Rapport de stage individuel

4ème année

The hydrology of a restored wetland : the water balance of Runkenbjerg

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1. Introduction

1.1. Hosting structure presentation

As part of my training, I completed a 12-week internship at Aarhus University in Denmark, within the Department of Ecoscience. The Department of Ecoscience is a multidisciplinary research department in the field of environment and nature. It focuses on the study of life in its entirety. The department is involved in teaching, consultancy, and research.

The Department of Ecoscience comprises approximately 275 employees, with around 100 based in Roskilde and the rest located at AU Campus in Aarhus. In Roskilde, there are five sections, while the campus in Aarhus has six sections. Among the staff members, approximately 200 are permanent employees, with 15 being Ph.D. students, 20 postdocs, and around 40 on fixed-term contracts. The collaborative efforts extend to Danish and international institutions, fostering an engaging and inspiring environment for both employees and students.

The department adopts an ecosystem approach, which is divided into four main academic strengths:

- **Marine ecology:** The research focuses on understanding the structure and function of marine ecosystems across diverse systems, spanning from coastal zones to open marine areas in the Arctic, temperate, and tropical regions. A key objective is to differentiate between natural variations and changes induced by human activity. To accomplish this, tools and methods are developed for assessing the marine environment's state, analysing factors influencing ocean dynamics and health.
- **Terrestrial ecosystems**: The research conducted contributes to the development of strategies for green transition and sustainable production in agriculture and forestry, with a specific focus on nature-based solutions. Tools are developed to facilitate effective and cost-efficient nature conservation, while methods are employed to address conflicts between nature and disturbances, such as those arising from hunting and outdoor recreation. The institution serves as the host for the topic center 'Dry nature and species' under the national monitoring program NOVANA, with responsibilities encompassing methodological development, data analysis, and annual reporting on the state of nature.
- **Freshwater ecology**: The research environment encompasses aquatic freshwater biology and ecology at an internationally recognized level. It includes diverse freshwater ecosystems such as streams, lakes, ponds, and the surrounding rural areas (catchments) that direct water towards freshwater regions, including both natural and constructed wetlands. The research benefits from long-term data collected through field studies and the department's specialized test facilities in Lemming, which house controlled and manipulated mini ecosystems to study pelagic abiotic and biotic dynamics.
- **The Arctic environment and nature**: For several decades, there has been an internationally prominent role in Arctic research, monitoring, and consultancy. The focus is primarily on studying Arctic nature and the environment, particularly in Greenland, while facilitating knowledge transfer through collaboration and consultancy with Greenland's self-government and the Greenland Institute of Natural Resources. The geographic emphasis on the Arctic region encompasses a broad academic scope across trophic levels, ranging from microbes, plants, animals, and birds, and examining individual, population, and ecosystem levels in marine, freshwater, and terrestrial ecosystems.

And among these 4 academic strengths, multiple approaches or themes are used and shared by the areas of strength, such as biodiversity, green transition, Innovating monitoring etc.

Eventually, the Department of Ecoscience has the mission to advise government agencies on solving societal problems by providing research-based knowledge.

1.2. Presentation of the team

The Department of Ecoscience has several areas of research, and this internship falls within the Catchment Science and Environmental Management section. Within this section, research is conducted to gain new knowledge and insights into the threats faced by aquatic areas, including lakes, streams, and fjords. These consequences arise from increased nutrient input, environmentally hazardous substances, and other factors resulting from urban communities, agriculture, global climate change, and human activities. The acquired knowledge serves as a basis for providing consultancy to various national and international authorities, as mentioned above. By doing so, the aim is to ensure that the management of the aquatic areas is informed by the latest research findings. Activities in this catchment section can be divided into four core areas:

- Nutrient dynamics and hydrology
- Tools for reducing nutrient loss to the aquatic environment
- Wetlands and greenhouse gases
- Stream ecology

This internship took place within the Wetlands group, a subgroup of the Catchment Science and Environmental Management section.

The Wetland group consists of interdisciplinary scientists involved in freshwater wetland research. The research focuses on various aspects such as ecology, hydrology, biogeochemistry, and modelling within the field of wetland studies. Numerous significant projects at the Danish, Nordic, and European levels are currently underway. These projects primarily concentrate on riparian wetland restoration, restoration of low-lying organic soils, and the implementation of mitigation strategies to address nutrient loads originating from agricultural catchments. These mitigation measures include the use of constructed wetlands, integrated buffer zones, and saturated buffer zones.

This research group is comprised of approximately ten researchers and seventeen ongoing projects, including the project in which this internship is part of, the NIFA project [1].

1.3. Presentation of the mission

1.3.1. Context and problematic of the internship

In 2000, the European Union Water Framework Directive (European Commission, 2000) was established as a measure to address the pollution of water resources and safeguard the quality of surface water. This directive was specifically designed to tackle the multitude of pollution threats faced by these vital aquatic systems. Among the most significant pollutants are nitrogen (N) and phosphorus (P), whose excessive presence has become a pressing concern over the past five decades due to their detrimental effects on water quality and biodiversity (Petersen et al., 2020b). The primary consequence of the excessive N and P levels in water bodies is eutrophication. This process can lead to an increased biomass and changes in species composition of suspended algae. It can also have harmful diel fluctuations in pH and in dissolved oxygen concentrations and increase the probability of fish kills (Smith et al., 1999).

Wetlands act as vital interfaces between surface waters and uplands, playing a pivotal role in regulating nutrient flow into downstream areas. By serving as buffer zones, wetlands effectively reduce N loads in soils (Dørge, 1994). Consequently, Denmark established the Danish Action Plan on the Aquatic Environment II (DAPAE-II) in 1998, aiming to restore wetlands and decrease N levels in downstream recipients and the sea.

Denitrification and vegetation uptake, occurring within the soil, have been identified as the primary mechanisms for N removal in wetlands (Hill, 2019). Studying N removal in wetlands requires understanding hydrology, particularly the dominant flow paths (figure 1). The efficiency of N removal depends on these pathways, as some favour microbial denitrification more than others. Optimal denitrification requires anaerobic soils and sufficient carbon supplies. Research has shown that subsurface N removal is generally more efficient than surface flow removal (Mayer et al., 2007). Groundwater flow proves to be a more favourable environment for denitrification compared to direct overland flow. This is attributed to groundwater flow providing ideal conditions such as suitable soil moisture, low redox potential, high residence time, and temperature (particularly in winter when the temperature of the groundwater, around 8°C, is warmer than the water surface, encouraging higher rates of denitrification), enhancing N removal processes (Vidon et al., 2010).

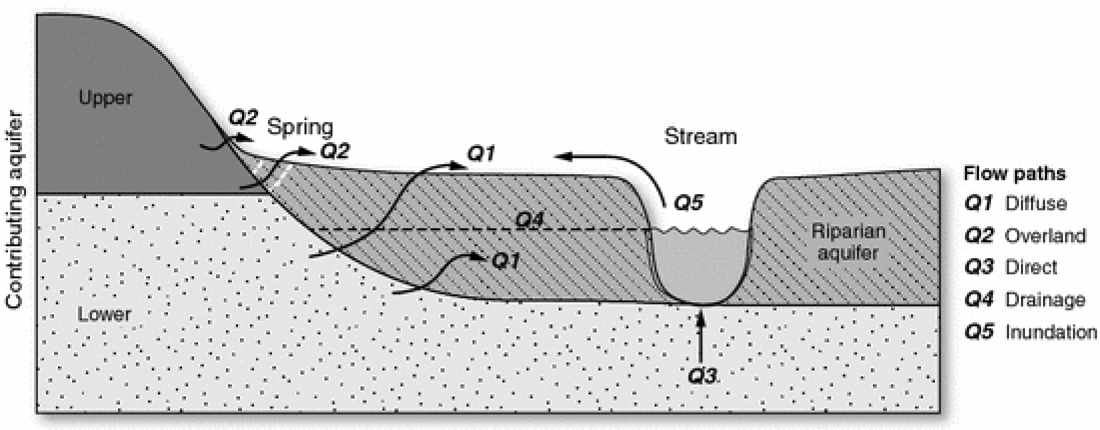

Figure 1: Dominant flow paths in a wetland (Hoffman et al., 2011)

The subject of study for this internship lies within the context mentioned above. The objective is to investigate the water balance and the diverse flow paths of water in Runkenbjerg, a restored drained wetland in Denmark. The end goal is to quantify transport, removal and/or release of nitrogen (N) and phosphorus (P) within this wetland ecosystem. Such nutrient balances rely entirely on water balances, and thus the identification and quantification of distinct flow paths in and out of the wetland is the foundation for investigations of wetland nutrient balances. This research topic is an integral part of the NIFA project, described in more detail in the following paragraph, which aims to monitor restored low-lying organic soils and gain insights into the hydrological and biogeochemical transformations before and after the rewetting process. The ultimate goal of this internship is to contribute to improving the understanding of the consequences of rewetting of wetlands from a hydrological and nutrient point of view, essentially N and P. More specifically, the goal is to calculate the water balance of a restored wetland in Runkenbjerg with a special focus on the groundwater flow.

1.3.2. NIFA project

The NIFA research project running from 2021-2025 is about the restoration of wetlands and the environmental effects of the restorations on hydrology, water quality, carbon sequestration and biodiversity. The NIFA project is divided into 8 subprojects in collaboration with Danish Centre for Environment and Energy (DCE) at Aarhus University, Southern Denmark University and the Geological Survey of Denmark and Greenland (GEUS). Currently, the Wetland group is working on 6 subproject or research topics, which include:

- Investigating nitrogen and phosphorus removal.
- Studying water sources and fluxes.
- Modelling the risk of nutrient swapping.
- Examining the impact of plant harvesting and filter materials as phosphorus traps.
- Assessing the effects of topsoil removal on phosphorus loss, greenhouse gas emissions, and biodiversity.
- Developing a toolbox for assessing the environmental effects of rewetting (figure 2).

