MSc Thesis ideas contained in this catalogue

23. Exploring the effects of extreme climate events on deep groundwater reservoirs through hydrological modelling
24. Hydrological modelling of a study catchment in Uganda
25. Locating tile drains in agricultural fields using gamma-ray soil sensing
26. Groundwater parks: Modelling the transition from highly intense agriculture to nature
27. Can soil moisture be used as a predictor of droughts and flashfloods?
28. Hydrological modelling of nutrient-poor peatlands: Bøllemosen
29. Data-driven estimation of groundwater recharge
30. Groundwater recharge below different land cover types
31. Your project?

1. Hydrological modelling in realtime and forecast mode for hydrological planning and warning systems

Hydrological warning systems are gaining increasing attention in Denmark, for example after the disastrous flooding events in Germany in the summer of 2021, or the historically wet winter 2023/24 in Denmark. Hydrological warning can encompass both flood and inundation warning and monitoring and warning of water resources status and drought. For this purpose, the National Hydrological Model (DK-model) at GEUS is running as a real-time model and with weather forecasts. The weather forecasts used to produce the hydrological forecasts, most importantly forecasts of rainfall, however, can have systematic biases compared to the climate observations that usually are used with the DK-model. This might affect the performance of the DK-model in the forecast period, as it is originally setup and calibrated to the climate observations. Besides that, there is significant uncertainty in the spatio-temporal patterns of weather forecasts: Inevitably, the forecasts are not perfect, and the predicted rainfall amounts and/or locations can be erroneous.

The severity of these aspects with regards to hydrological forecasts remain unexplored for the specific Danish case. They can be relevant both for flood forecasting (with short-term forecast horizons of a few days), or for the monitoring of the hydrological cycle and droughts (with medium-term forecasts up to 15 days or even seasonal forecasts).

As a master student involved in this work you can gain experience on both hydrological model development, operationalization as well as data processing and analysis. A MSc project can contain some of the elements below or combinations.

Objectives

- Evaluation of general biases and differences in spatio-temporal patterns between precipitation forecasts and historic observations (Klimagrid Danmark). How do these differences affect hydrological model performance?
- Event-based uncertainty evaluation of precipitation forecasts and their impact on hydrological forecasts. Based on a comparison of data from a forecast archive with observation data. How large is the uncertainty introduced by the forecast on the hydrological output (streamflow in case of flood warning; soil moisture, groundwater levels or streamflow in case of hydrological/drought monitoring)
- How skillful are short-term forecasts, e.g. for flood warning?
- How skillful are long-term/seasonal forecasts, g. for drought monitoring? The longer the forecast horizon, the worse typically the forecast skill. At some point, simple forecasting based on average climate starting from initial conditions (e.g. in groundwater levels) can beat weather forecasts.

Contact persons: Raphael Schneider (rs@geus.dk), Lars Troldborg (ltr@geus.dk), Simon Stisen (sst@geus.dk) and Karsten Høgh Jensen (khj@ign.ku.dk).

2. Fluoride release and transport in alluvial aquifers in the arid regions of Kenya

Groundwater fluoride (F^-) concentrations exceeding the WHO recommended drinking water guideline of 1.5 mg/L are one of the major hazards to drinking water safety in Kenya. High groundwater F^- is associated with water-rock interactions, geothermal mixing, and shifting calcite and fluorite equilibria due to saline intrusion or evaporation-induced increase in salinity and pH. Climate change and unsustainable groundwater abstraction may further increase groundwater salinity and thus exacerbate F^- release from the sediments. Despite the complexity of the involved processes, and high spatial variability of groundwater F^- concentrations, partially controlled by salinity, the isolated effect of each of the F^- controlling processes have rarely been properly constrained in previous studies. The aim of this study is to explore and advance conceptual models of F^- cycling in aquifers in Turkana County, Kenya based on conceptual groundwater system models developed under the project REACH at the University of Nairobi.

Objectives:

- To conduct a literature review on F^- cycling in arid regions.
- To prepare maps of groundwater F^- and other relevant constituents in the study area.
- To conduct PhreeqC speciation calculations to derive mineral saturation indices.
- To integrate information from REACH project and national databases into a conceptual F^- cycling model.
- To set up a hydrogeochemical model of F- release and transport in the alluvial aquifers of Turkana County, Kenya.

The activities are related to an ongoing project awarded by the Danida Fellowship Centre on behalf of the Ministry of Foreign Affairs of Denmark. The thesis will be co-supervised by the researchers at the University of Nairobi and Geological Survey of Denmark and Greenland (GEUS). The master student will have an office space at the Geochemistry Department, GEUS.

Contact persons: Søren Jessen (sj@ign.ku.dk), Daniel Olago (dolago@uonbi.ac.ke), Jolanta Kazmierczak (jka@geus.dk)

3. Eksperimentel test af CO_2 fangst i basalt

Lagring af CO_2 i formationer af frisk og porøs basalt har vist sig at være en effektiv måde at lagre flere tusinde ton CO_2/år i form af sekundær kalcit (e.g., Snæbjörnsdóttir et al., 2020). Lagringen foregår som et resultat af opløsning af basalt i kulsyre, og opløseligheden kan dermed bruges som indikator for lagringseffektivitet.

Dette speciale vil teste opløseligheden af tre typer basalt ved temperatur- og tryktilstande som kan forventes at findes i undergrunden relevante for potentiel CO_2 fangst i Grønland, Færøerne og Danmark. Resultaterne vil kombineres med en geokemisk model af systemet til bedst mulig evaluering af potentialet for CO_2 fangst i et komplet system. Specialet vil derfor inkludere laboratoriearbejde med anvendelse af et højtryk og -temperatur autoklave-system med mulighed for anvendelse af en bred vifte af klassiske geologiske instrumenter såsom XRD, SEM-AQM og ICP-OES.

Forsøgene vil udføres i et samarbejde mellem GEUS (Geokemisk afdeling samt afdeling for Kortlægning og Mineralske råstoffer), IGN og Ministeriet for mineralressourcer i Grønland (MMR), hvoraf laboratoriearbejdet vil fordeles over GEUS og IGN-faciliteter.

Contact persons: Knud Dideriksen (kdi@geus.dk), Nynke Keulen (ntk@geus.dk) eller Maja B. Rasmussen (mr@ign.ku.dk).

