WATERAGRI

D4.3: Description of Developed Drainage Technologies

M36, April / 2023

WP 4 Nutrient Recovery from Streams

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Abstract:	Deliverable 4.3 addresses Task 4.2 Drainage Systems and covers the outcomes from drainage solutions C2 in Finland and Austria (OULU, ALCN), supported by results of activated biochar B6 and C4 (ALCN). This deliverable aims to develop and assess innovative, bio-inspired multilayer drainage systems (C2) that capture nutrients from runoff and other streams. The solutions proposed by the WATERAGRI project have an excellent potential for nutrient recovery. Therefore, they can help mitigate the adverse effects of pollution by agricultural non-point sources. Recovery of nutrients from agricultural water is necessary; if their reuse can be performed, it could contribute to the overall circularity of agricultural production. Drainage systems and bio-inspired multilayer filter systems, which this deliverable described, are nature-based solutions for agricultural water treatment. Tests were and still are being performed in Sweden and Austria to enhance their performance and propose innovative nutrient recovery methods.

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List of Abbreviations and Acronyms	
AS	Acid Sulphate
CD	Controlled Drainage
GW	Groundwater
GWTL	Groundwater table level
IoT	Internet of Things
IBC	Intermediate bulk container
TN	Total Nitrogen
TOC	Total organic carbon
TRL	Technology readiness level
WP	Work Package

1. Preface

Deliverable 4.3 addresses Task 4.2 Drainage Systems and covers the outcomes from drainage solutions C2 in Finland and Austria (OULU, ALCN), supported by results of activated biochar B6 and C4 (ALCN). This deliverable aims to develop and assess innovative, bio-inspired multilayer drainage systems (C2) that capture nutrients from runoff and other streams. The solutions proposed by the WATERAGRI project have an excellent potential for nutrient recovery. Therefore, they can help mitigate the adverse effects of pollution by agricultural non-point sources. Recovery of nutrients from agricultural water is necessary; if their reuse can be performed, it could contribute to the overall circularity of agricultural production.

Drainage systems and bio-inspired multilayer filter systems, which this deliverable described, are nature-based solutions for agricultural water treatment. Tests were and still are being performed in Sweden and Austria to enhance their performance and propose innovative nutrient recovery methods.

2. Common Introduction

Agricultural wastewater contains considerable nutrient loads that are released to the environment due to insufficient treatment. Capturing these nutrients and reusing them in agriculture can have a big economic and environmental potential.

One of the objectives of WP4 (Nutrient Recovery from Streams) is to develop and assess individual nutrient recovery technologies, namely:

- Farm-constructed wetlands (solution C1)
- **Bio-inspired and multilayer drainage system (solution C2)**
- Membrane-based solution (solution C3)
- **Activated biochar (solutions B6 and C4)**
- Microfluidic nutrient recovery technology (solution C5)

These solutions are being developed and tested in different tasks of WP4, and the final results for each of them will be presented in separate deliverables towards the end of the project. All the project activities related to these technologies are currently running.

Deliverable 4.3 addresses **Task 4.2 Drainage Systems** and covers the outcomes from Solutions C2 (UOULU, ALCN), supported by results of activated biochar B6 and C4 (ALCN). Task 4.2: Development of a nature-inspired multi-layered drainage system (C2) with the assessment of biochar for water retention (B6) and biochar adsorbents for nutrient uptake (C4). This deliverable, '**Deliverable 4.3 Description of drainage systems'**, will focus on nature-inspired multilayer drainage systems (C2) results from UOULU and ALCN case studies. These systems used biochar as one of the filter materials. The supporting results of biochar adsorbents for nutrient uptake (C4) are presented in Deliverable 4.5.

The purpose of this deliverable is to develop and assess innovative, bio-inspired and multilayer filter systems (C2, ALCN) that can capture nutrients from agricultural runoff (Mistelbach) and subsurface drainage pipes (Gleisdorf). This deliverable also explains how controlled drainage (C2) was tested at the UUOULU field sites in Tyrnävä and Ruukki (pilot site operated by Finnish Natural Resource Institute Luke). UOLU teams have observed hydrology (Ruukki, Tyrnävä) and nutrient leaching (Rukki) for fields that have been used for controlled drainage.

In the present document, each of the solutions highlighted in bold was addressed in a separate section, preceded by an introduction including their short description and explanation related to their operation and main characteristics.

3. Controlled Drainage (OULU)

3.1. Introduction

Controlled drainage (CD) was first developed and tested in the USA to retain water in agriculture. The method is based on control at drainage field outlet where water is retained by raising and lowering the water level to influence groundwater tables and soil moisture. In this way, by limiting drainage, more water can be stored for plant water needs. As runoff is retained, also nutrient runoff to water courses is reduced. In Finland, a few trials have been carried out in the past (e.g., Salla et al. 2021). Controlled drainage has been proposed as an effective approach to manage summer droughts in Nordic agriculture.

In the below section, we explain how controlled drainage was tested at the OULU field sites in Tyrnävä and Ruukki (pilot site operated by Luke). OULU team have observed hydrology (Ruukki, Tyrnävä) and nutrient leaching (Ruukki) for fields that have been used for CD. At Ruukki and some other sites in Finland, OULU has also developed in parallel past and recent projects on smart management and automation in water management. OULU WATERAGRI team have observed the hydrology of the fields in Ruukki. Related to drainage management, we have also assessed water balance to schedule irrigation and drainage, which is reported in Mustafa *et al.* 2022. Further improvements to the developed model with a component of the control drainage principle mentioned by Skaggs et al. 2010 are discussed.

3.2. Methods and objectives

A set-up was planned for Tyrnävä on mineral soils with potato farming and for Ruukki on peat soils with grass production. While water retention for improved yield is an aim at both sites, the sites also have specific aims:

At Tyrnävä, the main objective is, improved water retention during the short summer drought that occasionally occurs in potato farming. Here, the controlled drainage wells were manually operated by the farmer. At this site, we observed soil moisture and groundwater levels, and we also used the HGS model to assess drainage. Moreover, to improve the water balance model, which was first developed with an irrigation scheduling approach (D3.1 and Mustafa et al. 2022), the component of the controlled drainage principal is also applied to model field scale water balance situations.

At Ruukki experimental farm, the aim was to understand hydrology and to limit nutrient leaching and greenhouse gases by water table control. Ruukki had an automatically controlled drainage system. The monitoring setup is explained below for both sites.

3.3. Tyrnävä Case Study Site

3.3.1. Site description

Tyrnävä study area (6.43 ha) is located 32 km southeast of the city of OULU in the municipal region of Tyrnävä, between 64°45’21” N to 64°45’33” N Latitudes and 25°43’ 40” E to 25°43’0” E Longitudes in the North Ostrobothnia region of Finland. Potato is cultivated in the field.

The study field has a boreal or cold climate with a long period of sub-zero temperatures and subsurface frost situations during the winter period. Normally, the region is covered by snow from late October until April. Generally, late May until September is considered the best period for potato production. Crop harvesting usually takes place in mid or late-September, during the cropping season, with a long sunny daytime period of nearly 24 hours during mid-summer.