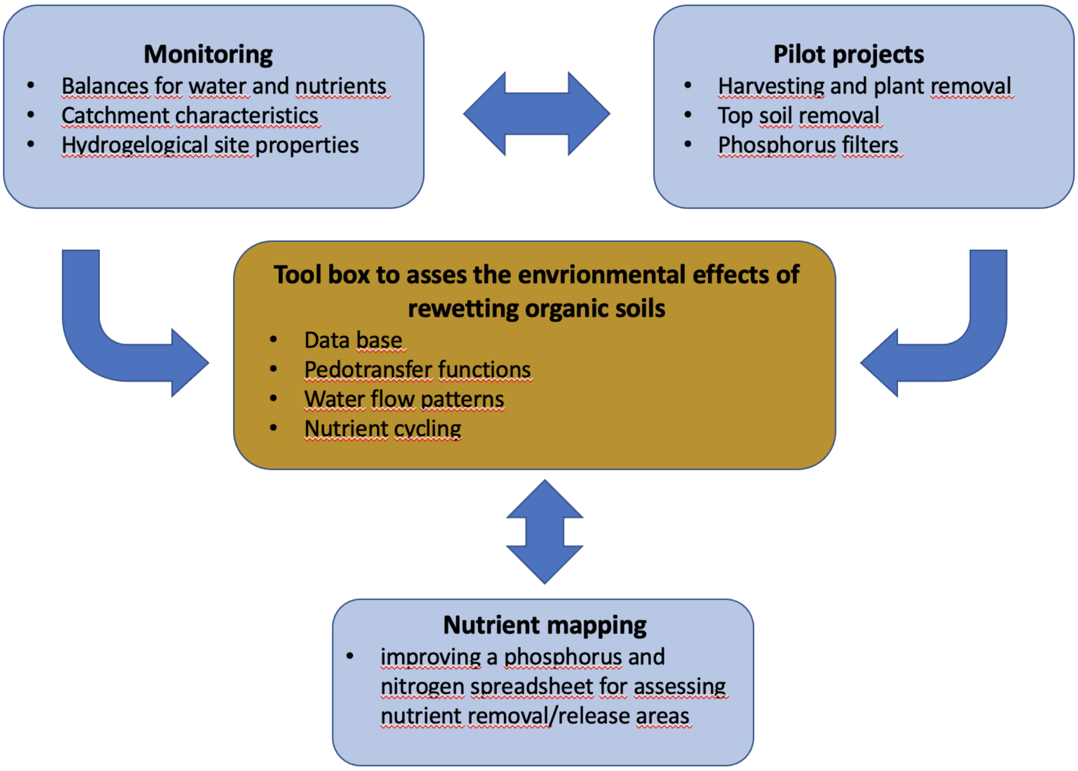

Figure 2: NIFA project overview (Source: Aarhus University)

The project network receives funding from the Environmental Ministry of Denmark and maintains close connections with the peatland restoration monitoring project called "ReWet-DK". This collaboration supports the instrumentation of the NIFA project sites and other project locations to be established as "Living Wetland Labs” (figure 3). These labs serve the purpose of closely monitoring greenhouse gas emissions, water dynamics, and nutrient fluxes in organic soils.

Figure 3: All wetlands included in the NIFA project. (Source : Rasmus Jes Petersen)

1.3.3. Tasks carried out during the internship

During this internship, I was given several tasks. The most important part was the water balance calculation, carried out entirely using the Python programming language. The data for calculating this water balance were supplied directly to me. The other part of my internship was the modelling of the groundwater flow. To do this, I carried out slug tests in the field, then calculated the groundwater flow using Excel. I made several other field trips for various missions, all closely or distantly related to the subject of my internship, such as collecting water samples or cleaning piezometers. Finally, unless otherwise stated, the maps in this report were produced by me. The data for them were entrusted to me by my supervisor, Rasmus Jes Petersen.

2. Materials and Methods

2.1. Site description

The study site is Runkenbjerg, a wetland located in the municipality of Vejle, in eastern Jutland, Denmark (55°38'56.8 "N 9°16'30.8 "E). The study area covers approximately 18.47 hectares. To the west of the area, there is a hillside, while an adjacent stream runs along its eastern boundary. The northern and southern parts of the study area consist of extensively managed grasslands and natural areas, including Natura 2000 zones. Prior to the restoration project, Runkenbjerg was an area of pasture in rotation, grazed by cows [2].

The climate near Runkenbjerg is mild temperate. Significant precipitation is recorded throughout the year, even in the driest months. The average annual temperature is around 8.7°C. Annual precipitation averages 782 mm. The hottest month is July, with an average temperature of 17.0°C, and the coldest month is February, with an average of 1.3°C. As for precipitation near Runkenbjerg, the wettest month is August, with 82 mm of precipitation. The least rainy month is April, with 50 mm of precipitation (these data apply to the town of Vejle, near Runkenbjerg, and are an average from 1991 to 2021.) [3].

The restoration project at Runkenbjerg spanned from May 2015 to June 2018, with the actual rewetting of the area taking place between August and October 2017. This project was undertaken as part of the EU's rural development program. The primary objective of the project was to mitigate greenhouse gas (GHG) emissions from carbon-rich low-lying soils by implementing measures such as ceasing cultivation and reestablishing natural hydraulic conditions through the removal of drains and ditches.

By creating oxygen-poor conditions through soil flooding, the project aimed to prevent further peat degradation and minimize the release of carbon dioxide (CO_2) into the atmosphere. To estimate the potential reduction in t CO_2-eq per ha per year that a wetland restoration project could achieve, a preliminary study was conducted. Furthermore, another study focused on determining the specific actions necessary to maximize CO_2 reduction.

The findings of these studies indicated that the restoration project at Runkenbjerg would result in an annual reduction of 395 tonnes of CO_2-eq per year [1].

Runkenbjerg encompasses multiple monitoring points to assess its hydrological characteristics. Firstly, there is an inlet named “Inlet Forest” (Indløb skov) (figure 4), positioned at the forest exit. This inlet is equipped with an electromagnetic flowmeter (Krohne WaterFlux 3070), measuring the continuous flow of water flowing over the surface at the wetland inlet.

Additionally, there are two outlets from the wetland. The first outlet, “Outlet Forest” (Udløb skov), enables the measurement of surface water leaving the wetland. The second outlet, “Overflow” (Overløb), allows the measurement of overflow water from the wetland.

To monitor groundwater flow, the wetland area is equipped with a network of 44 piezometers, organized into 13 nests. These piezometers provide valuable data regarding groundwater movement and levels within the wetland.

The combined data collected from the inlets, outlets, and piezometers will be utilized to determine the water balance of the wetland. The inlets and outlets allow for the measurement of surface water flow, while the piezometers offer insights into groundwater flow patterns. This comprehensive approach aids in developing a holistic understanding of the wetland's water dynamics.

In addition to these measurement points, two stream stations, “Inlet” and “Outlet” (Indløb and Udløb, respectively), are located along the stream that borders the wetland. These stations are designed to measure stream flow immediately upstream from the wetland and immediately downstream from the wetland (figure 4).

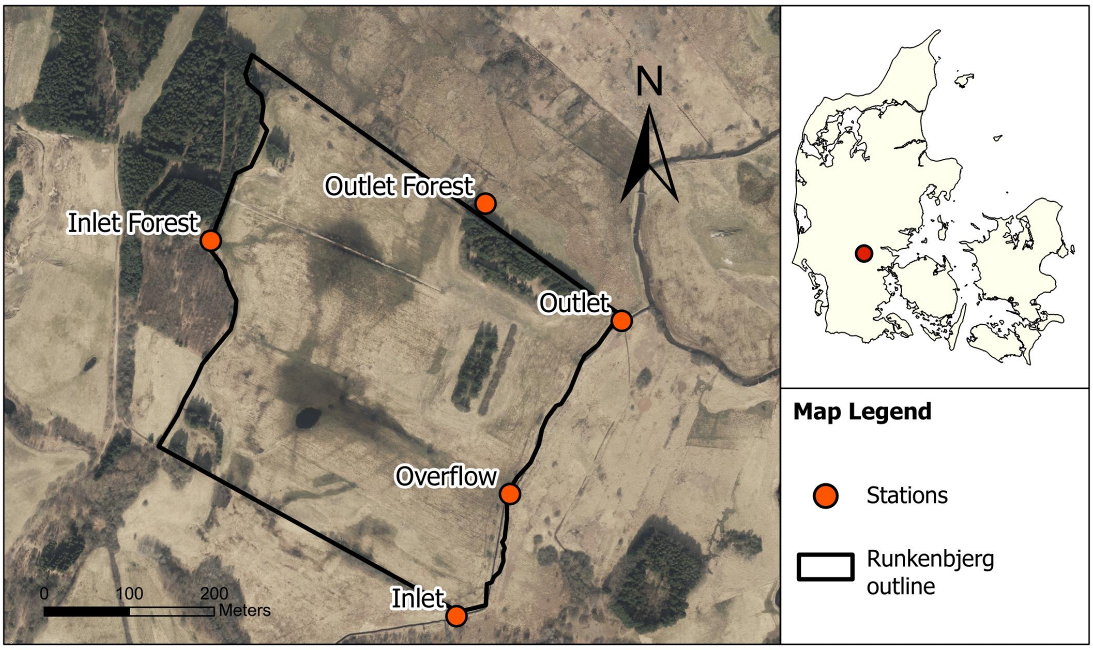

Figure 4: Localisation of the different stations in Runkenbjerg

2.2. Soil characteristics

In previous studies, before installation of piezometer pipes, a soil survey was carried out.

The various soil layers were determined in thirteen boreholes drilled along transects (figure 5). In short, the soil profile is typical of a wetland area, with a thin layer of sand (0 to 1 m) on top usually followed by a layer of peat (up to several meters), then a layer of gyttja, considered impermeable (also up to several meters). Finally, there's another layer of sand.