4. Machine learning of groundwater fluoride and salinity in Turkana (Kenya)

The major hazards to drinking water safety in Kenya are droughts, high fluoride, and increasing salinity in groundwater. In Turkana County (98,600 km2), in the arid part of Kenya, only 50% of the population has access to potable water. Rural communities rely mostly on unimproved surface water sources, which are under pressure due to climate change and population growth. Existing groundwater resources could alleviate these issues, but their suitability for drinking water purposes has not yet been explored. The main issue is high spatial variability in salinity and fluoride concentrations. While salinity affects the taste (at e.g. sodium concentrations >200 mg/l), high fluoride concentrations could cause dental or skeletal fluorosis. WHO has set a guideline value of 1.5 mg/L for fluoride, which is exceeded in some parts of Turkana where fluoride ranges 0.15–5.9 mg/L. The overall aim of this master project, therefore, is to elucidate the spatial patterns of fluoride and salinity in groundwater in Turkana County and identify environmental variables governing it, so sustainable and safe future groundwater use can be ensured. This master project will contribute to the project "*Groundwater fluoride and salinity vs. equity in arid regions: Obtaining inclusive and sustainable resource management (GEM)*" funded by DANIDA (2025-2029). As a master student you will be collaborating with GEM project participants in Denmark and Kenya and GEUS' Department of Geochemistry will provide you with a desk for your thesis work.

Objectives:

- Conducting short literature review identifying potentially important variables for the spatial variability of groundwater fluoride and salinity
- Quality assurance of existing groundwater chemistry data, and pre-processing of other data (explanatory variables e.g. lithology, climate, soil-moisture, etc.)
- Applying a machine learning model to elucidate the spatial variability of groundwater fluoride and salinity and mapping areas with acceptable salinity and fluoride levels

For your thesis work you will be working with GIS, database tools (excel, python or alike) as well as geospatial data exploration and machine learning models (python). Experience in programming is an advantage but not a requirement.

Contact persons: Julian Koch (juko@geus.dk), Denitza Voutchkova (dv@geus.dk), Søren Jessen (sj@ign.ku.dk).

5. UAS and Satellite Hydrometry

KU-IGN is coordinating a large EU Horizon project on Uncrewed Airborne Systems (UAS)and Satellite Hydrometry (https://uawos.dtu.dk/). In this project we develop new contactless airborne monitoring technology to survey water surface elevation and water surface slope in rivers, riverbed geometry and river flow velocity/discharge. We combine airborne datasets with satellite EO data, specifically from the SWOT and ICESat-2 missions to parameterize, calibrate and validate river models in poorly instrumented and remote regions. Within the UAWOS framework, there are multiple opportunities for MSc thesis projects. Depending on the student's interest, projects can focus on airborne data acquisition and processing (potentially including field work in one of the UAWOS field sites,

https://uawos.dtu.dk/demonstration-cases), river modelling in Mike+ or similar hydraulic modeling software, and inland water satellite earth observation using SWOT and ICESat-2 datasets.

UAWOS water penetrating radar drone payload

Objectives:

- Estimating river discharge from contactless airborne datasets of water surface elevation, riverbed geometry and surface water velocity
- Hydraulic modeling of rivers using airborne and satellite hydrometric datasets
- Developing rating curves for poorly monitored and remote river reaches
- Improving flood risk assessment models and flood forecasting systems with airborne and satellite EO inland water datasets

Contact persons: Peter Bauer-Gottwein (pbg@ign.ku.dk), Zhen Zhou (zhezh@dtu.dk).

6. Nitrate as a Tracer to Assess Groundwater Vulnerability

In the Danish Pesticide Leaching Program (PLAP), nitrate levels are routinely monitored alongside pesticides and their transformation products across five agricultural fields. While bromide has traditionally served as a tracer for model calibration in these fields, the potential of nitrate as a tracer remains unexplored. Hence, our objective is to analyze measured nitrate concentrations to discern nitrate leaching patterns across various agricultural fields representing diverse geological conditions. Additionally, we aim to integrate nitrate measurements into the calibration of 1D models representing these fields. Through this approach, we seek to enhance our understanding of how nitrate measurements can optimize model calibration and, ultimately, predict the risk of solute leaching into groundwater.

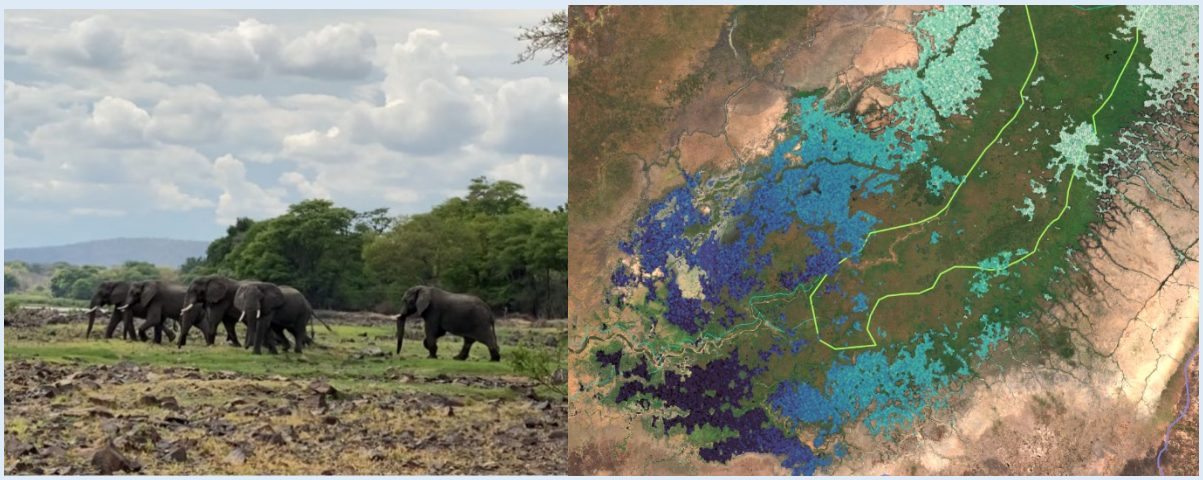
Objectives:

- Analyze time series of nitrate data from different fields representing varied geological conditions.
- Prepare nitrate data for model calibration purposes.
- Compare the outcomes of model calibration using nitrate with those obtained using bromide.

Contact persons: GEUS: Sachin Karan (saka@geus.dk), GEUS: Rasmus Jakobsen (raj@geus.dk) and IGN: Søren Jessen (sj@ig.ku.dk).