3.3.2. Drainage systems

Figure 1 (top view, profile view, sectional view) presents the schematics of the subsurface drainage system installed in the Tyrnävä field study area. The case study field installed with a subsurface tile drainage system (Figure 1) consists of a total of 25 laterals (corrugated PVC pipes, Ø 65 mm) installed at a depth of around 1 m, with 14 m drain spacing. The drainage pipes were covered with gravel (0.2 – 4 mm). The profile view presents how the lateral drains are connected to a main drainage pipe (around Ø 160 mm) that leads drainage water into a collector/drainage well (internal diameter Ø 600 mm, height 220 cm). Although the agricultural field is very flat (~ 1.0%), two drainage wells/collectors are present in the field, based on topography. Both wells virtually divide the drainage occurring from the entire field into two from the position where drainage well AA is in the field. Thirteen lateral pipes were connected to a drainage pipe that drains into a drainage well AA, as shown in Figure 1. Whereas the remaining lateral pipes drain into another drainage well AV (Figure1). All the drainage from the field takes place from only one drainage ditch adjacent to the field marked as D1 in Figure 1. However, the field area is surrounded by other drainage ditches either provided for the adjacent agriculture fields or a divide between the fields with different land uses, such as small forest field. These fields have the potential to influence groundwater levels in the field, which could affect the subsurface drainage system. Figure 2 presents the pictorial details of the subsurface tile drainage system installed at the field.

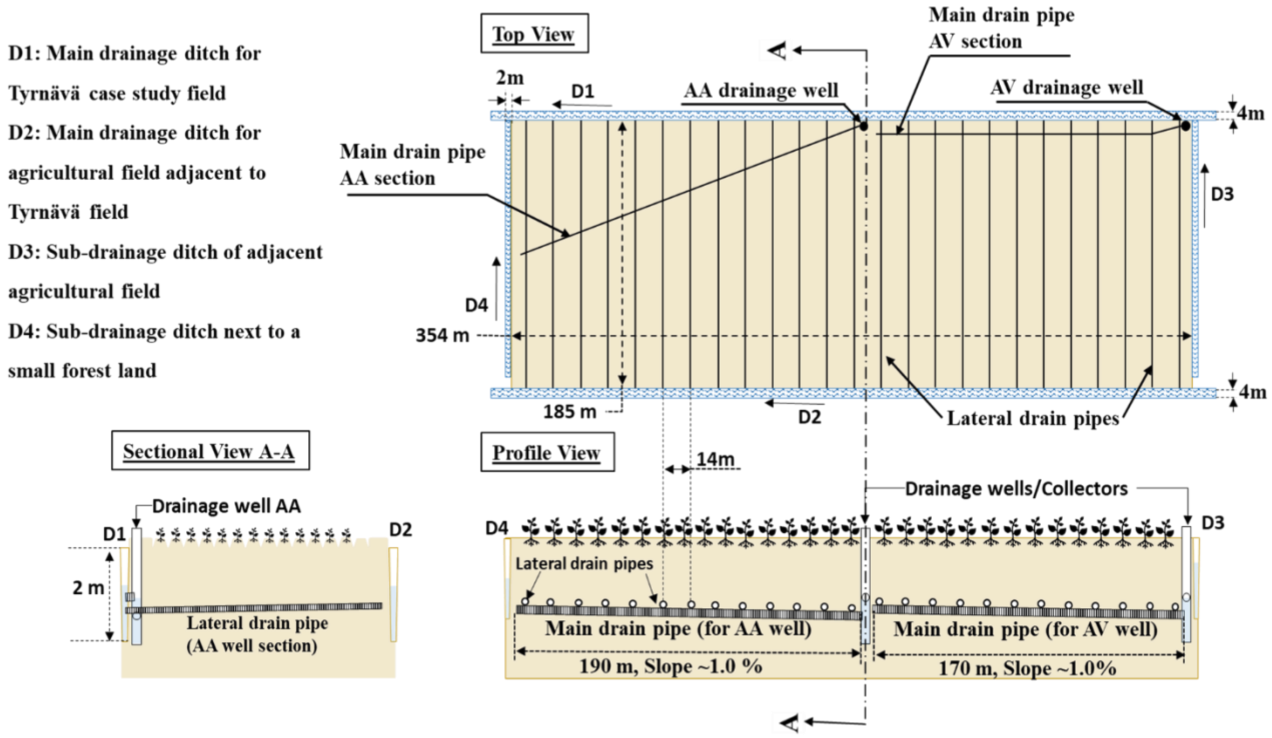


Figure 1. Schematics of subsurface tile drainage system (Top – Profile - Cross-Sectional (A-A) view) installed at Finland I -Tyrnävä case study site.

Overall, the installation of hydrometeorological monitoring sensors was carried out at five different locations in the field, as indicated in figure2. The orthographic view of Tyrnävä study field can be seen in Figure 2a. The extension of the lateral pipes lying under the field facilitates cleaning by flushing (Figure 2d). The main drainage ditch that was cleaned in 2021 can be seen in figure2b, drainage well AA can be seen in Figure 2c, and Figure 2d shows the extension of one lateral pipe.

Figure 3 presents the schematics of one drainage well installed in the Tyrnävä field. A drainage well is provided with the facility to raise or lower the pipe that can control the water level in the well and, thus, in the field below the ground surface depending on hydrogeological (i.e., rainfall, air temperature, ground water level, soil characteristics) and crop physiological (i.e., crop growth stage, water requirement, root depth) parameters that could provide sufficient soil moisture through the capillary rise.

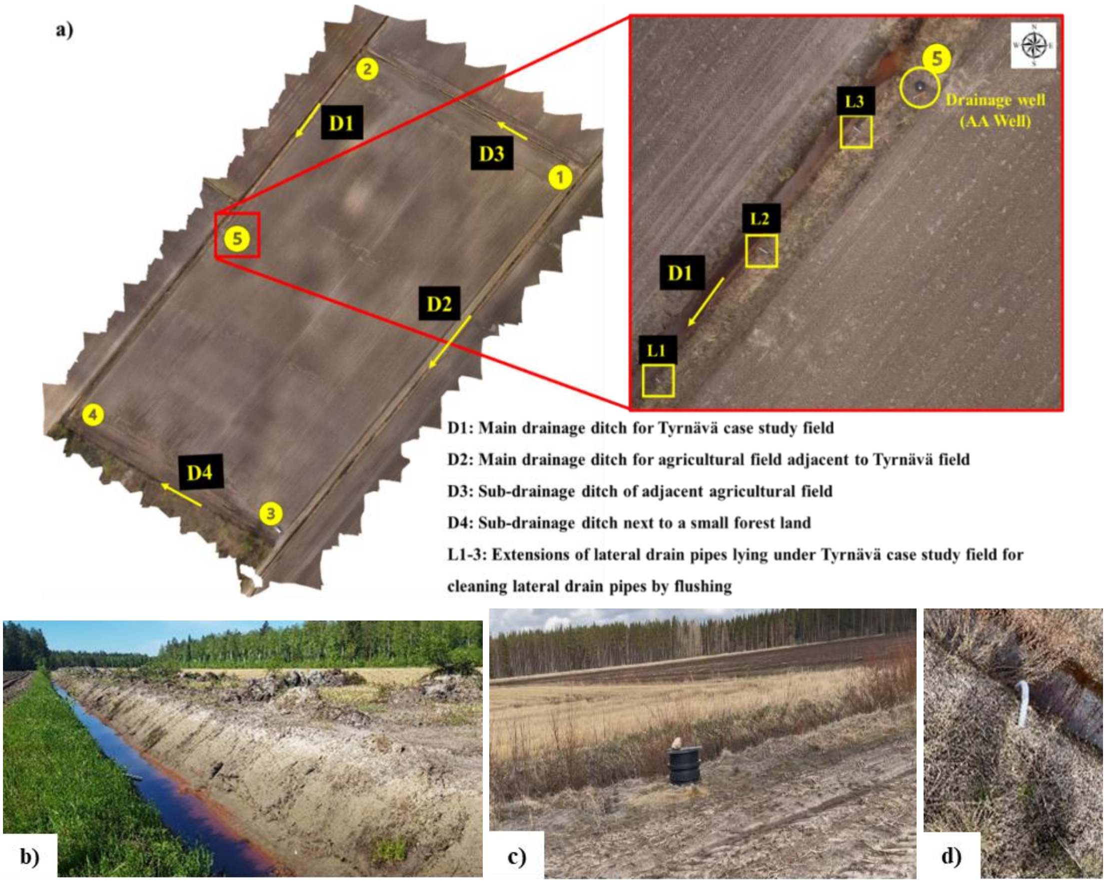


Figure 2. Finland I: Tyrnävä Case Study Field description. a) Orthographic view of tile drainage system; b) Main drainage ditch; c) One Drainage well / collector (AA Well) in the field (location point showed as 5 in Figure a); d) Extension of lateral drainage pipe installed in Tyrnävä field (L1-3 showed in Figure a).