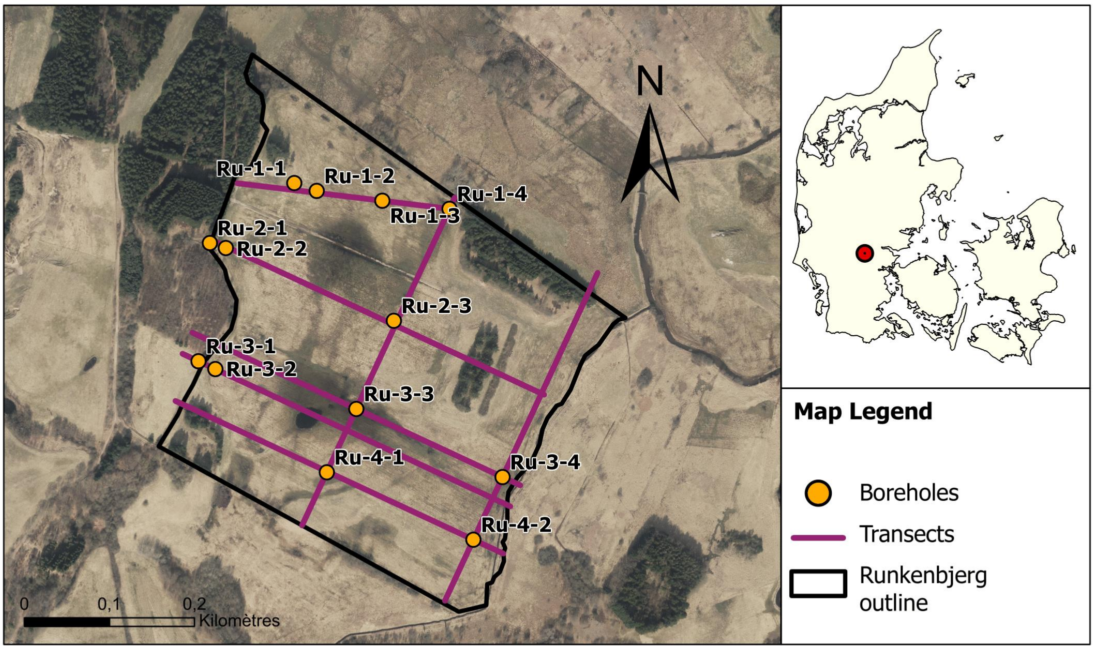

Figure 5: Localisation of the boreholes along the transects in Runkenbjerg

In addition to the boreholes, soil resistivity was also measured using towed, ground-based, transient electromagnetic system (tTEM) to determine the extent to which the soil conducts an electric current, and thus gain insight into the different soil layers.

Knowing the composition of the soil is crucial to understand the behaviour of the groundwater. For example, water flowing through clay or gyttja will be much slower than water flowing through sand.

Regarding peat, hydraulic conductivity varies significantly in this type of soil (ranging from 10^-8 to 10^2 cm/sec). This variation across different types of peat can be attributed to factors such as overburden pressure, bulk density, substance volume, and composition. Additionally, there have been few attempts to confirm if peat adheres to Darcy's law for fluid flow (Rycroft et al., 1975).

2.3. Hydrology

2.3.1. Water balance calculation

In order to understand the hydrology of a wetland, i.e. the different paths taken by water when it reaches the wetland, it is necessary to calculate what is known as the water balance. For the purposes of this internship, the water balance formula is as follows:

$$GW_{in} + SW_{in} + P = GW_{out} + SW_{out} + ET + \Delta S$$

With:

- **GW**: Ground water in and out
- **SW**: Surface water in and out
- **P**: Precipitation
- **ET**: Evapotranspiration
- **ΔS:** Storage

The water balance therefore consists of calculating the water arriving in the study area and subtracting the water leaving the study area.

2.3.2. Surface water flow

The "Inlet" and "Inlet Forest" inlets, the "Outlet" and "Outlet Forest" were used to calculate the surface water component. The “Inlet” and “Outlet” stations are used to determine the flow into and out of Runkenbjerg in the stream, while the “Inlet Forest” and “Outlet Forest” stations are used to determine the flow of water entering and leaving the wetland by runoff or infiltration. To help fill gaps in the flow time series a nearby reference station (“Afløb Engelsholm Sø”) was included in the analyses.

To calculate surface water flow, the programming language Python 3.10.9 was used under the open-source web application Jupyter Notebook.

To obtain this initial continuous discharge data, it is necessary to establish a relationship between discharge and water level (Q-h relationship). Since water levels were measured continuously,

it is therefore possible to estimate the discharge at a station by establishing a relationship between water level and discharge. However, no linear regression was satisfactory.
Consequently, an alternative approach was employed. A gauging station located outside the study area, but with similar conditions, was utilized to obtain continuous discharge data. This allows for the application of the Q-Q relationship method without relying on the Q-h relationship. By utilizing data from the "Afløb Engelsholm Sø" gauging station, continuous discharges at the inlet and outlet of the Runkenbjerg stream can be determined.

To determine the continuous discharges at the "Inlet" and "Outlet" stations, where the discharges are not measured continuously, it is necessary to establish a discharge-discharge relationship (Q-Q relationship) between these stations and a station with continuous measurements. Scatter plots were created, plotting the discharge of one station on the x-axis against the discharge of the other station on the y-axis. These graphs allow for the identification of a relationship, whether linear or otherwise, between the different discharges.
By establishing this relationship, it becomes possible to estimate the discharge at one station based on the discharge measured at another station. Therefore, with continuous discharge data available for a single station, it becomes feasible to infer the continuous discharge at all stations using the Q-Q relationships. However, this approach relied on having knowledge of the continuous discharge at one station.

The second step is to determine the discharge at the "Inlet Forest" and "Outlet Forest" stations. The "Inlet Forest" station is equipped with an electromagnetic flowmeter (EM flowmeter). A logger connected to the flowmeter registers a count for every 100 L passing through the flowmeter. Unfortunately, due to a faulty logger, only the cumulative flow read manually during field visits every three weeks were available. An estimate of discharge based on the available values was therefore made in order to obtain daily discharge rates. As for the "Outlet Forest" station, the Q-Q relationship method can be applied.

2.3.3. Precipitation and evapotranspiration

Precipitation and evapotranspiration data were obtained from the Danish Meteorological Institute (DMI) and are contained in the Climate Grid Denmark dataset. The Climate Grid Denmark is made up of 609 10 km x 10 km grid cells used for precipitation and 178 20 km x 20 km grid cells used for evapotranspiration. This Climate Grid Denmark covers the entire Danish land area (Danish Meteorological Institute).

To ensure accurate precipitation measurements, the values obtained from rain gauges are corrected for measurement biases. Wind-induced turbulence is one such bias that can affect the accuracy of measurements. The presence of wind can disrupt the normal flow of precipitation into the measuring device, leading to distorted results.
Another significant measurement bias is evaporation. Evaporation can occur from the free water surface of the precipitation inside the gauge, or it can result from the evaporation of a small portion of the precipitation adhering to the walls of the gauge. Both scenarios can lead to an underestimation of the actual precipitation amount collected (Danish Meteorological Institute).

To calculate precipitation and evapotranspiration for the water balance, the data obtained from the DMI must be multiplied by the Runkenbjerg surface area. This is done to determine the amount of water precipitated or evaporated over the study area, and thus to include it in the water balance of the wetland. Two distinct areas were identified for which to calculate precipitation and evapotranspiration. The first area, referred to as the "left" area, represents the rainfall occurring directly over the study area that can reach the stream. The second area, denoted as the "right" area, accounts for rainfall occurring to the right of the stream that can also contribute to the stream's water flow (figure 6). This "right" area was determined using the topographic catchment area based on the national Danish digital elevation model (0.4 m × 0.4 m horizontal resolution, 0.05 m vertical accuracy).

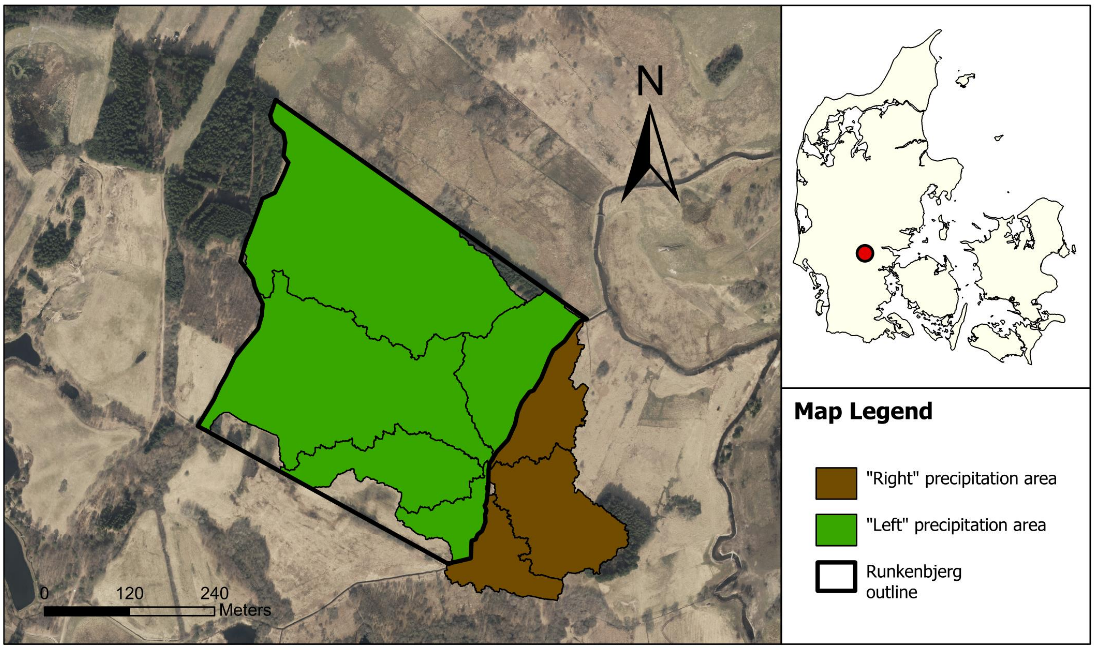

Figure 6: The two areas used to calculate precipitation and evapotranspiration

Multiplying the level of rainfall or evaporation by the surface area of the study area gives a volume of water precipitated or evaporated at Runkenbjerg per day, as precipitation or evapotranspiration values are measured every day.