7. Integrated hydrological modelling and monitoring of the Usangu Wetlands, Tanzania

KU-IGN hosts the Global Wetland Center project (https://globalwetlandcenter.ku.dk/). This project aims to develop new observation and modeling technology to simulate and quantitatively estimate wetland greenhouse gas emissions and understand wetlands' greenhouse gas budgets from local to global scale. One of the field sites of the project are the Usangu Wetlands in Tanzania. For this wetland, we are developing an integrated hydrological model in Mike SHE, simulating inflow, outflow, evapotranspiration, flooding and subsurface flow processes. We aim to couple the integrated hydrological model with a vegetation and biogeochemical process model to estimate the greenhouse gas emissions from the wetland and explore their dependence on key hydrological variables such as depth to water table. Due to limited availability of on ground measurements, satellite remote sensing data will be used for model calibration and as inputs into machine learning methods.



Left: Herd of elephants roaming in Usangu Wetlands. Right: Surface water from the SWOT pixel cloud product over the western Usangu wetlands. The green line indicates the boundaries for the Ihefu swamp at the center of the wetlands.

Objectives:

- Set up, parameterize and calibrate an integrated hydrological model of the Usangu Wetlands, using all available in-situ observations as well as satellite earth observations from multiple missions, including SWOT and ICESat-2.
- Develop and implement a model for wetland greenhouse gas emissions as dependent on key variables simulated by the integrated hydrological model, using Mike Ecolab or similar generic modeling software.
- Develop data-driven surrogate modeling approaches for efficient and global-scale assessment of wetland greenhouse gas balances, based on satellite earth observation and insights from detailed integrated hydrological modeling.

Contact persons: Sarah Franze (safr@dhigroup.com), Peter Bauer-Gottwein (pbg@ign.ku.dk).

8. Modelling and monitoring of compound flooding in deltas and estuaries using satellite earth observation

Recent satellite earth observation missions such as SWOT and ICESat-2 datasets provide continuous water surface elevation datasets across the river-coast-ocean interface in estuaries and river deltas for the first time. Such datasets are extremely valuable for the calibration and validation of integrated hydrodynamic models used to simulate compound flooding events, when flooding is caused by a combination of high river flows, storm surges in the ocean and extreme local precipitation. Low lying deltas, such as the Mekong River delta, are particularly exposed to compound flooding events, events that are expected to be more frequent and harmful with future climate change and sea level rise. At KU-IGN, we explore and exploit the value of these datasets using the Mekong River delta in Vietnam as a case study. This work is funded by an industrial postdoc project carried out in collaboration with DHI.

Left: Flooding over the Mekong Delta on 2011 (source https://floodlist.com/asia). Right: SWOT water surface elevation and extent raster product.

Objectives:

- Develop an integrated river-coastal hydrodynamic model in Mike Flood
- Compare model outputs to spatio-temporally distributed water surface elevation datasets from SWOT and ICESat-2
- Calibrate and adjust the model to improve the match between simulated and observed water surface elevation in the inland water and coastal domains
- Use the model to simulate the impact of compound flooding events
- Simulate how future climate change scenarios and sea level rise will affect compound flooding events
- Explore strategies and modeling workflows for efficient transfer to other sites

Contact persons: Monica Coppo Frías (mcf@ign.ku.dk), Peter Bauer-Gottwein (pbg@ign.ku.dk).

9. Global river hydrologic and hydraulic modelling using satellite earth observation

From recent satellite earth observation missions such as SWOT and ICESat-2, we now get water surface elevation at ca 10m spatial resolution for any larger river of the world (wider than ca 20m) and at relatively high temporal resolution (5-15 acquisitions per month, depending on where we are on the planet). Moreover, from ICESat-2 or local LiDAR DEMs we can extract the unsubmerged cross section shapes for all rivers. What we still miss for a complete hydraulic characterization of world rivers are (a) submerged cross section shape, (b) hydraulic roughness, (c) runoff, (d) information on river and reservoir regulation. In many parts of the world, it is reasonable to assume that hydraulic roughness and cross section shape are stable in time. For 1D hydraulic/hydrodynamic models, one can lump them into a conveyance curve (as explained in https://doi.org/10.5194/hess-25-6359-2021) and parameterize the curve in terms of a zero-conveyance elevation and one or two shape parameters. This work is funded by an industrial PhD project carried out in collaboration with DHI.

Left: Satellite tracks at low flow (yellow) and full flow (green) conditions. The high flow can be seen in the top of the river bend, with a satellite image from a different day. Right: Estimated river channels from the low flow (top) and full flow (bottom) satellite pass.

Objectives:

- Develop, test, and apply workflows for automatic extraction of river cross section geometry from ICESat-2 and local LiDAR DEM datasets.
- Develop, test and apply workflows for extraction of WSE datasets from SWOT for any river and for comparison of SWOT data with river modeling results.
- Develop an inverse modeling framework to jointly estimate rainfall-runoff model parameters and conveyance curve parameters along the river.
- Apply developed workflows and modeling concepts to selected world rivers

Contact persons: Aske Folkmann Musaeus (afm@ign.ku.dk) and Peter Bauer-Gottwein (pbg@ign.ku.dk).

10. Safeguarding Groundwater Resources

Pesticide leaching and its potential threat to groundwater reservoirs is a significant concern both in Denmark and globally. Recent media coverage has highlighted the relevance of this issue, underlining the urgency to address it (for more information in Danish, follow this link: https://www.dr.dk/nyheder/tema/sproejtegift-i-drikkevandet). Since 1999, the Danish Pesticide Leaching Program (PLAP) has monitored potential pesticide leaching across five field sites, with

ongoing efforts by GEUS to gather and analyze hydrological and geochemical data using various methodologies.

Previous research has demonstrated significant disparities in pesticide leaching potential depending on the geological setting. For instance, fields situated in Quaternary moraine clay deposits may exhibit greater vulnerability compared to those in postglacial sandy deposits, attributed to fractures in clay facilitating faster pesticide transport (for more information in Danish, follow this link: https://www.dr.dk/nyheder/indland/grafik-saadan-kan-pesticider-komme-ned-i-grundvandet). Here, our objective is to assess leaching potential at the field scale in 3D by utilizing spatially distributed continuous monitoring data in numerical models. This approach represents a significant advancement in understanding and mitigating the risk of pesticide leaching in agricultural settings.

Objectives:

- Establish a local unstructured grid model implementing the knowledge of the geological depositions using MODFLOW.
- Simulate flow and solute transport using MODLFOW.
- Optimize the model using observation data.
- Compare the effectiveness of pesticide leaching assessment between the 3D model and conventional methods in pesticide regulatory procedures.