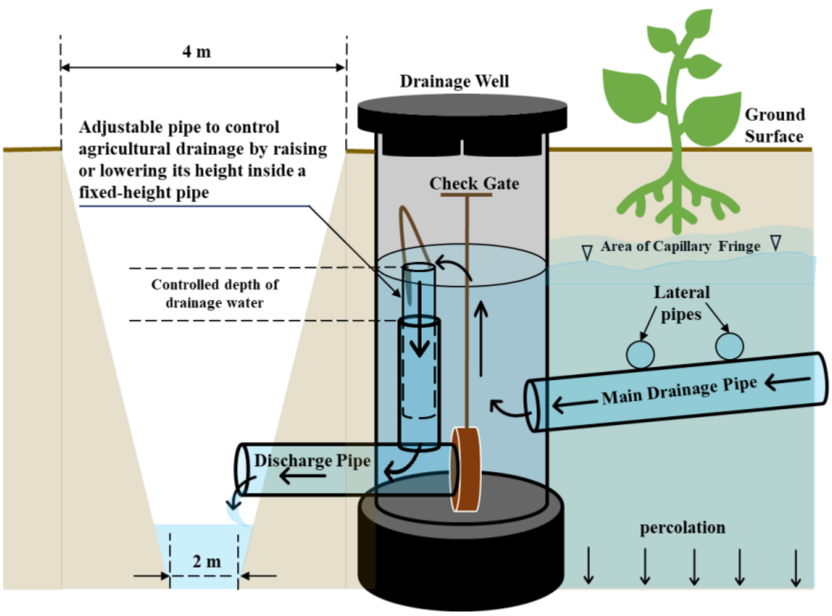


Figure 3. Schematics of controlled drainage well to collect water draining from the network of laterals, then to the main drainage pipe and then into the drainage well where the depth of water draining from the well can be controlled before it will drain out into the drainage ditch.

3.3.3. Hydrological monitoring

Tyrnävä sites have been monitored in a previous project (Timako - *Tietopohjainen maaperän kosteudenhallinta perunanviljelyssä*/Information-based soil moisture control in potato farming). The site monitoring for WATERAGRI started again in 2021.

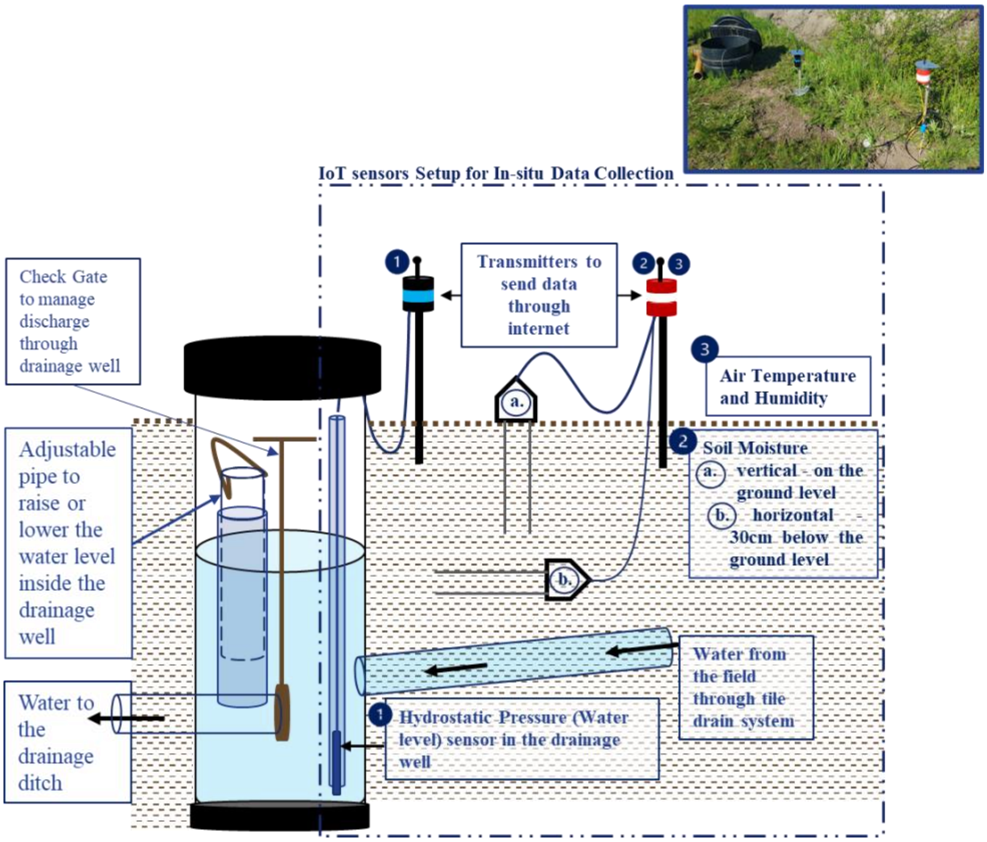
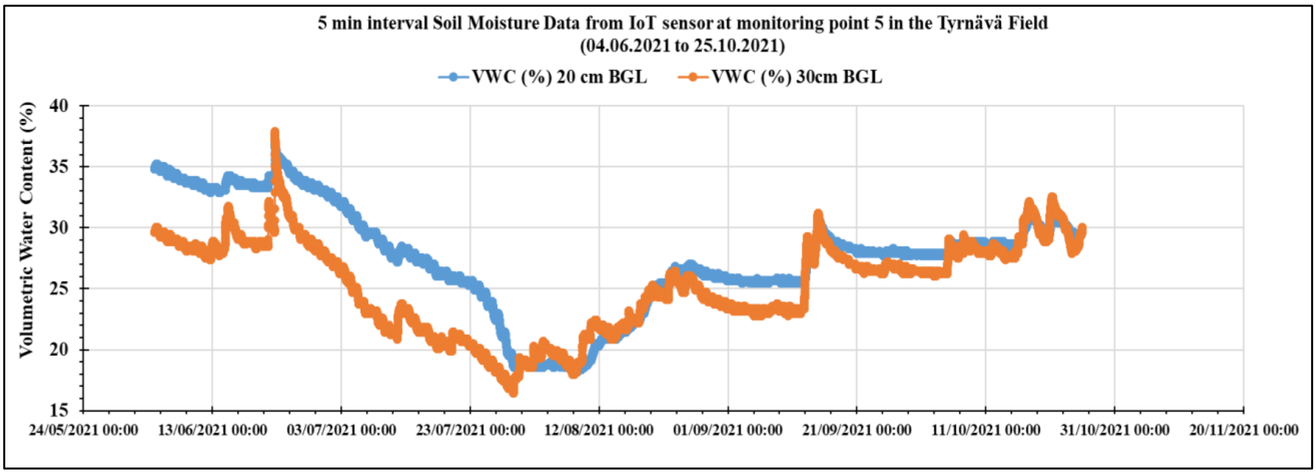


