information, including from the Well Archive

An overview of the legal framework and regulations can be found at the Danish Environmental Protection Agency (Miljøstyrelsen):
[Brønde og boringer - Miljøstyrelsen].

The Borehole Order (Boringsbekendtgørelsen)
The rules for how boreholes must be constructed and how boreholes and wells must be cancellated (decommissioned) are found in the Borehole Order: Executive Order No. 1260 of 28 October 2013 on the Construction and Abandonment of Boreholes on Land.

The Education Order (Uddannelsesbekendtgørelsen)
The rules for the training of personnel performing the construction and abandonment of boreholes and wells on land are found in the Education Order: Executive Order No. 915 of 27 June 2016.

The Borehole Guidelines (Boringsvejledningen)
The guidelines for avoiding the risk of groundwater contamination during drilling operations are found in the Borehole Guidelines: Guidelines on Boreholes on Land.

Cancellation of Boreholes and Wells
When a well or borehole is cancellated, it must be performed in such a way that the site remains sufficiently sealed for all future time to prevent groundwater contamination or the exchange of water between different aquifers. The cancellation of boreholes or wells must be performed by individuals with the necessary training as certified well drillers. The technical requirements for cancellation are specified in the Borehole Order.
The abandonment must be reported to GEUS (using a cancellation form).

Drilling Permit
Before any drilling work can commence, a drilling permit must be obtained. The drilling permit is applied for at the respective municipality.

Reporting of Borehole Information
The rules for reporting boreholes to GEUS are set out in Chapter 5 of the Borehole Order. All information regarding the drilling method, stratigraphy, soil and water samples, well completion including intakes (screens), casing, and sealing must be reported to GEUS no later than 3 months after establishment. Once the final localization is available, this must likewise be reported to GEUS.

See the overview and guidelines for reporting here:
https://www.geus.dk/produkter-ydelser-og-faciliteter/arkiver/boreark-ivet/indberetning-af-boringer-skemaer-og-vejledninger

www.geus.dk
https://www.geus.dk/vandressourcer/overvaagningsprogrammer/grundvandsovervaagning/

GEUS