The thesis project will primarily involve modeling analysis using MODFLOW.

Contact persons: GEUS: Sachin Karan (saka@geus.dk) and IGN: Søren Jessen (sj@ign.ku.dk).

11. Using Groundwater Temperatures to Understand the Potential for Managed Aquifer Recharge (MAR)

In Spain, the ramifications of climate change are increasingly evident, with more frequent extreme droughts and heightened stress on groundwater reserves. Addressing these challenges requires innovative approaches and technologies. Managed Aquifer Recharge (MAR) emerges as a promising strategy, involving the infiltration of water from various sources into depleted groundwater aquifers. However, the feasibility of MAR hinges on the presence of suitable hydrogeological properties.

This thesis project focuses on southern Spain, where droughts and saltwater intrusion into coastal aquifers are escalating. Collaborating with the University of Granada, Spain, we aim to explore the MAR potential by utilizing heat as a tracer to investigate the properties of a proposed recharge site and the underlying groundwater aquifer. We will employ MODFLOW 6, a cutting-edge groundwater modeling code integrated into GMS software and Python, for our analysis.

Objectives:

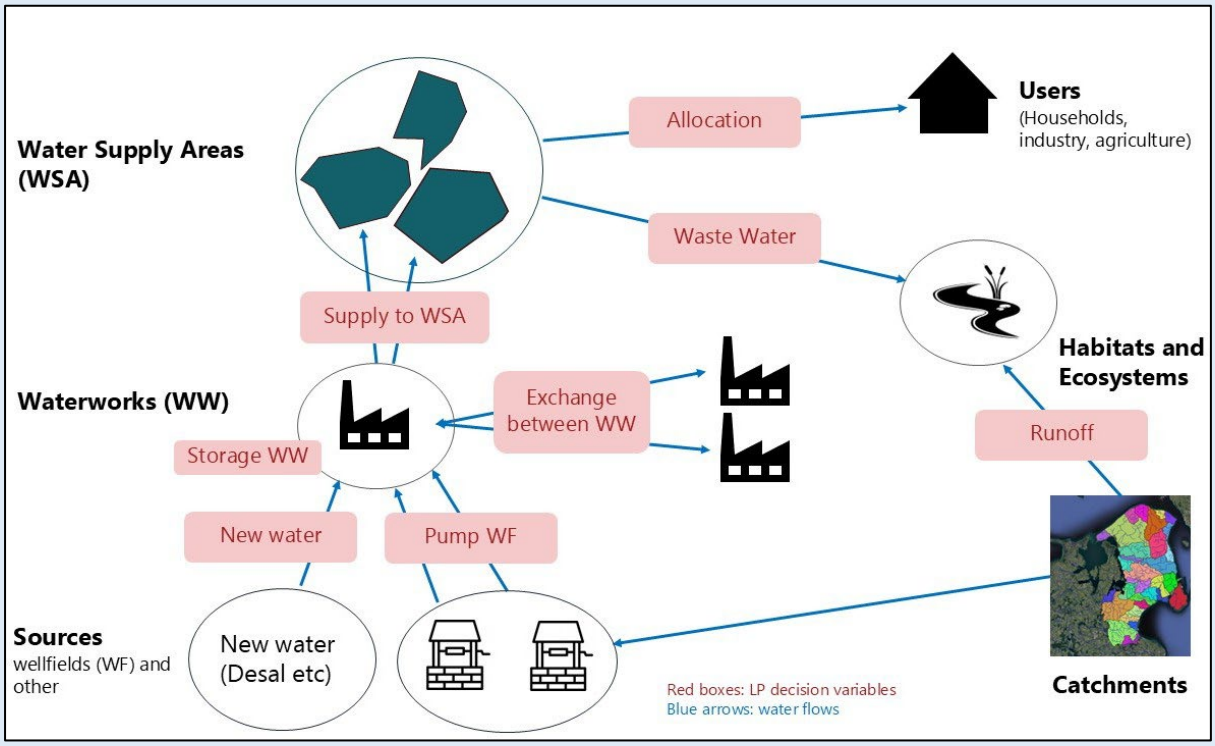
- Develop a MODLFOW 6 model for a local field site in Spain using available data.
- Calibrate the model against field observations.
- Explore the capabilities of MODFLOW 6 in simulating heat transport within the groundwater.
- Re-calibrate the model using temperature observations from the field site.
- Evaluate the field site and aquifer properties based on groundwater model analyses.

The thesis primarily entails modeling based on available data from the Spanish field site.

Contact persons: GEUS: Sachin Karan (saka@geus.dk) and IGN: Søren Jessen, (sj@ign.ku.dk).

12. Water Supply Security in Denmark to 2050

The 2022 agreement on green hydrogen will increase water demand in DK by ca. 5% in 2030. Water demand in other sectors will grow too (industrial expansion, population growth in cities, irrigation demands). At the same time, groundwater resources are already regionally overused, future groundwater availability is uncertain, and wellfields are vulnerable to pollution. There is a need to quantitatively analyze supply-side and demand-side solutions and to develop a holistic framework to evaluate portfolios of investments and policy changes that can ensure water supply security in Denmark to 2050. This project will develop a new integrated water supply and use decision support framework, combining the National Hydrological Model, models of the water supply infrastructure, and models of water users. The framework will be used by the water utilities and the municipalities to plan and quantitatively analyze the performance, reliability and robustness of various demand-side and supply-side investments and policy changes to determine optimal and climate-robust policy portfolios that will ensure Denmark's water supply security to 2050.



Conceptual model of the groundwater and water supply management problem

Objectives:

- Develop industrial, domestic and agricultural water demand scenarios to 2050
- Develop spatio-temporally explicit supply models (quantity-cost) for new water sources (desalination, reclaimed wastewater, treated groundwater).
- Develop coupled optimization modeling framework linking GEUS' national hydrological model, models of non-groundwater sources, models of the water supply infrastructure (wellfields-waterworks-water supply areas), and water use models.
- Evaluated and benchmarked present value, reliability, robustness, and other relevant performance criteria for multiple portfolios of infrastructure investment and policies that ensure secure water supply to 2050.

Contact persons: Peter Bauer-Gottwein (pbg@ign.ku.dk).

13. Groundwater-Surface Water Exchange

Regional groundwater models typically employ cell sizes on the order of hundreds of meters due to the vast areas they cover. Consequently, cells representing stream areas are also sized in the hundreds of meters, despite streams typically being only tens of meters wide at most. This discrepancy results in simulated groundwater fluxes to and from streams that may not accurately reflect reality, as the drainage areas near the streams are inadequately represented within the large cells occupied by the streams. Consequently, predictions made using such models concerning groundwater-surface water exchange, including both flow and solute transport, in scenarios such as climate or land use changes, may be unreliable.