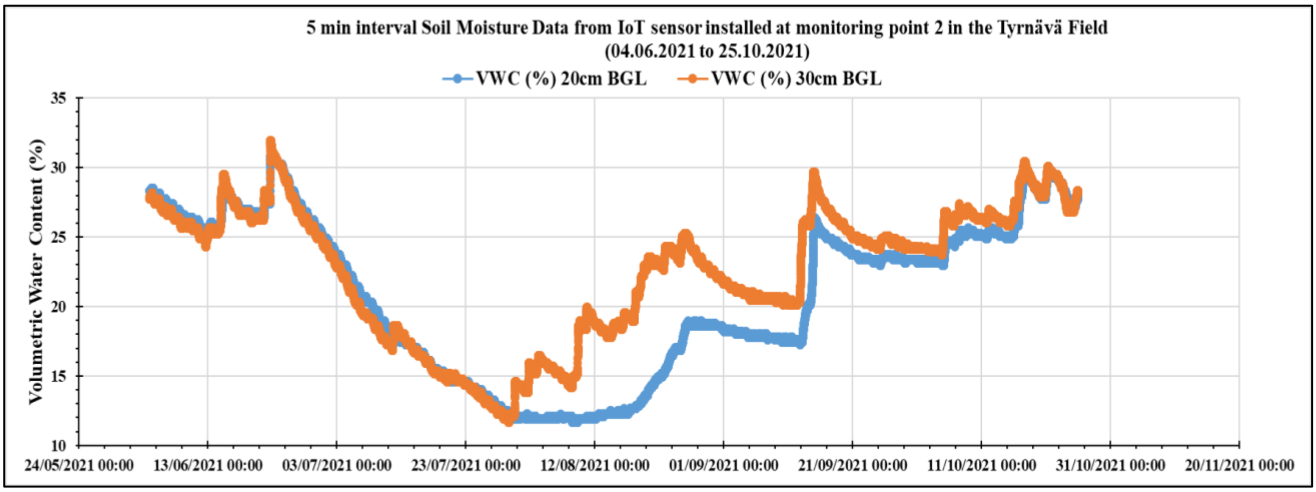
Figure 4. The installation setup of hydrometeorological monitoring in the Tyrnävä case study field

Figure 4 illustrates the monitoring setup in place during the crop season 2021 for soil moisture (% volumetric water content) data collection at two different depths (i.e., 20 and 30 cm below ground level), the water level in the drainage well / collector (hydrostatic pressure in cm), air temperature and relative humidity.

The data collection for monitoring these hydrometeorological parameters in the field was carried out between June 4th, 2021, and October 25th, 2021, at 5 min intervals (Figure 5).



a)



b)

Figure 5. Soil moisture data collected from the Tyrnävä Field using IoT-based sensors. a) shows the soil moisture trend recorded at monitoring point 5 near AA Well. b) shows soil moisture data collected at monitoring point 2 in the Tyrnävä case study field (for locations, see Fig.2).

For soil moisture data, two *Campbell-CS650 Soil moisture sensors* were installed at two different locations in the field, point 5 (Figure 5a) and point 2 (Figure 5b). For water level data in the drainage well, a Submersible OEM-Pressure Transmitter BD sensor 18.605 G (Developed by the Intelligent Machines and Systems research unit at the University of UOULU) was installed for two drainage wells in the field. The data was collected using cost-effective sensors which transmit data using LoRaWAN technology. The sensors were developed by the Intelligent Machines and Systems research unit at the University of UOULU and were used in a previous project (TIMAKO) as well.

Furthermore, later during the crop season of 2022, the hydrometeorological activities remain continued. However, the soil moisture (volumetric water content) and groundwater level monitoring operations were started to be carried out with another project at a larger scale around the Tyrnävä study area I.e., Temmes catchment. The details of installed monitoring devices are explained below 1) at the field scale and 2) at the catchment scale.

3.3.3.1. Monitoring set-up

At the site, hydrology (soil moisture at two locations for four depths and groundwater table at 4 locations) is monitored at the field scale and catchment scale (in collaboration with another project at a larger scale).

However, before the start of the crop season 2022, it was informed that there will not be any agricultural activities carried out for season 2022. Therefore, the plan to install soil moisture sensors in the Tyrnävä field was not confirmed at the start of the season. Also, respective information was conveyed to WATERAGRI members in early April 2022 before the 5th GA meeting. But, since the groundwater pipes to monitor water level fluctuations below ground in Tyrnävä field were not installed during crop season 2021, it was planned and successfully executed before the start of crop season 2022. Later during the second half of June 2022, from the online weather station images, it was realized that the agriculture on the field is ongoing; therefore, the decision to install soil moisture sensors along with ongoing groundwater monitoring activity was made and executed. Moreover, to extend the hydrogeological monitoring from the Tyrnävä field scale to the bigger catchment scale, the installations of several IoT-based soil moisture and offline groundwater level monitoring sensors (as per availability) were carried out and successfully completed. All the details regarding these activities are explained below.

Tyrnävä field scale monitoring setup – season 2022:

Groundwater monitoring pipes were installed (Figure 6), and the data collection was started during the crop season 2022 from 20th May 2023.

Table 1. Details of groundwater monitoring readings observed at the Tyrnävä case study field during crop season 2022.

Date of Field Visit	AA Well	AV Well	GWp1	GWp2	GWp3	GWp4
07/07/2022	-	-	2.08	1.53	1.58	1.82
18/08/2022	1.46	1.55	2.3	1.8	1.78	1.99
22/09/2022			2.09	1.66	1.68	1.88
04/04/2023	1.51	1.56	2.60	2.31	-	2.23

A total four number of *Solinst Levelogger 5 (Model 3001)* and 1 *Solinst Barologger 5 (Model 3001)* are installed, and the monitoring is ongoing. Another two water level loggers were placed in the main drainage ditch that drains out the agricultural runoff from the Tyrnävä case study area through two drainage wells. 2 *Campbell soil moisture sensors* were also installed into the drainage ditch D1 as shown in Figure 2. Among all the offline data loggers installed in the field, data from three loggers installed in the groundwater pipes (GWp1, GWp2, and GWp4) were collected.

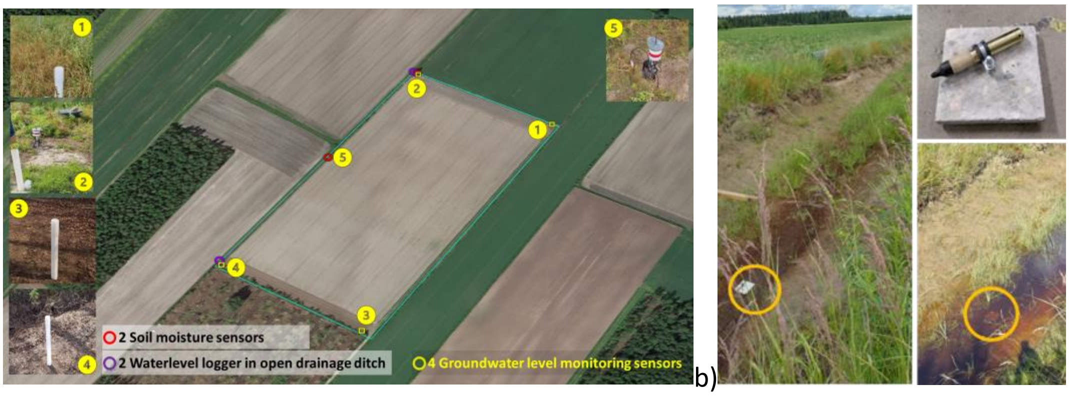
a)  b)

Figure 6. a) The picture shows locations where groundwater level monitoring pipes, soil moisture sensors, and water level loggers in the drainage ditch were installed at the Tyrnävä field scale. b) water level loggers installed in the main drainage ditch of the case study area (WATERAGRI project).