2.3.4. Groundwater flow

2.3.4.1. Theory

Groundwater flow occurs when water migrates through water saturated subsurface material such as soil or rock. Water is stored in porous spaces in the ground, in cavities, cracks, etc. There are two types of groundwater systems. There is a confined system and an unconfined system. An unconfined system is one where water can be exposed at the surface. A confined system, on the other hand, is a deeper system with an upper boundary that puts the water under a certain pressure. In the context of this internship, only unconfined groundwater flow will be considered.

Groundwater flow may be determined via the other components of water balance. For example, the water balance equation can be expanded to:

$$\underbrace{Q_{inlet} + Q_{inlet\ Forest}}_{SW_{in}} + \underbrace{P_{left\ side} + P_{right\ side}}_{P} + X = \underbrace{Q_{outlet} + Q_{outlet\ Forest}}_{SW_{out}} + \underbrace{ET_{left\ side} + ET_{right\ side}}_{ET}$$

In this formula, the X corresponds to groundwater flow. Knowing all the other parameters, it is therefore possible to determine the quantity of water coming from the ground.

Another way of determining the amount of groundwater flow is to model it using Darcy's Law. Darcy's law is a fundamental equation in fluid dynamics that provides a phenomenological description of fluid flow through porous media. The law was formulated by the French engineer, Henry Darcy, based on the results of experiments on water flow through sand beds (Abdon Atangana, 2018). The formula of Darcy's law is as follows:

$$q = -K \times \frac{dh}{dx}$$

With:

- **q**: the flux discharge per unit area, with units of length per time (m/s)
- **K**: the hydraulic conductivity (m/s)
- **dh/dx**: the hydraulic gradient (figure 7)

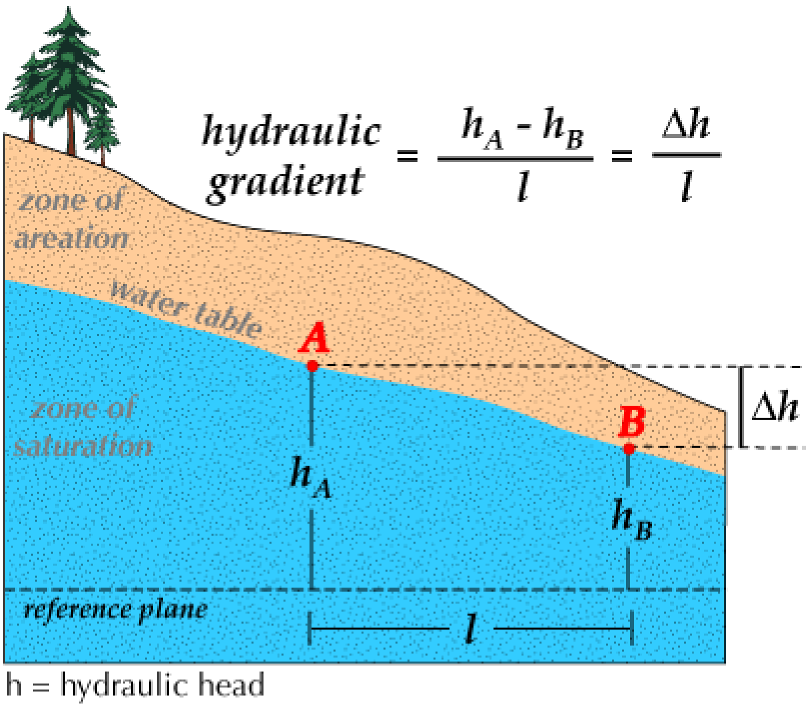

Figure 7: Hydraulic gradient measurement (with : hA – hB = dh ; l = dx)

To obtain the hydraulic gradient, as illustrated in the provided figure, a straightforward method involves measuring the difference in elevation between two points and dividing it by the distance separating the two points. In the context of this study, the elevation difference and distance are measured between two piezometers.

As for hydraulic conductivity, this parameter quantifies the degree to which a medium facilitates the movement of water. Materials with higher hydraulic conductivity allow for easier water transmission compared to those with lower hydraulic conductivity. This parameter depends on both properties of the porous medium and the fluid (e.g., density and viscosity). In this case, water is the fluid so constant values of density and viscosity are expected (neglecting temperature dependencies) (Schwartz and Zhang, 2002). The hydraulic conductivity can be determined using a slug test. The slug test method is specifically developed for piezometers or wells and is utilized to estimate hydraulic conductivity (K). In a slug test, the water level in the borehole is rapidly raised or lowered, and the subsequent response of the water level over time is observed as it returns to its initial position (William W. Woessner, 2017).

Once the flux discharge per unit area (q) is known, all that remains to do is multiply this value by the width of the soil layer and the area of the zone to obtain a flow rate.

$$Q = q * L * A$$

With:

- **Q**: the discharge in m^3/s
- **L**: the width of the soil layer in m
- **A**: the depth of the soil layer in m

2.3.4.2. Slug tests

The "slug test" is a method for determining the hydraulic conductivity of a soil. Knowing this hydraulic conductivity value, it is then possible to determine the groundwater flow using the Darcy's law formula described above.

The method used here is the method developed by Bouwer and Rice (1976). It involves abruptly changing the water level in a piezometer and measuring the gradual return of the water level to an equilibrium position (Herman Bouwer, 1989).

Specifically, when the water level in a piezometer was less than one meter above the top of the screen, water was rapidly added to the piezometer. When the water level was more than one metre above the top of the screen, water was rapidly pumped out, the height of water pumped out depending on the height of the water column above the screen. If the water level was below the top of the screen, then the slug test could not be performed.

The formula for determining hydraulic conductivity is as follows:

$$K = \frac{r_c^2 \ln\left(\frac{R_e}{r_w}\right)}{2\, L_e} * \frac{1}{t} * \ln\frac{y_0}{y_t}$$

With:

- r_c**:** the radius of the casing
- R_e**:** the effective radial distance over which y is dissipated
- r_w**:** the radial distance of undisturbed portion of aquifer from centerline

- **L_e:** the length of the screen
- **y_0:** the vertical difference between water level inside piezometer and static water table outside piezometer at time 0
- **y_t:** the vertical difference between water level inside piezometer and static water table outside piezometer at time t (figure 8).

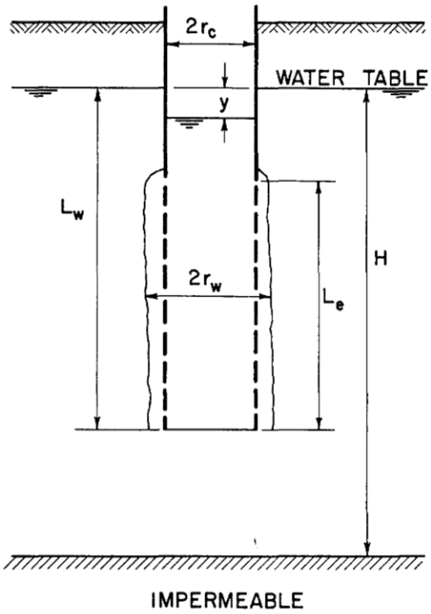

Figure 8: Geometry and symbols for slug test in an unconfined aquifer. Diagram taken from Herman Bouwer, 1989.

The first step in a "slug test" is to measure the initial water level, then, depending on this water level, the piezometer is either filled or pumped. The water level is then measured regularly, in this case every second, until the water has returned to approximately 2/3 of the equilibrium position. The water level is measured using a probe (Solinst 3001 Levelogger 5) inside the piezometer, which measures the absolute pressure (water column + atmospheric pressure). A second probe (Solinst 3001 Barologger 5), measuring atmospheric pressure, is then used to determine the water level. Then, from these measurements, a graph showing the water level as a function of time is plotted. And from this graph, another can be obtained enabling K to be known. This plot is a plot of ln y_t versus t. It shows a straight line. Then, several y and t measurements can be taken and [ln (y_o/y_t)] /t determined as the slope of the best-fitting line through the y versus t. These graphs are shown in the results section.

3. Results

3.1. Soil characteristics

What emerges from these boreholes is that, overall, the soil at Runkenbjerg is composed of 3 different layers of varying thickness. A first layer of sand is found in almost all the boreholes, except for 2-2, 2-3, 3-2 and 3-4. Boreholes 2-2, 2-3 and 3-2 are initially made up of a thin layer of detritus mud. This sand layer varies from 0 to 1 m (borehole 2-1). After the sand layer comes a layer of peat, which also varies in thickness, up to several meters. Finally, in most boreholes, the next layer is composed of gyttja, an organic lake sediment, which relatively to sand and peat may be considered impermeable.

These three main layers are generally underlain by another layer of sand, except for boreholes 3-3 and 3-4, which have a layer of clay.

3.2. Hydrology

3.2.1. Surface water flow

As mentioned in the method section, graphs representing the Q-Q relationship between two stations were produced in Python (figure 9).