In this thesis project, we aim to investigate the disparity in exchange fluxes by employing different conceptualizations to represent streams in regional groundwater models. The findings of this project will contribute to a better understanding of the optimal conceptualization of streams in regional groundwater modeling, facilitating more accurate simulations related to climate and land use changes. Candidates for this project should possess a strong interest in groundwater modeling, with proficiency in tools such as Python, GMS, or MIKE SHE, as well as experience in applying GIS for handling model inputs and outputs.

Objectives:

- Extract various areas from the DK-model and convert them into MODFLOW models.
- Conceptualize these extracted areas within MODFLOW using both structured grid sizes (uniform cell size throughout the area) and unstructured grid sizes (variable cell sizes with smaller cells near streams).
- Calibrate and compare the different conceptualizations in terms of parameters and simulated groundwater fluxes along streams.

Contact persons: GEUS: Sachin Karan (saka@geus.dk) and IGN: Søren Jessen (sj@ig.ku.dk).

14. Groundwater Vulnerability in Turkana County, Kenya

In Turkana County, Kenya, only 50 % of the population has access to potable water, and high fluoride levels and salinity threaten drinking water safety (LinkedIn_post). In this project, we are establishing a monitoring transect in Turkana County to make regular measurements of changes in groundwater levels and groundwater quality. Data from this transect will be used to establish a 2D groundwater model to analyze and understand the salinity input from the surface to the groundwater.

Objectives:

- Develop a groundwater model for the established transect.
- Simulate and quantify the impact of saltwater generation from surface-near processes on groundwater quality.

Contact persons: GEUS: Sachin Karan (saka@geus.dk). Jolanta Kazmierczak (jka@geus.dk), and IGN: Søren Jessen, (sj@ign.ku.dk).

15. Quantifying the Degree of Preferential Leaching

Rapid preferential flow through biopores and fractures is a well-documented phenomenon that significantly influences flow dynamics and solute transport to groundwater and surface water (for more information in Danish, follow this link: https://www.dr.dk/nyheder/indland/grafik-saadan-kan-

pesticider-komme-ned-i-grundvandet). However, efficient methods for determining the size and distribution of fractures on a larger scale are currently lacking.

GEUS is actively involved in the ongoing Danish Pesticide Leaching Assessment Program (PLAP), which focuses on monitoring hydrological and geochemical data to evaluate the risk of pesticide leaching (http://plap.dk). Studies within PLAP have demonstrated that fractures within clayey tills may transport pesticides much faster than observed in sandy soils. Consequently, GEUS seeks to employ stable oxygen isotopes and analyze previously applied tracers to quantify preferential flow and assess its impact on pesticide transport.

Objectives:

- Analyze ongoing monitoring data from the PLAP field and collected data to estimate the contribution of fracture flow to drainage, streams, and groundwater.
- Compare preferential leaching at different fields to investigate what variables mainly control the leaching.

The thesis project will primarily involve data analyses. If preferred by the candidate, fieldwork can be included.

Contact persons: GEUS: Sachin Karan (saka@geus.dk) and IGN: Søren Jessen, (sj@ign.ku.dk).

16. How to Mitigate Aquifer Depletion in Southern Spain

In Spain, the impacts of climate change are becoming increasingly evident, with more frequent extreme droughts and heightened stress on groundwater reserves. To ensure the sustainability of groundwater resources, novel technologies and strategies are imperative. One such approach is Managed Aquifer Recharge (MAR), which involves replenishing depleted groundwater aquifers by infiltrating water from various sources.

This thesis project focuses on southern Spain, where droughts and saltwater intrusion into coastal aquifers are on the rise. Collaborating with the University of Granada, Spain, we aim to investigate the potential of MAR to mitigate aquifer depletion using the state-of-the-art groundwater modeling code, MODFLOW 6. MODFLOW 6 is integrated into both GMS software and Python. While much of the data from the study area has been collected, there is potential for a field visit and collaboration with the University of Granada contingent upon funding availability.

Objectives:

- Develop a MODLFOW 6 model for the field site in Spain using the available data.
- Calibrate the model based on field observations.
- Explore the capabilities of MODFLOW 6 to simulate various MAR processes and structures.
- Incorporate climate change projections and assess the MAR requirements to maintain a sustainable groundwater resource.

The thesis will primarily entail modeling based on the data gathered from the Spanish field site.

Contact persons: Sachin Karan (saka@geus.dk) and Søren Jessen, (sj@ign.ku.dk).

17. Can we use water isotopes to derive groundwater age?

Groundwater is derived from rainwater. The isotope signal (the ratio between heavy and light water molecules) of rainwater is a function of the temperature in the cloud where the rain is formed. Global warming leads to an increase in the temperature, implying that the increasing temperature will lead to

a change in isotope signal in the groundwater. This means that we may be able to use the water isotope signal of the groundwater to estimate when the infiltration of the water now pumped from a well took place. The isotope signal was measured for all of the GRUMO wells during 2022 (GRUMO is the national groundwater monitoring program). For some of these wells the year of infiltration has been determined using $^{3}H/^{3}He$, giving a possibility of making a direct comparison!

In other places a more qualitative comparison can be made based on the depth of the groundwater, possibly supported by data from the "DK-model" of the Danish hydrological system or perhaps other models made in relation to the groundwater resource management of the water works. A nationwide monitoring of the precipitation has slowly started, this should give us an idea of the national variation. At the moment the GRUMO samples from 2022 have been measured – but the results still need to be associated with the wells they come from (something GEUS can hopefully find resources for soon) and then of course the more interesting part is associating the isotope data with existing data from those wells of especially the groundwater age. In addition there is a partial dataset of GRUMO wells from some years ago (Sascha Müller).

Objectives:

- Objective 1.1: Analyse the literature for similar studies.
- Objective 1.2: Assist in the establishing of the national precipitation network to obtain the first impression of the national variation in the isotope composition of the precipitation.
- Objective 1.3: Make the coupling between isotope data and data from the GRUMO wells.
- Objective 1.4: Extract probable groundwater ages from the DK-model.
- Objective 1.5: Evaluate the potential of using water isotopes for age estimates of groundwater in a warming (or cooling) world.