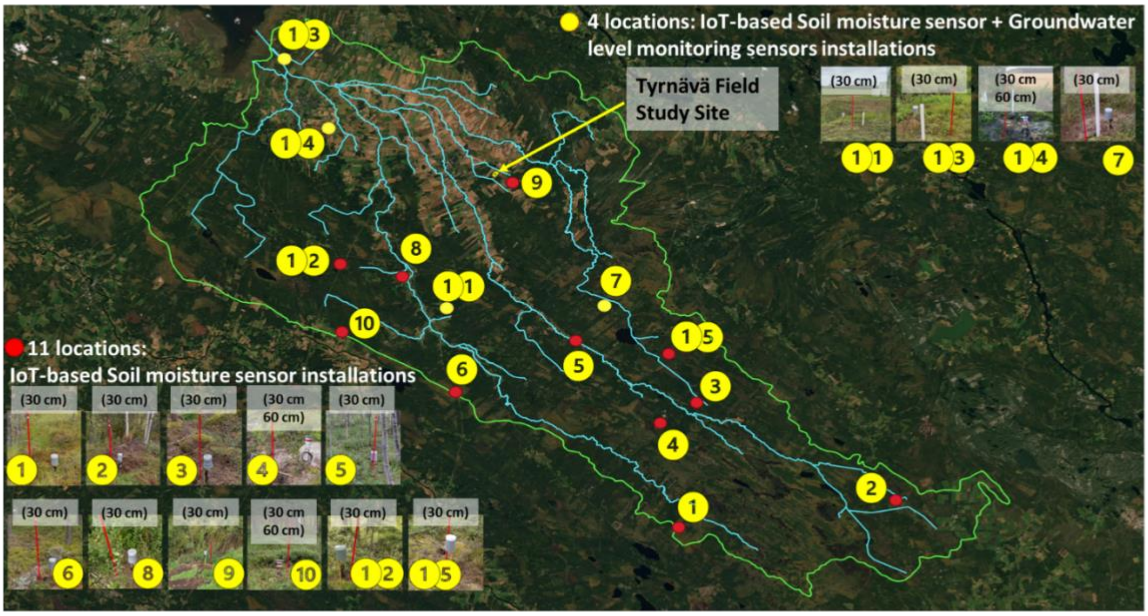


Figure 7. The picture shows the locations where groundwater level monitoring pipes and soil moisture sensors were also installed in the Temmes catchment (that are available from the Waterline project).

In addition to the Tyrnävä field scale monitoring setup (Figure 6), a total of four groundwater level monitoring pipes were installed at the catchment scale (
Figure 7) excluding four at the Tyrnävä field. 4 *Solinst Levelogger 5 (Model 3001)* and 2 *Solinst Barologger 5 (Model 3001)* were installed in the groundwater pipes. Moreover, IoT-based soil moisture monitoring sensors were installed at 15 locations, excluding the two at the Tyrnävä Field scale. Among the 15 locations, the Campbell-CS650 soil moisture sensors were installed at 3 locations which provide the soil moisture data from two different depths below the ground surface. Whereas, at all other locations, *Decentlab DL-TRS12 soil moisture, temperature and electrical conductivity sensors* were installed, which gives the soil moisture readings from only 30 cm depth below the ground surface.

Finally, in the whole catchment, a total of eight soil moisture sensors were installed in agricultural fields, whereas nine soil moisture sensors were installed in forest areas.

3.3.4. Preliminary results

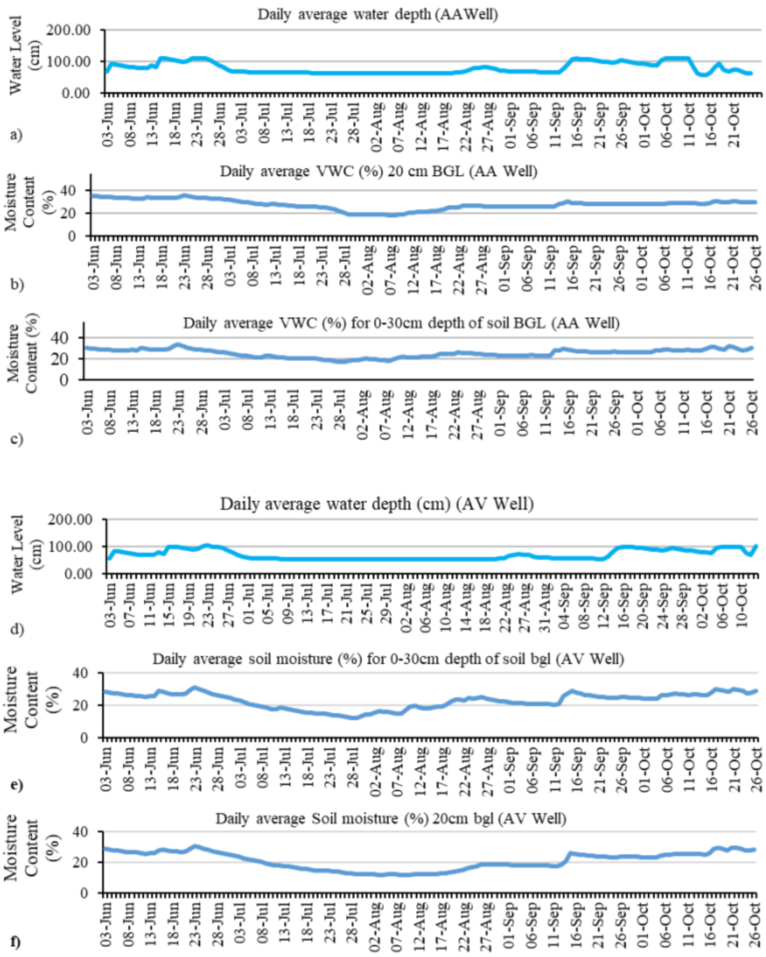


Figure 8. a) daily average water depth observed in AA well during crop season 2021, b-c) daily average soil moisture (%) 20cm and 0-30cm below ground level from sensors installed near AA well. d) daily average water depth observed in AV well during crop season 2021, e-f) daily average soil moisture (%) 20cm and 0-30cm below ground level from sensors installed near AV well.

Figure 8a-f presents the daily average soil moisture data and water level data calculated from a daily 5-min interval dataset recorded in the Tyrnävä field during crop season 2021.

3.4. Ruuki Case Study Site

3.4.1. Site Description

The experimental field is located at the Ruukki research station (25.00°E, 64.42°N) in the Siikajoki municipality, about 60 km southwest of UOULU, Finland. Its elevation is circa 45 m above the mean sea level, and the distance from the current seashore is 26 km. The station belongs to the Natural Resources Institute Finland (Luke).

The current experimental field was established in 2016 to allow monitoring of GHG emissions and the leaching of nutrients and other substances. The surface soil is sedge peat mixed with different amounts of coarse silt, and the subsoil consists of actual and potential Acid Sulphate Soils. The present experimental area was already entirely in agricultural use about 100 years ago, as proven by a soil map drawn in 1933. The experimental field has an area of 19.56 ha, divided into six plots, 2.97–3.77 ha each, and it has a slope of less than 0.5%. The field belongs to the European network of platforms for Analysis and Experimentation on Ecosystems (AnaEE). See more from (Yli-Halla et al., 2022). Ruukki study site has been used to estimate controlled drainage impacts on hydrology and water quality in cultivated peatlands.

3.4.2. Drainage system

The experimental plots' drainage system (Figure 9) consists of multiple lateral subsurface plastic pipes (corrugated PVC pipes, Ø 65 mm) installed at a depth of 1.1 – 1.3 m, with drain spacing of 12 m. Above the drainage pipes, around 6.5 m^3 of gravel (0.2–4 mm) per 100 m was used. The lateral pipes are connected to collectors (diameter Ø 160 mm), which lead the drainage water into a control well (Ø 800 mm, height 1800 mm) located in the corner of each plot.