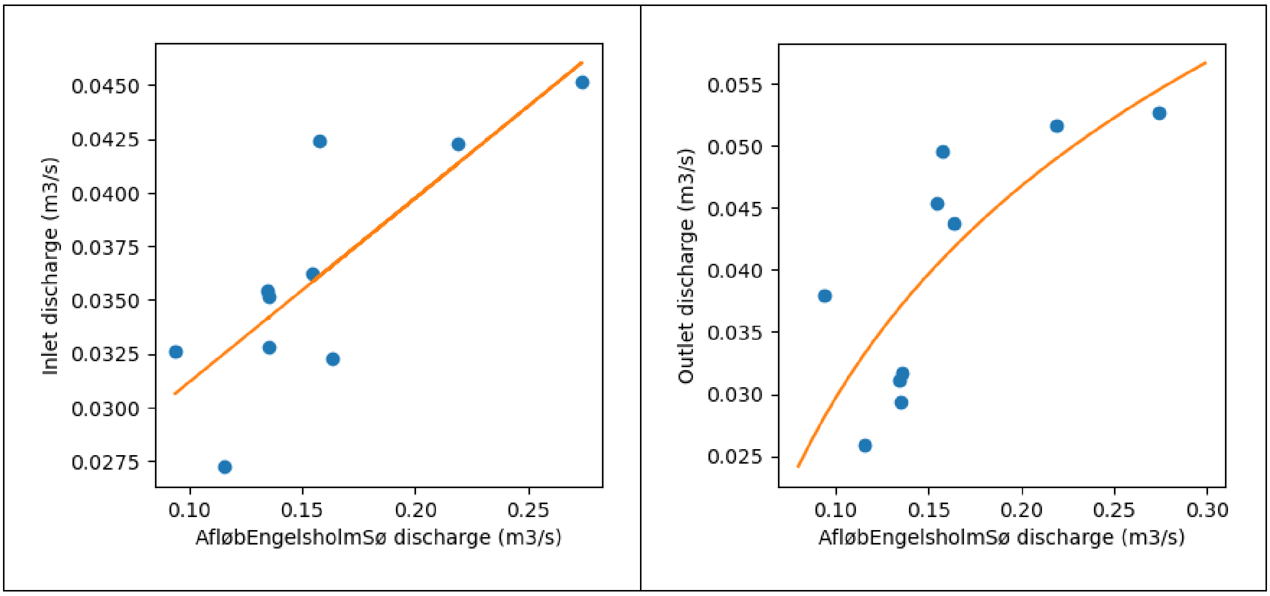

Figure 9: Q-Q relations to determine continuous discharge at the Inlet and the Outlet.

On the x-axis, for both graphs, are the discharges of the reference station "Afløb Engelsholm Sø" and on the y-axis the discharges of the Inlet and Outlet, respectively. The discharge from the reference station is continuous, but that from the Inlet and Outlet is not. So, to produce these graphs, the number of values for the Inlet and Outlet was a limiting factor. Indeed, the same dates had to be compared with each other. Relationships were found for each graph in order to obtain continuous discharge for the Inlet and Outlet. A linear relationship was thus determined for the Q-Q relationship involving the Inlet with a coefficient of determination of 0.652. A non-linear relationship was found for the Q-Q relationship involving the Outlet with a coefficient of determination of 0.564. In the absence of a better reference station, these relationships were used to determine continuous discharges.

Continuous discharge at the Inlet and Outlet was therefore determined and plotted on the following graph (figure 10).

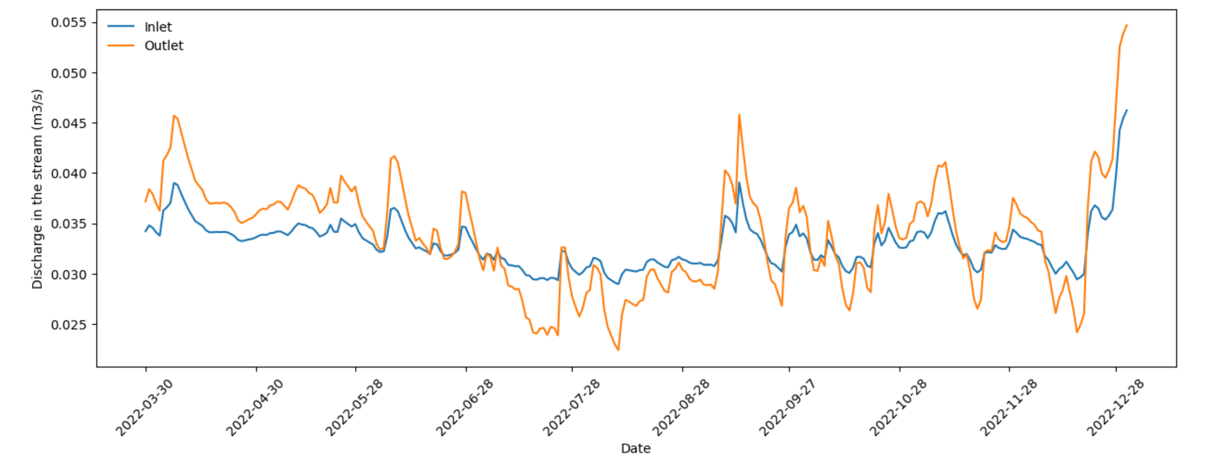

Figure 10: Continuous discharge at the Inlet in blue and at the Outlet in orange.

The discharge values obtained are those for the period March 30, 2022, to December 31, 2022, at the Inlet (blue) and the Outlet (orange). The minimum discharge at the Inlet is 0.029 m^3/s at the beginning of August, and the maximum discharge is 0.046 m^3/s at the end of December. For the Outlet, the minimum discharge value is 0.022 m^3/s in August and the maximum value is 0.055 m^3/s in December. In spring, overall, there is more discharge at the Outlet than at the Inlet, the opposite is true in summer, and there is almost as much flow in as out in autumn.

Continuous discharges were also determined at Inlet Forest using an EM flowmeter. However, most values had to be calculated manually following a malfunction of the flowmeter. To obtain continuous discharge values, we had to calculate the difference between two values, then divide the result by the number of days between two measurements. The result obtained is therefore a mean flow for some random days. Finally, the flows had to be transformed into discharges. Only a dozen values were available. To obtain data for each day, the values were duplicated between two measurements.

3.2.2. Precipitation and evapotranspiration

As can be seen from the graphs (figure 11 and 12), the amount of water precipitated or evaporated is much greater for the left-hand side, as it has an area almost 4 times larger (17.08 ha for the left-hand side and 4.4 ha for the right-hand side).

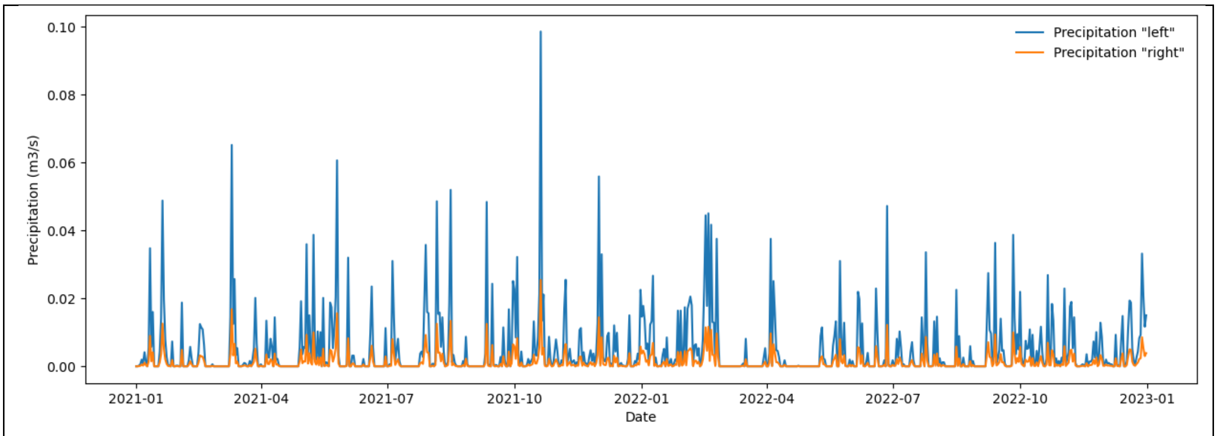

Figure 11: Precipitation in the area of Runkenbjerg in blue and in the right side of the stream in orange.

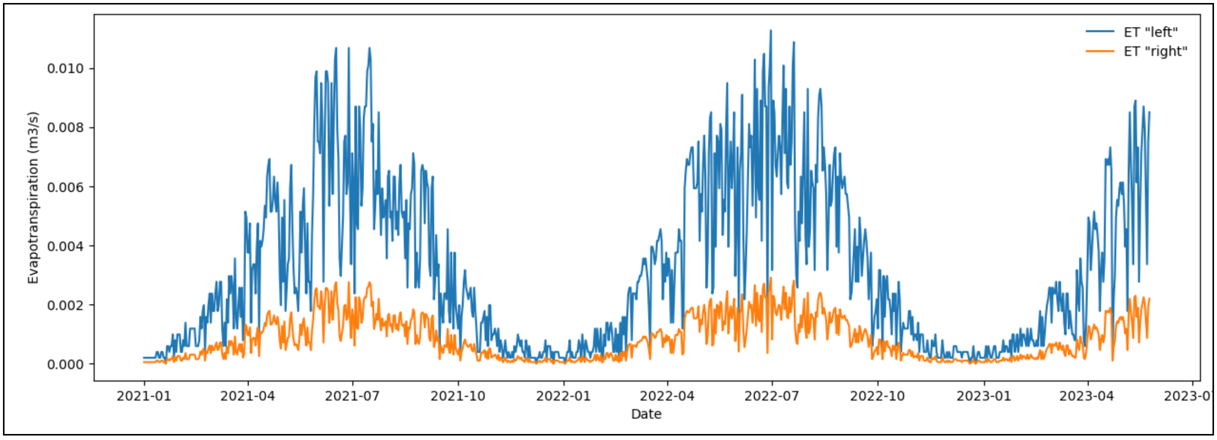

Figure 12: Evapotranspiration in the area of Runkenbjerg in blue and in the right side of the stream in orange.

While for precipitation no pattern is easily identifiable, for evaporation on the contrary a pattern emerges. In fact, evaporation is almost nil in the December-February period and reaches 0.010 m^3/s in the June-August period for the "left" part and 0.002 m^3/s for the "right" part.

3.2.3. Water balance

After summing the discharge at the Inlet, the Inlet Forest and precipitation on one side, and the outlets and evapotranspiration on the other, the following graph was obtained with the discharge curve arriving at Runkenbjerg in blue and the discharge leaving Runkenbjerg in orange (figure 13). The discharge from the Outlet Forest could not be added to the water balance. Very little data was available for this station, so it was impossible to find a suitable relationship for the Q-Q relation graph. A linear interpolation between measurements was therefore carried out. A graph comparing Inlets and Outlets on a monthly basis was also plotted (figure 14).