Contact persons: Søren Jessen (sj@ign.ku.dk) and Rasmus Jakobsen (GEUS, raj@geus.dk).

18. Hydrological modeling for sustainable groundwater management in South Africa

Semi-arid regions are dominated by highly irregular precipitation patterns, which strongly influence the hydrological cycle and water resources availability. Large temporal and spatial variations in precipitation causes large variability in runoff and groundwater recharge. Because of its climatic characteristics the Hout/Sand river catchment in the Limpopo province of South Africa is prone to droughts, and combined with irrigation for intensive agriculture, a growing population and climate change the region is facing severe water challenges. In order to identify sustainable groundwater management scenarios a better understanding of the hydrological processes is required, in particular the replenishment of groundwater.

Several projects can be developed in relation to an on-going Danida funded project in South Africa:

1) Further development and calibration of the MIKE SHE model for the study area using both traditional data in the form of river discharge and groundwater levels and remote sensing data such as soil moisture, evapotranspiration and flooding extent. Since the rainfall-runoff relationships are complicated and partially unknown new conceptualizations need to be tested as well as alternative targets for calibration.
2) Replenishment of groundwater can occur as diffuse or focused recharge. Diffuse recharge is recharge that is distributed over the catchment in response to precipitation and in semi-arid areas it often occurs as episodic events. Focused recharge occurs from rivers and managed recharge from e.g. farms and varies significantly in space and time. The two recharge components and their mutual significance at catchment scale should be analyzed using the MIKE SHE model in combination

with historical data on groundwater levels as well as data currently collected from two field infrastructures established in the study area.
3) Development of an alternative modelling framework for the study catchment based on MODFLOW-6 incorporated in the GMS system.
4) Analysis of impact of climate change on the hydrological components and on groundwater use and management.
5) Downscaling of the hydrological model simulations to community and farm scale using machine learning techniques to help improving groundwater management at smaller scales.
6) Analysis of reactive transport of a managed recharge site using geochemical modelling.

If relevant, the project can partly cover travel expenses to South Africa.

Contact persons: Elisa Bjerre (elbj@ign.ku.dk), Søren Jessen (sj@ign.ku.dk) and Karsten Høgh Jensen (khj@ign.ku.dk).

19. Using groundwater geochemistry in a South African semi-arid catchment to detect the source of groundwater

Groundwater in many semi-arid regions form by infiltration through the river bed to the aquifer during very short periods of extreme flow. The groundwater formation is therefore focused to occur mainly near the river channel and over short periods of time: so-called *focused groundwater recharge*. Sampling of groundwater is currently being undertaken in the Hout/Sand river catchment in the Limpopo province of South Africa. The area is prone to droughts, and their severity are further exacerbated by increasing demands of irrigation water, a growing population and climate change. In this context groundwater potentially serves as a stable source of water during droughts.

This study makes use of analysis of stable isotopes of water and water chemistry to interpret the source of groundwater and in particular the importance of focused recharge. Knowledge derived from this interpretation will aid the sustainable management of water in the changing climate of the region.

Objectives:
- Make maps of electrical conductivity and isotopic signatures.
- Make figures showing electrical conductivity and isotopic signatures as function of distance to nearest river.
- Conduct geochemical 'speciation calculations' using PHREEQC to derive mineral saturation indices and partial gas pressures.
- Establish geological models showing the distribution of different lithologies that may affect the groundwater chemistry via rock-water geochemical interactions.
- Calculate effects of rock-water reactions and compare the results to the chemistry of rain water not affected by rock-water interactions.
- Derive evaporation using chloride as tracer.
- Establish a conceptual model explaining the spatial distribution of water with different chemistry and thereby explaining the modes of aquifer recharge.

If relevant, the project can partly cover travel expenses to South Africa.

Contact persons: Søren Jessen (sj@ign.ku.dk), Elisa Bjerre (elbj@ign.ku.dk) and Karsten Høgh Jensen (khj@ign.ku.dk).

20. Tracing intrusion and freshening from groundwater chemistry patterns in coastal aquifers

The process of cation exchange in coastal aquifers gives rise to characteristic hydrochemical 'signatures' of the groundwater that reveal the direction of groundwater movement. For example, intrusion of Na-Cl seawater in to a fresh aquifer with a Ca-HCO_3 type groundwater results in a Ca-Cl_2 water type. And during freshening, the flushing of a saline aquifer by fresh Ca-HCO_3 water forms a Na-HCO_3 water type. These effects are typically visible when data are plotted in Piper diagrams and Stiff diagrams, which are commonly used by the industry in hydrological investigations. However, the cation exchange processes are non-linear and the salt-freshwater interface may move forth and back. The net result is, that the hydrochemical 'signatures' may become blurred or masked. The aim of the proposed project is to unmask these patterns, via reactive transport modeling of cation exchange during repeated (modelled) intrusion and freshening. The results of conceptual model cases will be compared to hydrochemical data from the SaltCoast projects activities at Rømø and Brede Stream estuary/delta in south-western Denmark.

Objectives:

- Collect estuary/delta sediment and depth-matched water samples.
- Measure in the laboratory the amounts of exchangeable cations, and the cation exchange coefficients to be used in the modelling.
- Setup a 1D model to derive the hydrochemical 'signatures' arising from single and repeated events of intrusion and freshening.
- Develop an automated plotting scheme of the 1D-model result into e.g. Piper diagrams in Python.
- Conceptualize the findings in order to broaden the applicability thereof by industry users.

Contact person: Søren Jessen (sj@ign.ku.dk)

21. Iron oxidation kinetics at the iron oxide surface

Iron oxidation is immensely important geological and geochemical process that has been studied widely. Yet, there is still rooms for more studies. This laboratory and PHREEQC modelling study will determine the kinetics of the oxidation of ferrous iron in the presence of the surface of different iron oxide:

Objectives:

- Review the literature – part of it; there are tons of literature on iron oxides.
- Make and freeze-dry a suite of different iron oxides in the laboratory (e.g. goethite, hematite and ferrihydrite).
- Measure the specific surface area of the iron oxides and determine their type using XRD. Perhaps do some SEM imaging.
- Make oxygenated suspensions of each iron oxide and add an initial concentration of ferrous iron. Monitor the Fe(II) concentrations using ferrozine. Filter out and dry the product.
- Measure the specific surface area of the product and do XRD analysis to document if mineral phase changes have occurred.
- Set up a PHREEQC model to simulate iron oxidation kinetics. Do the rates per m^2 of iron oxide surface depend on the type of iron oxide? If so, the iron oxidation is intimately linked to the chemistry at the surface.
- Conceptualize the findings in an scientific article-like document.