The groundwater table level (GWTL) of the plots can be controlled by adjusting the height of the outlet pipe in the control well. From each control well, a separate outlet pipe conveys water to the sampling station at the lower end of the field. In this area, rust precipitates constantly and clogs the drainage pipes; therefore, every lateral has a joint tubing that extends to the soil surface and can be used for flushing rust out of the pipes. In plot 6, surface runoff waters can also be collected using two surface runoff gutters in the corner of the plot, then channelled into the sampling station.

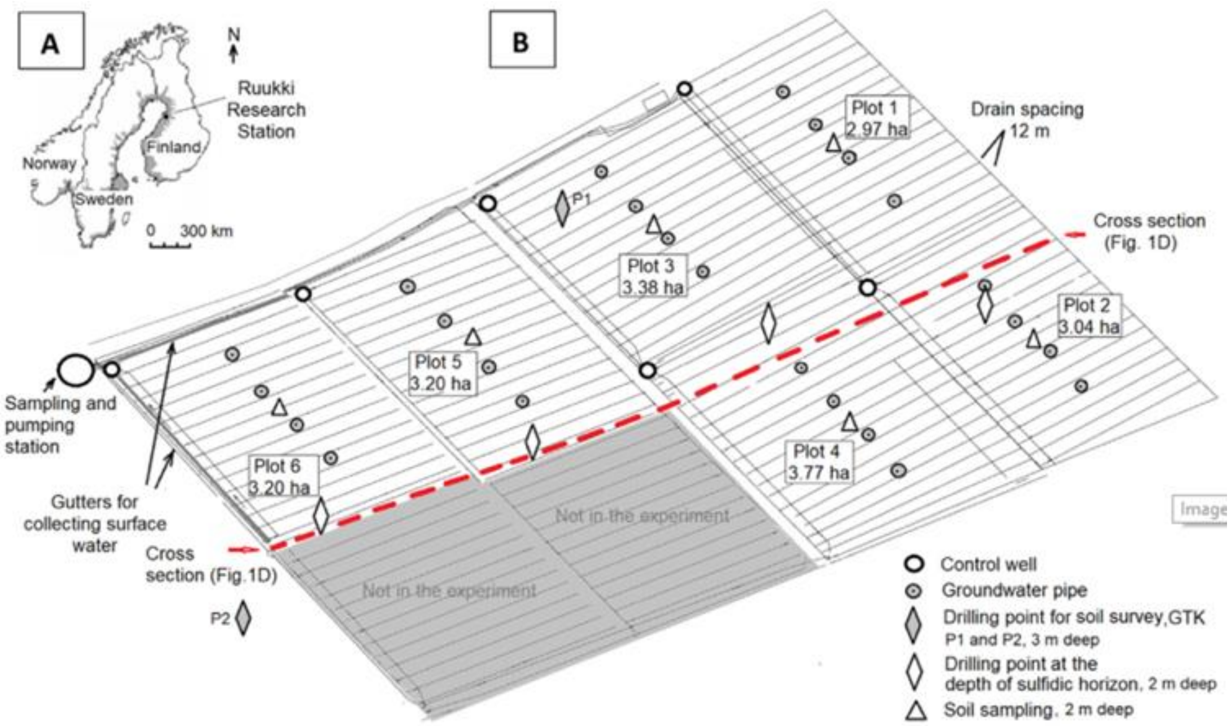


Figure 9. A) The location of the Ruukki field, with the shaded area, shows the potential location of acid sulfate soil. B) The drainage setup and soil survey map of the Ruukki experimental field (Yli-Halla et al. 2022).

3.4.3. Hydrological monitoring

Perforated groundwater (GW) pipes (diameter Ø 50 mm) were installed in each field, reaching a depth of 2 m (Fig. 9). In total, four pipes were installed in each plot between the laterals. The GW levels were monitored manually from all pipes between July 5th and August 28th, 2017, and continuously (at 15-min intervals) using Solinst Levelogger sensors installed in two pipes at each plot between March 26th and November 1st, 2021 (the average of two sensor values is used to indicate the GWTL of the plot). The drainage discharge was collected at the sampling station from each plot individually, and the water volume was measured using a V-dam and water pressure sensor (type: STS PTM/N). The discharge waters are rich in dissolved Fe, and rust tends to precipitate onto the lower corner of the V-dam opening, resulting in erroneous results of the discharge volume. Therefore, a system was developed to remove the precipitates at intervals of 6 h automatically with pressurized (3–4 bar) air. Soil moisture of each plot is measured continuously using installed soil moisture sensors (Soil Scout wireless moisture sensor) at two locations for each plot, each location at a depth of 10, 30 and 50 cm. The discharge and moisture data were collected and stored in a cloud service that could be viewed via the internet.

3.4.4. Preliminary results on hydrology and water quality

3.4.4.1. Hydrology

The three-year monitoring period (2019-2021) of the field started with a dry year (455 mm in precipitation), followed by two rainier years (669 mm and 684 mm, respectively) when compared to the 30-year average precipitation 1991-2020 (555 mm). The mean runoff ratio (percentage of precipitation that ended up as subsurface discharge) of the field was 38% (2018-2019), 43% (2019-2020) and 50% (2020-2021). During the three years of observation, subsurface discharge rates in all plots were typically high for a brief period from the end of March until mid-May (due to snowmelt) before dropping to very low during June – early August (warm period with low precipitation, and the drainage control wells were closed to prevent excessive reduction in groundwater level from evapotranspiration, even then groundwater level can drop past two meters depth in some plots), then increased moderately in late autumn and winter (due to storms that flooded the system, and the opening of the control wells typically in November). The spring melting of winter-accumulated snow and frost was responsible for most of the peak discharge rates over the years and provided a significant portion of the field's annual discharge (averaging 62% of annual total discharge). The discharge rate for these melting periods could get as high as 10 mmd^{-1} or 100 $m^3\ ha^{-1}\ day^{-1}$ (plot 4, 2019) or 108 $m^3\ ha^{-1}\ day^{-1}$ (plot 4, 2021), and GWTL showed saturation in the field. The period from winter 2019 to spring 2020 experienced an unusually warm winter, with snow cover building–melting cycles frequently occurring on the field (Figure 10). As a result, discharge was significantly higher during this winter (occurred in multiple smaller discharge peaks), and the spring melting discharge rate was significantly lower than usual. Aside from that, snow cover and frozen soil typically lasted from late November until early May. However, soil frost measurements revealed that frost only reached -30 – 50 cm depth underground, thus, 50 cm or more of soil depth above the drainage pipes was never frozen, allowing water to enter the drainage pipes. During winter, the control wells were open, thus, discharge and leaching occurred.