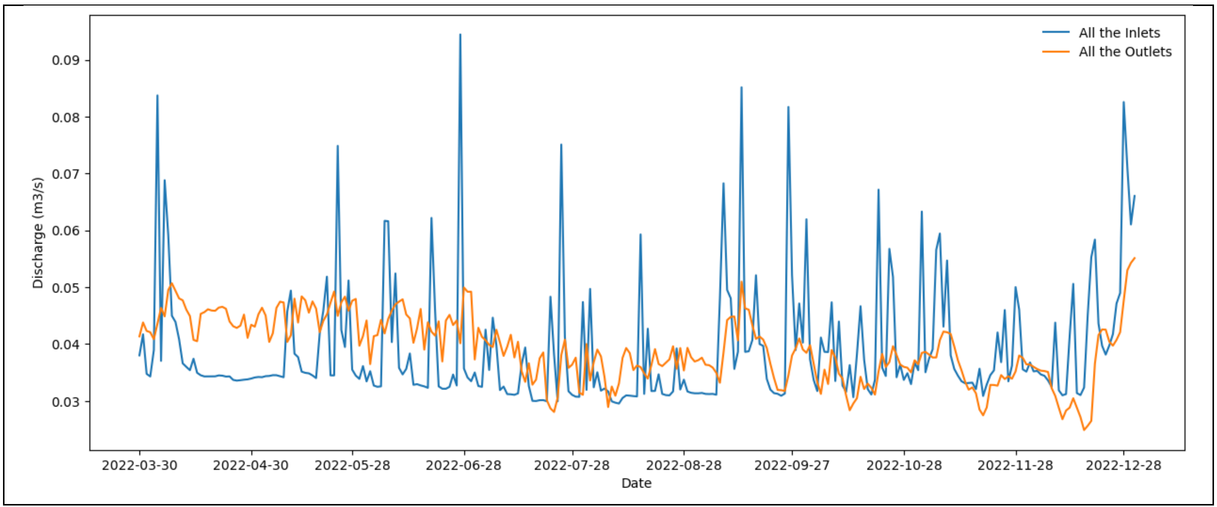

Figure 13: Water balance of Runkenbjerg.

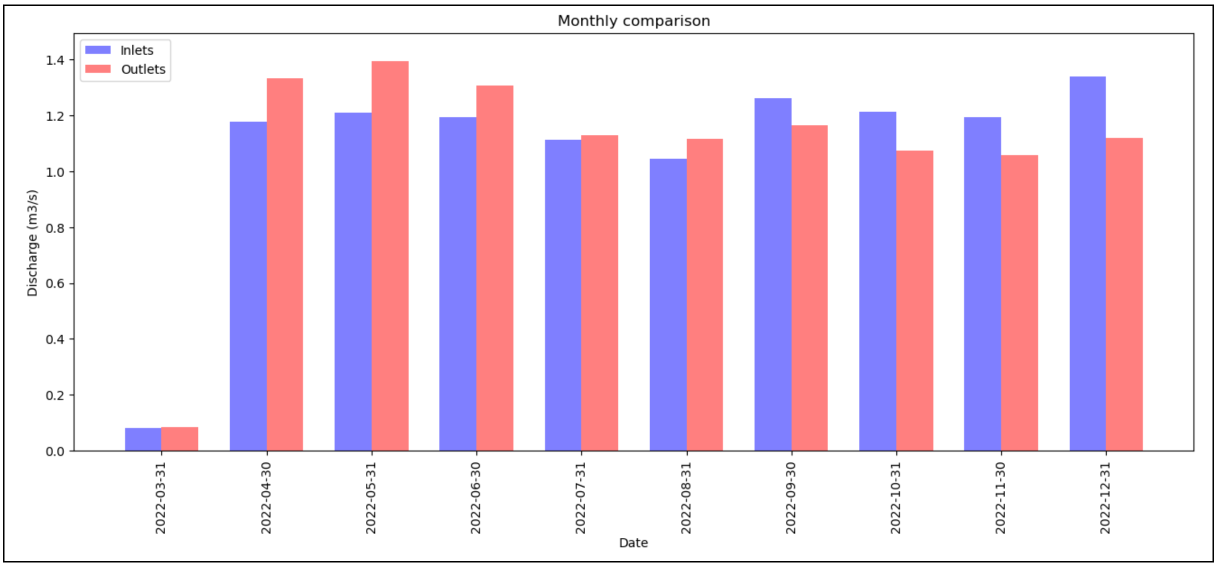

Figure 14: Monthly comparison of the Inlets and the Outlets.

The monthly comparison graph gives a clear picture of the discharge entering and leaving Runkenbjerg each month. Visually, it appears that in total, the discharge entering the zone is more or less equal to that leaving it. The total sum of inflows and outflows has therefore been calculated. The total sum of inflows is 259.10^6 m^3 and the total sum of outflows is 258.10^6 m^3. According to the results of this water balance, there is no groundwater flow nor overland flow, although there should be. In this case, the water balance is not viable for calculating groundwater flow. A change of method is therefore necessary.

3.2.4. Groundwater flow

After carrying out the slug tests in the field, a graph was obtained for each piezometer showing the water level in the piezometer as a function of time. In the rest of the results, only one example of a graph used to determine the hydraulic conductivity (K) for a piezometer will be presented (figure 15).

To determine groundwater flow, a pair of piezometers is needed to obtain a hydraulic gradient and thus be able to use Darcy's Law. To determine the groundwater flow entering the wetland, pairs of piezometers Ru-1-1/Ru-1-2, Ru-2-1/Ru-2-2 and Ru-3-1/Ru-3-2 were used. To determine the outgoing groundwater flow, the Ru-1-3/Ru-1-4, Ru-3-3/Ru-3-4 and Ru-4-1/Ru-4-2 piezometers were used (figure 5).

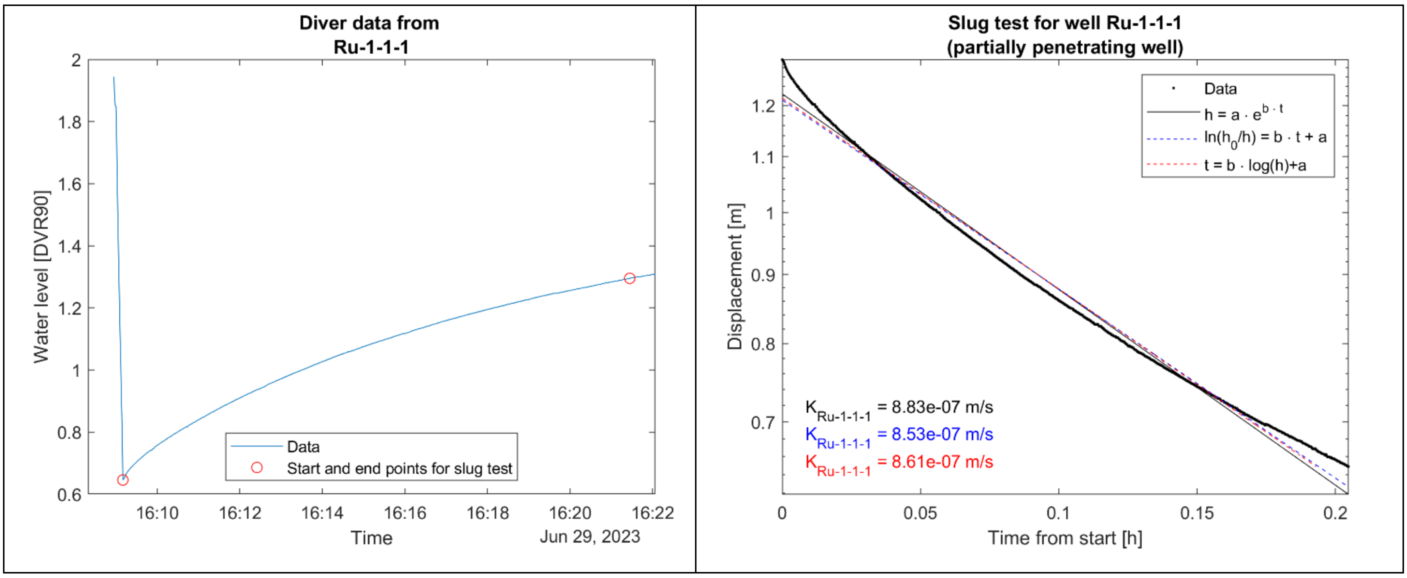

Figure 15: Graph 1: Slug test results for the piezometer Ru-1-1-1. Graph 2: Curve fit to determine the hydraulic conductivity.

The slug test results presented above are from the Ru-1-1-1 piezometer (the piezometer with the deepest screen in the Ru-1-1 piezometer nest) located to the north-west of the Runkenbjerg site. The first graph was obtained in the field on 29 June 2023. The second was obtained using the MATLAB programming language.

Several K values were obtained as different curve fits were plotted to try and find the most appropriate one. The same graphs for all the other piezometers were plotted and a K value was chosen for each (table 1).

Table 1: Soil type corresponding to the different piezometer screens and the associated K values.