Contact person: Søren Jessen (sj@ign.ku.dk)

22. Collaboration with the consulting companies Niras, Rambøll, Geo, COWI, DHI, or others.

Consulting companies are often left with ideas for further investigations when their consulting projects end, which often occur when the funding is used. Interesting MSc projects can formulated on this basis and the companies are often very interested in pursuing and providing support to these projects.

The project ideas vary all the time and therefore one of us can make contact to companies and arrange meetings to discuss options.

Contact persons: Majken Zibar (mcl@ign.ku.dk), Peter Bauer-Gottwein (pbg@ign.ku.dk), Karsten Høgh Jensen (khj@ign.ku.dk) and Søren Jessen (sj@ign.ku.dk).

23. Exploring the effects of extreme climate events on deep groundwater reservoirs through hydrological modelling

With a changing climate, more frequent weather extremes, such as heavy rainfall, flooding, and droughts are to be expected. Denmark experienced a severe drought in the summer of 2018, while the winter of 2023/2024 had record breaking amounts of precipitation. During the recent years, Greater Copenhagen Utility (HOFOR) has observed decreasing groundwater levels in some of the catchments where groundwater is abstracted. Consequently, there is a need to investigate the effects of extreme climate events and changes in rainfall patterns on the deep groundwater resources. The aim is to enhance our understanding and knowledge of what the potential impact of the dry summer of 2018 and wet winter of 2023 on the deep groundwater reservoir is. The project furthermore aims to provide an understanding of whether the wet winter of 2023 can compensate for the dry summer of 2018.

The project will be based on an existing MIKE SHE model to simulate various model scenarios for some of HOFORs catchment areas by using available climate data, hydrological data, and groundwater level data. The MSc thesis will be executed in collaboration with HOFOR and consist of the following:

Objectives

- Setup of a hydrological model in MIKE SHE.
- Validation of the model using a comprehensive time series dataset of groundwater levels and river discharge.
- Selection and assessment of which extreme climate scenarios to simulate.
- Scenario simulation of extreme weather conditions.
- Analysis of how climatic parameters affect the deep limestone groundwater reservoir.
- Optionally, geological fault lines and their impact on groundwater resources may be analyzed.

Contact persons: Karsten Høgh Jensen (khi@ign.ku.dk), Kristian Bitsch (HOFOR, krbi@hofor.dk) and Lena Ali (HOFOR, lenali@hofor.dk)

24. Hydrological modelling of a study catchment in Uganda

A new research project funded by Danida will be launched in 2025 in which four Ugandan partners and three Danish partners are involved. One of the activities will involve development and calibration of an integrated hydrological model of the Enyau River study catchment using the Soil and Water Assessment Tool (SWAT). This open-source modelling platform is considered as one of the most versatile hydrological models in terms of functionality, applicability and implementation and has been

extensively used worldwide for semi-arid regions to assess water resources, nutrient dynamics and sediment transport to analyze the impact of water and agricultural management practices, soil conservation, land use and climate change.

Objectives

- Collection of in-situ, satellite retrieval and global database data
- Conceptualization of hydrological model in the SWAT modelling platform
- Calibration of the hydrological model against collected data using state-of-the-art optimization techniques
- Analysis of water resources dynamics
- Retrieving an ensemble of climate projections from the latest generation of global and regional climate models, bias correcting and downscaling
- Applying the model to quantify the impact of projected anthropogenic and climate changes on water resources and agricultural production

Contact persons: Elisa Bjerre (elbj@ign.ku.dk), Karsten Høgh Jensen (khj@ign.ku.dk)

25. Locating tile drains in agricultural fields using gamma-ray soil sensing

Tile drains are used extensively in clayey agricultural soils to ensure optimal soil moisture conditions for maximum crop productivity. By installing tile drains, excess soil water can be removed by maintaining the groundwater table below the root zone. In Denmark, the use of artificial drainage of agricultural soils employing tiles started around the 1850s and today approximately half of all agricultural fields are drained by tiles or pipes. Unfortunately, the exact layout of the drainage system is not always known and may be important if the system has deteriorated and needs to be repaired. Also, in numerical assessment of water resources, identifying drain locations can help achieve more representative water balance estimates. To obtain this information, conventional methods such as tile probes or trenching equipment, can be used. However, these are costly and invasive procedures which may cause damage to the drainage system.

Gamma-ray soil sensing is a method that records the natural emission of gamma radiation from the soil produced by the decay of Potassium-40, Uranium-238 and Thorium-232. The recorded gamma radiation depends mainly on the type of soil, as clay minerals contain higher concentrations of these radioactive nuclides. However, water in the soil also affects the measured gamma radiation as the gamma rays are attenuated by the water and thereby reduce the signal from the soil. A non-invasive estimation of soil moisture can therefore be deduced from measurements of gamma radiation.

This project aims to evaluate the use of gamma radiation maps to locate the drainage system of one or several agricultural fields with known drainage layouts (such as the PLAP-fields managed by GEUS). By collecting spatial gamma radiation during and after a rainfall event the drains can be delineated as the largest soil moisture change should be found directly above and in close vicinity to the drain pipes.

Contact persons: Mie Andreasen (GEUS, ma@geus.dk), Sachin Karan (GEUS, saka@geus.dk) and Majken Looms Zibar (mcl@ign.ku.dk)

26. Groundwater parks: Modelling the transition from highly intense agriculture to nature

To protect the drinking water resource in Denmark several groundwater parks are being planned in Denmark. The parks are located in groundwater recharge zones, and generally involve farmland being taken out of practice and converted to nature, such as wetlands, forests and open meadows. The concept

is that nitrate and pesticide application will be reduced or removed from the recharge that replenishes the drinking water reserve. Further benefits such as biodiversity, recreational areas and climate adaptation are also a part of the transition. In an ongoing project in Denmark's largest abstraction site, Holmehave, on Funen, we combine well-established and new techniques for monitoring the effect of the upcoming extensive land conversion. The project involves several collaborations with the water utility company and the municipalities. However, to upscale and project the impacts of the conversion, hydrological modelling is needed to track shifts in the hydrological system as the natural landscape grows and to quantify impacts on the groundwater resource. An MSc project can contain some of the elements below or combinations of these:

Ideas/content

- Fieldwork: Setup and analysis of a hydrological monitoring network with new innovative measuring equipment.
- Modelling: Detailed hydrological modelling of the area, before and after the transition, including setup and calibration.
- Modelling: Modelling of energy fluxes, with a focus on the change in evapotranspiration from agriculture to forest.
- Modelling: Analyzing future hydrology under climate change and more extensive land use conversion.