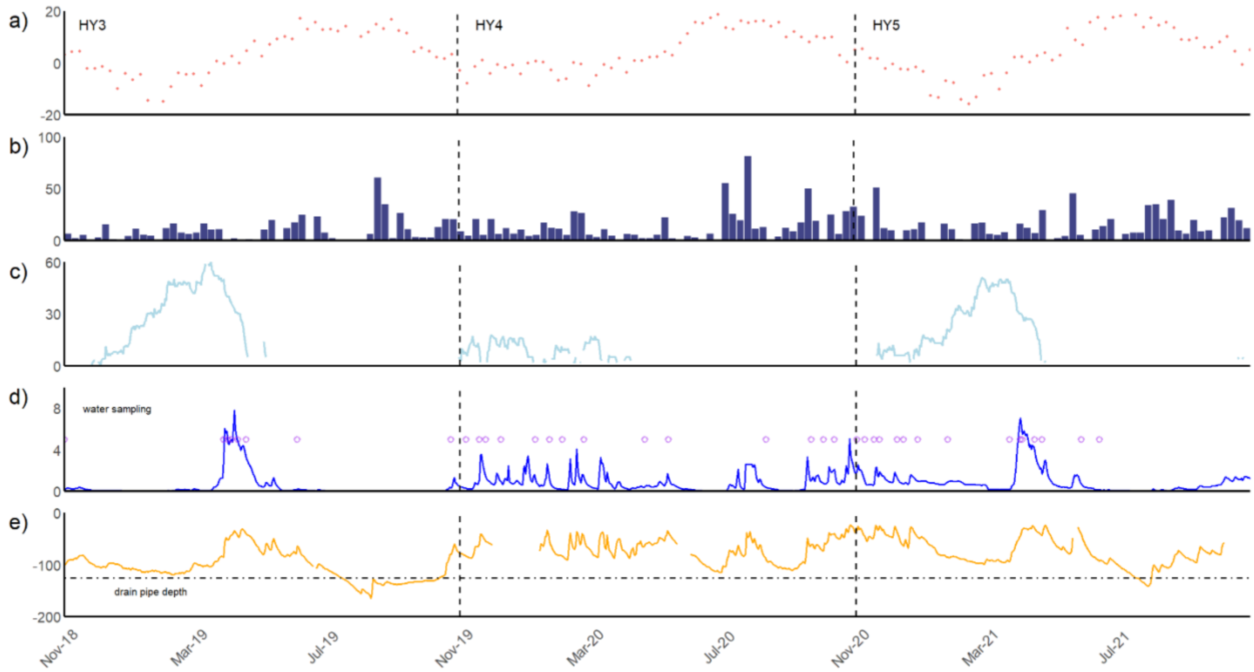


Figure 10. a) Weekly average temperature (°C); b) Weekly average precipitation (mm); c) Daily snow depth (cm); d) Field average specific subsurface discharge (mm); e) Field average groundwater depth (cm)

All data belongs to the period from November 1st, 2018, to October 31st, 2021, divided into three hydrological years (HY3-5), with each year starting on November 1st and ending on October 31st of the subsequent year.

3.4.4.2. Water quality

The nitrogen load in subsurface discharge waters increased upon increasing peat depth. The load of TN was also moderately high in periods when there was no vegetation cover (plots 1-4). Overall, the TN load was similar to other fields with thicker peat topsoil, lower than is commonly reported from mineral soils when under perennial grass cover but moderately higher when left bare. The proportion of NO_3-N fluctuated under different conditions and was the main driver for TN load/concentration changes. The discharge concentration of NH_4-N and N_{org} was mostly stable and low.

The total P load was low, compared to thick peat and even mineral soils, because the coarse silty and clayey mineral subsoil likely effectively adsorbed P in the seepage water, the retention being more effective the thicker the mineral soil horizons are before the pore water reaches the drainage pipe. However, the proportion of dissolved PO_4-P increased upon increased peat depth. The load and discharge concentration of total organic carbon (TOC) was also found to be higher for thicker peat plots. Heightened concentrations of sulphur and acidity in the discharge water indicated the oxidation of sulfidic materials in the subsoil. The water quality result suggests that N, dissolved P, and TOC loads transported through subsurface drainage pipes from a shallow peat field are lower than from a thick peat soil where the drainage pipes have been installed in the peat.

Our results indicate that peat cover can mitigate the negative environmental impacts of Acide Sulphate (AS) soils by hindering the oxidation of sulfidic material, thus preventing the formation of acidity, but the required thickness of the peat cover to achieve this effect should be studied in greater detail. In cultivated peatlands, like our experimental field, the GHG emissions, especially those of CO_2 and N_2O, are higher than in comparable mineral soils.

Due to the short measurement campaign and the recent establishment of the study field, the effects of peat depth or crops cannot be clearly seen from this data set. The CO_2-C emissions into the atmosphere were abundant during the monitored summer weeks, and the daily losses were equal to or higher than the amounts of TOC transported through the subsurface drainage pipes during the whole year, but N loss in the form of N_2O at least in the summer, was small compared to N loss contained in discharge water.

4. Drainage systems in Austria - Nature-inspired multi-layered drainage system C2 (ALCN)

4.1. Introduction

Agricultural run-off or subsurface drainage water transports a significant amount of nitrogen and phosphorus leached after the fertilization period. Agricultural run-off characteristics show high spatiotemporal load variability, low concentration of nitrogen and phosphorus but high flow velocity, and high sediments in the run-off. In order to address the agricultural run-off issue, two experimental vertical flow filter systems have been installed on the slope of an agricultural field in Mistelbach, Austria. While sub-surface drainage water was treated with 3D-printed prototypes filled with biochar and zeolite and inserted in a drainage pipe in Gleisdorf.

The goal was to capture nutrients and retain water from agricultural field runoff caused by heavy rainfall (Mistelbach) and from subsurface drainage water (Gleisdorf). Retaining nutrients on the edge of farmland can protect water catchments from pollution, prevent flooding and contribute to the reuse of the nutrients as fertilizer once the filters are saturated. The filter systems had several layers containing substrates such as biochar, a mineral substrate (Draingarden®), zeolite and the presence or not of vegetation.

The main expected outcome was to test the capabilities of the bio-inspired multilayer filter to function as a water retainer and a nutrient retainer addressing agricultural surface run-off. The filter system can be of practical use if an excess of nutrients being washed out is of concern in the fields of the practitioner by keeping the surrounding waters clean. This approach may result in economic value by re-using the saturated biochar as fertilizer and improving the soil structure, thus increasing long-term soil fertility. The system is expected to be low maintenance, apart from harvesting the plants yearly and changing the biochar when it is saturated with nutrients.

4.2. Methods

The solutions developed by ALCN for agricultural runoff and subsurface drainage water treatment in Austria case study II (Mistelbach) and III (Gleisdorf) consisted of:

- Two vertical-flow bio-inspired multilayer filter systems to retain nutrients from agricultural runoff (Mistelbach case study). Biochar and Draingarden were used as substrates in the main layer of one unvegetated and one vegetated filter system.
- A horizontal filter prototype was inserted in a subsurface drainage collector (Gleisdorf case study). Zeolite and biochar were used as substrates in the filter structure.

4.3. Mistelbach (C2) Case study 8.2 – Austria

The purpose was to build bio-inspired multilayer filter systems containing biochar and other substrates, able to retain water and nutrient from agricultural runoff of a delimited catchment area of 30 m2. After the literature research on nature-based solutions such as drainage filter systems, edge-of-field techniques and vegetated ditches, a design for two drainage filter systems and a soil filter as reference (*Figure 12*) was developed based on the Austrian standard for constructed wetlands (ÖNORM, 2009).

Using data from material analysis for nutrient adsorption from Task 4.4, as well as additional physical and water retention data from Task 3.4, the filter material was selected (biochar, Draingarden). The stakeholders at the Mistelbach pilot site were actively involved in choosing the planting of the filter and the location. The filters were dimensioned by a constructive student project in coordination with BOKU based on the expected amount of rainfall and overland flow. The bio-inspired multilayer filter systems were built in May 2021 and monitored during the vegetative season June-September in 2021 and 2022.