Piezometer	Screen's Soil	K (m/s)	Piezometer	Screen's Soil	K (m/s)
Ru-1-1-1	Sand	8,61E-07	Ru-3-1-1	Sand	8,99E-06
Ru-1-1-2	Peat	4,71E-09	Ru-3-1-2	Sand	-
Ru-1-2-1	Sand	6,23E-06	Ru-3-2-1	Sand	4,83E-05
Ru-1-2-2	Peat	1,45E-06	Ru-3-2-2	Peat	2,19E-06
Ru-1-2-3	Peat	3,36E-07	Ru-3-2-3	Sand	-
Ru-1-2-4	Peat	4,98E-07	Ru-3-3-1	Clay	1,45E-05
Ru-1-3-1	Sand	3,35E-05	Ru-3-3-2	Peat	4,69E-06
Ru-1-3-2	Peat	8,00E-06	Ru-3-3-3	Peat	3,39E-06
Ru-1-3-3	Peat	2,64E-07	Ru-3-3-4	Peat	4,40E-07
Ru-1-4-1	Sand	4,86E-05	Ru-3-3-5	Sand	2,93E-05
Ru-1-4-2	Peat	8,86E-07	Ru-3-4-1	Peat	4,39E-07
Ru-1-4-3	Peat	1,62E-07	Ru-3-4-2	Peat	5,52E-07
Ru-1-4-4	Sand	9,19E-05	Ru-3-4-3	Peat	9,44E-07
Ru-2-1-1	Sand	6,07E-06	Ru-3-4-4	Peat	1,79E-06
Ru-2-1-2	Sand	-	Ru-3-4-5	Sand	1,31E-05
Ru-2-2-1	Sand	3,42E-06	Ru-4-1-1	Sand	1,75E-05
Ru-2-2-2	Peat	3,04E-05	Ru-4-1-2	Peat	1,47E-08
Ru-2-3-1	Sand	1,63E-05	Ru-4-1-3	Peat	-
Ru-2-3-2	Peat	5,96E-07	Ru-4-2-1	Peat	1,50E-06
Ru-2-3-3	Peat	2,29E-07	Ru-4-2-2	Peat	2,31E-07
Ru-2-3-4	Peat	1,20E-07	Ru-4-2-3	Peat	4,99E-07
Ru-2-3-5	Peat	-	Ru-4-2-4	Peat	3,76E-08

Hydraulic conductivity values are generally higher in sand than in peat soils. K values range from 1.10-6 m/s to 1.10-4 m/s, with an average of around 9.5.10-5 m/s. For K values in a peat-type soil, they range from 5.10-9 m/s to 2.10-5 m/s with an average of around 4.10-7 m/s (figure 16).

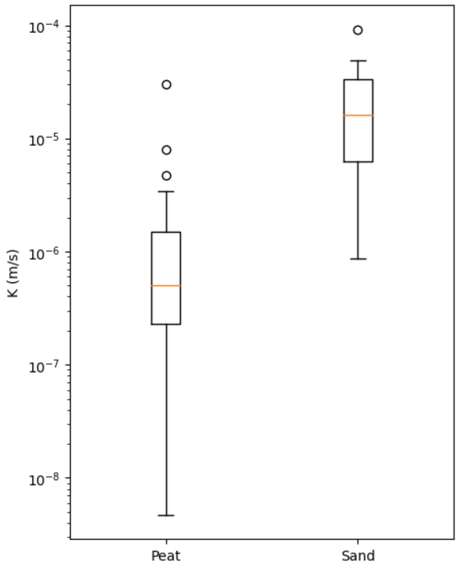

Figure 16: Hydraulic conductivity values depending on the soil.

Once all the hydraulic conductivity values have been calculated, all that remains is to calculate the groundwater flow, taking into account the hydraulic gradient between each pair of piezometers. Groundwater flow was calculated for five different dates, the dates on which water level measurements were taken in the piezometers. These dates are 16/08/2022, 06/12/2022, 22/03/2023, 30/05/2023 and 29/06/2023.

Once the groundwater flow has been calculated for five dates, the discharge on these dates can be determined using the thickness and width of the soil layer. The thickness of the soil layer was calculated as follows:

Layer thickness = Water level – (Z terrain – Depth of the aquifer)

The width of the soil layer was determined using ArcGIS Pro 3.0.3 software. The groundwater flow results and associated discharges for each date are presented in the following tables (table 2).

Table 2: Groundwater flow and discharge for all pairs of piezometers at the entrance and exit of Runkenbjerg.

Inlets

	Ru-1-1 / Ru-1-2		Ru-2-1 / Ru-2-2		Ru-3-1 / Ru-3-2	
Date	**q (m/s)**	**Q (m3/s)**	**q (m/s)**	**Q (m3/s)**	**q (m/s)**	**Q (m3/s)**
16/08/2022 12:00	-6,46E-10	-7,06E-07	2,64E-08	2,60E-05	-2,25E-08	-2,06E-05
06/12/2022 12:00	4,23E-09	4,76E-06	2,95E-08	2,95E-05	4,60E-08	4,37E-05
22/03/2023 12:00	3,91E-09	4,41E-06	8,60E-08	8,65E-05	9,76E-08	9,52E-05
30/05/2023 10:00	5,00E-09	5,55E-06	8,21E-08	8,11E-05	8,59E-08	8,08E-05
29/06/2023 12:51	4,00E-09	4,40E-06	8,73E-09	8,64E-06	4,99E-08	4,58E-05

Outlets

	Ru-1-3 / Ru-1-4		Ru-3-3 / Ru-3-4		Ru-4-1 / Ru-4-2	
Date	**q (m/s)**	**Q (m3/s)**	**q (m/s)**	**Q (m3/s)**	**q (m/s)**	**Q (m3/s)**
16/08/2022 12:00	1,67E-08	2,18E-05	2,59E-09	1,10E-06	1,30E-09	7,01E-07
06/12/2022 12:00	9,81E-09	2,74E-05	1,05E-08	4,37E-06	1,31E-09	7,90E-07
22/03/2023 12:00	8,88E-09	2,49E-05	1,22E-08	5,09E-06	1,58E-09	9,67E-07
30/05/2023 10:00	9,99E-09	2,71E-05	1,14E-08	4,53E-06	1,61E-09	9,32E-07
29/06/2023 12:51	6,52E-09	1,77E-05	9,48E-09	3,75E-06	1,59E-09	8,95E-07

Groundwater flow and discharge values are very low overall. This can be explained by the fact that Runkenbjerg is a rather flat wetland and therefore does not have a high hydraulic gradient. However, these values are on the whole slightly higher for the inlets than for the outlets, particularly for the Ru-2-1/Ru-2-2 and Ru-3-1/Ru-3-2 piezometers compared with the Ru-3-3/Ru-3-4 and Ru-4-1/Ru-4-2 piezometers.

In view of the very low values for groundwater flow, it would therefore appear that the most important flow path at Runkenbjerg is not groundwater flow but surface water flow and, in particular, overflow. An overflow station is located at the stream on the right-hand side of Runkenbjerg. A water balance to determine the discharge at this station could therefore be of interest. However, it is not possible with the available data to calculate a daily water balance since groundwater flow values are only available for five dates. Nevertheless, assuming that these groundwater flow values are valid for a whole month (the discharges being very low), it is possible, if not to calculate a daily water balance, at least to calculate a scenario for five months. In reality, only four months can be taken into account. No discharge data is yet available for the Inlet, Inlet Forest, Outlet and Outlet Forest for June 2023. To enable the water balance to be calculated over a month, the daily discharge values for Inlet Forest and Outlet Forest will be averaged over the whole month. The Inlet and Outlet stations will not be taken into account for this water balance as they are not useful for determining the discharge at the Overflow station. The formula for this water balance is therefore as follows:

GWin + Inlet Forest + P = GWout + Outlet Forest + ET + Overflow

Discharges are expressed in m³/d and the result of the water balance is presented in the following table (table 3).

Table 3: Water balance results for Overflow station discharges for 4 different months.

Date	Groundwater in (m3/d)	Inlet forest (m3/d)	Precipitation left (m3/d)	Precipitation right (m3/d)	Total in (m3/d)
08/2022	0,40	49,85	179,38	46,29	275,93
12/2022	6,73	64,37	662,67	171,02	904,79
03/2023	16,08	80,52	731,83	188,87	1017,31
05/2023	14,47	94,00	109,57	28,28	246,31
06/2023	5,08	-	-	-	-

Date	Groundwater out (m3/d)	Outlet forest (m3/d)	ET left (m3/d)	ET right (m3/d)	Total out (m3/d)
08/2022	2,04	19,67	539,89	139,34	700,94
12/2022	2,81	17,35	26,99	6,97	54,12
03/2023	2,68	24,21	162,52	41,94	231,35
05/2023	2,82	-	530,79	136,99	670,60
06/2023	1,93	-	-	-	-

Date	**Overflow (m3/d)**
08/2022	-425,01
12/2022	850,68
03/2023	785,96
05/2023	-424,28
06/2023	-

The discharge at the Overflow station is negative for the months of August 2022 and May 2023. This probably means that there is no discharge at this station and that the water therefore leaves the area in another way, in particular by evapotranspiration, which is consistent with the fact that these are warm months. However, for the winter months of December 2022 and March 2023, the discharges at the Overflow station are 851 m^3/d and 786 m^3/d respectively. There is much less evaporation during these months, so most of the water runs off the surface and overflows into the stream. The overflow path therefore seems to be dominant in winter, but not in the warmer periods of the year.

4. Discussion

To find out the levels of nitrogen transported by water and whether or not a wetland retains nitrogen, it is important to know the different flow paths that water follows. Among these flow paths, groundwater flow has often been ignored because it is difficult to calculate and uncertain. This parameter is difficult to calculate, mainly because of the heterogeneity of aquifers, which can complicate flow patterns (Freeze and Witherspoon, 1968). Furthermore, as mentioned in this report, the hydraulic properties of peat are difficult to measure (Rycroft et al., 1975).

At Runkenbjerg, the aim was to determine the different flow paths that the water took and in what quantities, in order to determine the nutrient losses. It was known that some of the water flowing through Runkenbjerg was groundwater, so the aim of this course was to calculate the amount of groundwater at Runkenbjerg. To do this, the first method was to calculate the water balance and thus deduce the groundwater flow. However, this method did not give satisfactory results. In fact, according to the water balance calculated, there is little or no groundwater flowing over the wetland. There are several reasons for this. Firstly, the data collected for the Outlet station may have been distorted by the fact that the stream bed at this station was very muddy. The discharge at this station is calculated manually using a current meter, which requires precise knowledge of the depth of the bed. And the fact that the bed was muddy probably meant that the current meter was not positioned correctly on the bed bottom, distorting the depth and therefore the discharge results. Secondly, the presence of the broad stream downstream may also have affected discharges at the Outlet station during floods. The Inlet station, on the other hand, may not have been affected, or only very slightly. Finally, the third source of error in calculating the water balance may have been working with large numbers. Calculating the difference between two large numbers can lead to uncertainty. If these numbers are close to each other and each has, for example, a 10% error, the difference between them will be smaller than the errors and therefore undetectable.