Contact persons: Torben Sonnenborg (GEUS, tso@geus.dk), Mie Andreasen (GEUS, ma@geus.dk), Ida Seidenfaden (GEUS, ika@geus.dk), Majken Zibar (mcl@ign.ku.dk) and Karsten Høgh Jensen (khi@ign.ku.dk)

27. Can soil moisture be used as a predictor of droughts and flashfloods?

In Denmark, the higher temperatures caused by the changing climate will affect the seasonal precipitation patterns. We can both expect wetter winters and longer and more severe periods of drought during the growing season. The wetter winters may cause high soil moisture levels in the upper soil layers. When the soil becomes saturated additional rainfall may not infiltrate fast enough and the excess water will produce increased quick flow with risk of flooding both locally and at downstream locations. Droughts during the growing season may in turn result in loss of agricultural yield but can also adversely affect natural ecosystems or cause damage to infrastructure (e.g., damage on buildings due to subsidence). In the recent years, both droughts (summers 2018 and 2023) and flashflood events (winters 2019/2020 and 2023/2024) have been recorded with large economic consequences to follow.

Soil moisture data has been collected at six agricultural sites across Denmark since 2000 by GEUS and at three field sites in Skjern characterized by different land covers (agricultural field, heathland and coniferous forest) since 2013/2014 by UCPH. These sites represent different weather regimes and soil types. This project will use data from these sites to investigate whether recorded soil moisture can be used as a predictor of drought and flash floods. The analysis will be data-driven, and will exploit additional data such as regional information of crop yield, floods, and satellite soil moisture data from SMAP.

Contact persons: Majken Looms Zibar (mcl@ign.ku.dk), Ida Karlsson Seidenfaden (GEUS, ika@ign.ku.dk) Mie Andreasen (GEUS, ma@geus.dk)

28. Hydrological modelling of nutrient-poor peatlands: Bøllemosen

The Bøllemosen bog, located 16 km north of Copenhagen, is encircled by forest and therefore generally nutrient poor. However, there are recent indications of deterioration of its ecological state which call for restorative actions. The bog has been previously biologically characterized, and, regarding nutrient loading, it is clear that the bog receives some nutrients by atmospheric deposition. However, little remains known about the hydrology and hydrogeochemistry of the bog, which may largely control the ecological state of the habitat. Therefore, in the proposed project, the influence of nutrient input from hydrological pathways will be addressed, in an assessment of the hydrogeology of Bøllemosen. Bøllemosen bog is one of 261 protected EU habitats in Denmark. Danish authorities therefore are responsible for securing or improving its ecological state.

Objectives

- Conduct a literature search to find existing (historical) hydrogeological data regarding Bøllemosen.
- Monitor a network of piezometers (existing + possibly new) and a rain gauge with respect to hydraulic head and water chemistry and stable isotopes of water.
- Conduct geophysical investigations in conjuncture with hand drillings and borehole information from existing borehole and create a conceptual hydrogeological model.
- Monitor the hydrology of surface hydrological features such as ditches, ponds, etc.
- Integrate the information with existing data to create a conceptual hydrogeological model and a water balance for Bøllemosen.
- Setup a numerical distributed hydrogeological model for Bøllemosen.

Contact persons: Majken Zibar (mcl@ign.ku.dk) and Søren Jessen (sj@ign.ku.dk)

29. Data-driven estimation of groundwater recharge

In Denmark, 100% of all drinking water is extracted from the groundwater resources. In order to sustainably use this resource, i.e. avoid a lowering of the groundwater table and maintaining the required inflow of groundwater to streams and lakes to ensure these ecosystems, it is necessary to quantify the amount and timing of water recharging the groundwater each year. Unfortunately, groundwater recharge is difficult to measure directly. Instead, this important water flux is typically estimated using hydrological models or by rearranging the water balance equation and using best-estimates of the other water fluxes, i.e.:

Recharge = Precipitation – (Evapotranspiration + Overlandflow + Interflow + Storage change).

This project will explore the possibilities of using time-series of river discharge to estimate land-cover dependent groundwater recharge in the Ahlergaarde catchment. The first step is to preform a hydrograph separation to remove the amount of river discharge that cannot be assumed to originate from groundwater recharge. Then a multi-station approach will be used to estimate the land-cover dependent recharge of the dominating land cover types in the area, i.e. agriculture, heathland, and forest. Finally, the estimates of recharge will be compared with modelling results from the DK-model and measurements of recharge below an agricultural field within the catchment.

Contact persons: Majken Looms Zibar (mcl@ign.ku.dk), Karsten Høgh Jensen (khj@ign.ku.dk) and Mie Andreasen (GEUS, ma@geus.dk)

30. Groundwater recharge below different land cover types

Since the 1990´s, planting forest has become a common water management practice. The change of agricultural land to forest (i.e., afforestation) is used to secure the quality of the underlying groundwater

resource by discontinuing the addition of nutrients, pesticides, and PFAS at the surface. In 2020, forest formed 14.7% of the total land cover in Denmark. It is a political goal that by the end of the 21st century, 20-25% of the country should be covered by forest. With increased afforestation, it is important to understand how different land cover types affect the water balance at the surface, and ultimately the groundwater recharge.

In this project 1D hydrological models (MIKE SHE using the SWAT module) will be setup for a unique field location close to Hillerød, i.e. the Frederiksborg ICP forest site. At this site, three different land cover types, i.e. open grassland, deciduous forest, coniferous forest, exist within 200 m of each other. Due to the close proximity, the external forcing of the system and the local geology are expected to be the same. Measurements of local throughfall, soil moisture, groundwater table are available at the three sites and will be used to calibrate the hydrological models to obtain estimates of groundwater recharge.

Contact persons: Majken Looms Zibar (mcl@ign.ku.dk), Karsten Høgh Jensen (khj@ign.ku.dk) and Mie Andreasen (GEUS, ma@geus.dk)

31. Your project?

Please remember that the above MSc Thesis ideas *are only ideas*. You are always welcome to bring your own ideas to the table, and to discuss with us in order to develop the project that suits you best.

Contact persons: Majken Zibar (mcl@ign.ku.dk), Peter Bauer-Gottwein (pbg@ign.ku.dk), Karsten Høgh Jensen (khj@ign.ku.dk) and Søren Jessen (sj@ign.ku.dk)