Questions may also arise concerning the relationships found for the Q-Q relations graphs. The R^2s do not exceed 0.66. This raises questions about the usefulness and accuracy of the relations.

After realising that the water balance method was inadequate for determining groundwater flow, the method involving Darcy's law was applied. However, here too the groundwater flow results are very low, whereas higher discharges for this flow path are observed in the field. The slug test method used to determine hydraulic conductivity may be one of the sources of error. This technique has been widely criticised in the groundwater literature (e.g., Osborne, 1993). Although a slug test is a widespread technique for measuring hydraulic conductivity in situ, it is not optimal for providing representative estimates of aquifer parameters, unlike an aquifer test, for example. Indeed, the quantity of water displaced in a piezometer is so small, the test probes only a small volume of the aquifer next to the piezometer (Schwartz and Zhang, 2002).

To improve the quality of slug tests, Butler et al (1996) proposed several solutions. Firstly, three or more slug tests should be carried out per piezometer so that the results are more statistically significant. During this course, only one slug test per piezometer was carried out. In addition, the water would have to be moved several times at the start of the test in order to obtain a different H0 (the initial water level in the piezometer). Indeed, in a piezometer in an unconfined formation with the screen close or across the water table, it is possible to observe a dependence on H0 as a result of changes in the effective length of the screen through which water flows in or out of the piezometer during the test. In conclusion, the slug test has the advantage of being economical and of providing very useful information in the case of this stage. However, it is not perfect and has been criticised for its accuracy.

With regard to the results obtained, at Runkenbjerg, overland flow appears to be the dominant pathway when evapotranspiration is low, i.e. in winter between December and March. The hypothesis that can be made is that overland flow is the major pathway for nitrogen transport during this period. It is then possible to distinguish two types of overland flow, overland flow by exfiltration, which therefore spent most of the time as groundwater flow, and direct overland flow, which spent little or no time in the subsurface. At Runkenbjerg, in view of the very low groundwater flow values, direct overland flow is potentially the dominant type of overland flow. And according to Petersen et al (2020b), while overland flow by exfiltration significantly reduces N concentration, direct overland flow reduces it only very slightly. This small reduction in direct overland flow suggests that there is still a reduction in N possible via the overland flow path and that there may therefore be downwards diffusive flows of N that enable denitrification.

At Runkenbjerg, the dominant water flow path should be determined more precisely and on a daily basis, and water samples taken from the various flow paths. These samples would make it possible to measure N concentrations within the wetland and thus understand the fate of this nutrient.

5. Conclusion

My internship at the Department of Ecoscience at the University of Aarhus was an enriching and formative experience. During these 12 weeks, I had the opportunity to immerse myself in the field of research, and in particular wetlands research. This reflective look back allows me to take a step back from the experience and highlight the significant learning I gained.

During my placement, I had the opportunity to carry out water balance calculations using the Python programming language, as well as modelling underground water flows by carrying out slug tests and Excel calculations. These tasks enabled me to develop my technical and IT skills, while gaining a better understanding of the importance of data and its rigorous processing in environmental research.

I also took part in fieldwork, such as collecting water samples and cleaning piezometers. These experiences have given me a better understanding of the reality of fieldwork and how data is collected, thus contributing to the reliability of research results.

All in all, I am convinced that the knowledge and skills I acquired during this placement will be invaluable assets for my future career.

6. Bibliography

Audet, J., Zak, D., Bidstrup, J., & Hoffmann, C. C. (2020). Nitrogen and phosphorus retention in Danish restored wetlands. *Ambio*, *49*(1), 324-336. https://doi.org/10.1007/s13280-019-01181-2

Bouwer, H. (1989). The Bouwer and Rice Slug Test—An Updatea. *Ground Water*, *27*(3), 304-309. https://doi.org/10.1111/j.1745-6584.1989.tb00453.x

Butler, J. J., McElwee, C. D., & Liu, W. (1996). Improving the Quality of Parameter Estimates Obtained from Slug Tests. *Ground Water*, *34*(3), 480-490. https://doi.org/10.1111/j.1745-6584.1996.tb02029.x

Freeze, R. A., & Witherspoon, P. A. (1968). Theoretical Analysis of Regional Ground Water Flow : 3. Quantitative Interpretations. *Water Resources Research*, *4*(3), 581-590. https://doi.org/10.1029/WR004i003p00581

Hill, A. R. (2019). Groundwater nitrate removal in riparian buffer zones : A review of research progress in the past 20 years. *Biogeochemistry*, *143*(3), 347-369. https://doi.org/10.1007/s10533-019-00566-5

Hoffmann, C. C., & Baattrup-Pedersen, A. (2007). Re-establishing freshwater wetlands in Denmark. *Ecological Engineering*, *30*(2), 157-166. https://doi.org/10.1016/j.ecoleng.2006.09.022

Hoffmann, C. Chr., Kronvang, B., & Audet, J. (2011). Evaluation of nutrient retention in four restored Danish riparian wetlands. *Hydrobiologia*, *674*(1), 5-24. https://doi.org/10.1007/s10750-011-0734-0

Mayer, P. M., Reynolds, S. K., McCutchen, M. D., & Canfield, T. J. (2007). Meta-Analysis of Nitrogen Removal in Riparian Buffers. *Journal of Environmental Quality*, *36*(4), 1172-1180. https://doi.org/10.2134/jeq2006.0462

Osborne, P. (s. d.). *Ground Water Issue : Suggested Operating Procedures for Aquifer Pumping Tests*.

Petersen, R. J., Prinds, C., Iversen, B. V., Engesgaard, P., Jessen, S., & Kjaergaard, C. (2020). Riparian Lowlands in Clay Till Landscapes : Part I—Heterogeneity of Flow Paths and Water Balances. *Water Resources Research*, *56*(4). https://doi.org/10.1029/2019WR025808

Petersen, R. J., Prinds, C., Jessen, S., Iversen, B. V., & Kjaergaard, C. (2020). Riparian Lowlands in Clay Till Landscapes Part II : Nitrogen Reduction and Release Along Variable Flow Paths. *Water Resources Research*, *56*(4). https://doi.org/10.1029/2019WR025810

Rycroft, D. W., Williams, D. J. A., & Ingram, H. A. P. (1975). The Transmission of Water Through Peat : I. Review. *The Journal of Ecology*, *63*(2), 535. https://doi.org/10.2307/2258734

Schwartz, F. W., & Zhang, H. (2002). *Fundamentals of Ground Water*. John Wiley & Sons.

Smith, V. H., Tilman, G. D., & Nekola, J. C. (1999). Eutrophication : Impacts of excess nutrient inputs on freshwater, marine, and terrestrial ecosystems. *Environmental Pollution*, *100*(1-3), 179-196. https://doi.org/10.1016/S0269-7491(99)00091-3

Vidon, P., Allan, C., Burns, D., Duval, T. P., Gurwick, N., Inamdar, S., Lowrance, R., Okay, J., Scott, D., & Sebestyen, S. (2010). Hot Spots and Hot Moments in Riparian Zones : Potential for Improved Water Quality Management [1]: H OT S POTS AND H OT M OMENTS IN R IPARIAN Z ONES : P OTENTIAL FOR I MPROVED W ATER Q UALITY M ANAGEMENT. *JAWRA Journal of the American Water Resources Association*, *46*(2), 278-298. https://doi.org/10.1111/j.1752-1688.2010.00420.x

Walton, C. R., Zak, D., Audet, J., Petersen, R. J., Lange, J., Oehmke, C., Wichtmann, W., Kreyling, J., Grygoruk, M., Jabłońska, E., Kotowski, W., Wiśniewska, M. M., Ziegler, R., & Hoffmann, C. C. (2020). Wetland buffer zones for nitrogen and phosphorus retention : Impacts of soil type, hydrology and vegetation. *Science of The Total Environment*, *727*, 138709. https://doi.org/10.1016/j.scitotenv.2020.138709

Woessner, W. W. (2017). Chapter 8—Hyporheic Zones. In F. R. Hauer & G. A. Lamberti (Éds.), *Methods in Stream Ecology, Volume 1 (Third Edition)* (p. 129-157). Academic Press. https://doi.org/10.1016/B978-0-12-416558-8.00008-1

7. Webography

[1]
Aarhus Universitet. (2023, 12 juillet). *Institut for Ecoscience*. Institut for Ecoscience. https://ecos.au.dk/

[2]
Runkenbjerg lavbundsprojekt - realisering. (s. d.). https://naturstyrelsen.dk/naturbeskyttelse/naturprojekter/runkenbjerg-lavbundsprojekt-realisering/

[3]
Climat Vejle : Pluviométrie et température moyenne Vejle, diagramme ombrothermique pour Vejle - Climate-Data.org. (s. d.). https://fr.climate-data.org/europe/danemark/danemark-du-sud/vejle-301/

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Noémie Hardy

2022-2023

The hydrology of a restored wetland: the Water balance of Runkenbjerg

Résumé :

This 12-week internship at Aarhus University's Department of Ecoscience focused on wetland research as part of the NIFA project. The objective was to investigate water balance and flow paths in the restored drained wetland, Runkenbjerg, emphasizing groundwater flow. The research contributes to understanding wetland rewetting's hydrological and nutrient consequences. Tasks involved water balance calculations using Python, groundwater flow modelling, fieldwork, and data collection. The NIFA project, funded by Denmark's Environmental Ministry, aims to restore wetlands and study environmental effects on hydrology, water quality, carbon sequestration, and biodiversity. This research provides valuable insights for wetland restoration and nutrient management, supporting evidence-based consultancy for environmental management.

Mots Clés : wetlands, hydrology, water balance, slug test

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