4.3.1. Site description

The bio-inspired multilayer filter system was designed and installed in an agricultural area in Mistelbach, Lower Austria (Figure 11). The mean annual precipitation in the area is 650 mm, and the mean annual temperature is 9.5°C. Klik and Rosner (2020) referred to a long-term mean annual rainfall of 621 mm for the period 1994-2018, 405 mm of which occurred in the growing season (May - October). The soil texture was identified as sandy loam, and the predominant soil type is Tschernosem (Kupelwieser, 2022). There are no drain tiles on the field. Due to the location of a slope, surface runoff occurs. In the vicinity of the pilot installation, previous studies have been carried out in the past on soil erosion, surface runoff, and nutrient and pesticide losses due to erosion processes from BOKU (Klik & Rosner, 2020).

Figure 11. Experimental site of the bio-inspired filter treating agricultural runoff, Mistelbach, Austria. Photo: June 2022.

4.3.1.1. Catchment area installation and water distribution

The catchment area of the agricultural run-off was installed 30 meters uphill of the filter systems (Section 3.3.2) in order to create the necessary height/altitude for distributing the collected agricultural run-off on top of the filter systems by gravity. The agricultural run-off area had dimensions of 10m x 3 m. It was confined by steel plates (1.5 mm thick, 2 m long) hammered in the agricultural land after spring sowing with maize to mimic natural conditions. A triangular steel funnel was aligned at the same land surface level, and its outlet was equipped with a net before connecting to the collecting pipe (*Figure 12*). The catchment area was connected with filter systems using 30 meters of PVC pipes (Diameter 150 mm, length 3 m each, ten pieces) attached to reach the filter systems.

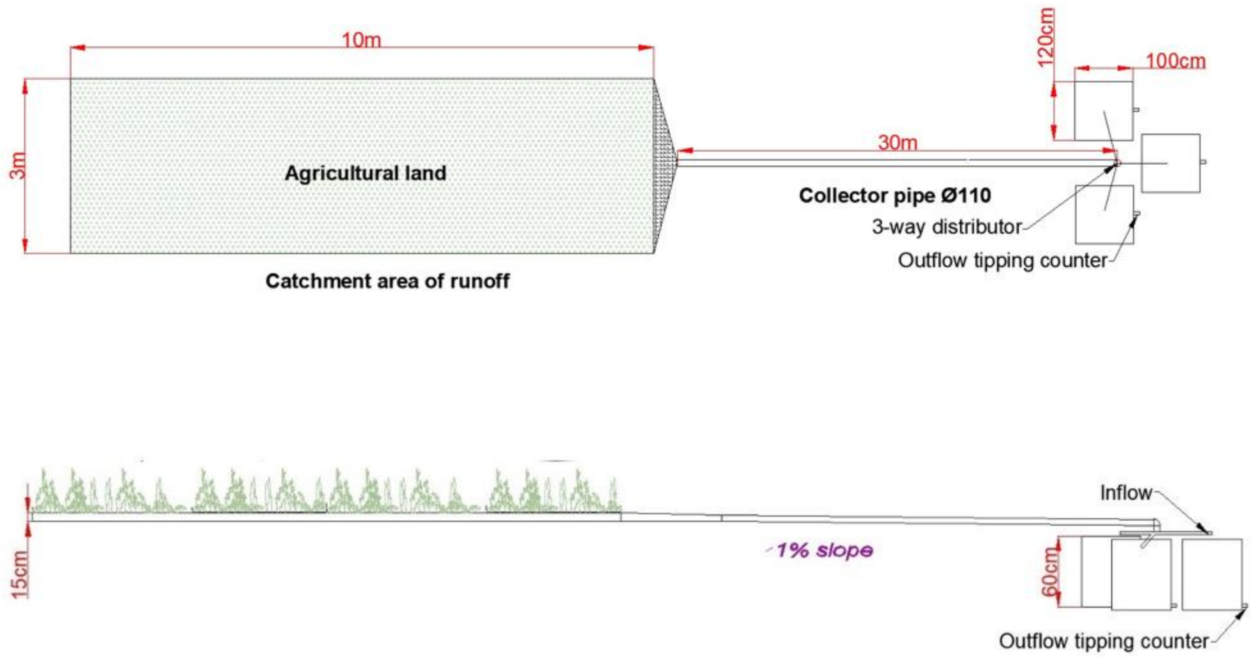


Figure 12. Top and lateral view of the catchment area, water collection pipe, the bio-inspired multilayer filter system, and a PV island (not shown) in Mistelbach (Austria II).

The collected agricultural runoff was distributed on top of the filter systems using an in-house developed water distributor with a mechanism to divide the water into three parts (one for each filter system). The distributor was designed based on a triple symmetrical (around the vertical axis) cylinder, where water enters concentrically and, after being calmed by passing through a vertical barrier, exits through 3 triangular outlets at the free drop (*Figure 13*).

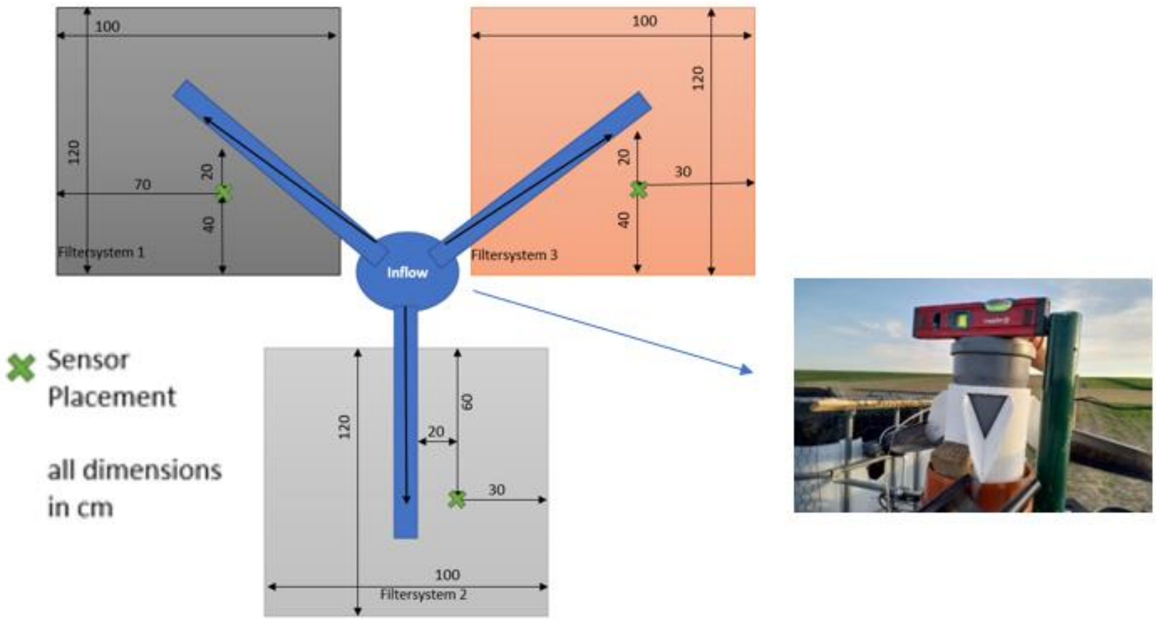


Figure 13. Arrangement of the three-way-water diverter in blue colour and position of soil sensors.

4.3.2. Bio-inspired multilayered filter for agricultural run-off

4.3.2.1. Design concept and technical information

Bio-inspired multilayer vertical-flow systems were constructed above ground in three intermediate bulk container (IBC) tanks in June 2021 on agricultural land, each having a surface area of 1.2 m^2 and 0.65 m filter height composed of different layers of substrates. Filter 1: a vegetated filter system (with Draingarden and biochar), Filter 2: unvegetated filter (with biochar in the main layer); Filter 3: a vegetated system with local soil as reference. Designs and information for each layer are given in *Figure 14* and Figure 15. The surface agricultural run-off was collected from a catchment area of 30m^2 (1% slope) and directed with a 30 m long pipe in a three-way distributor, which fed each system with surface runoff.

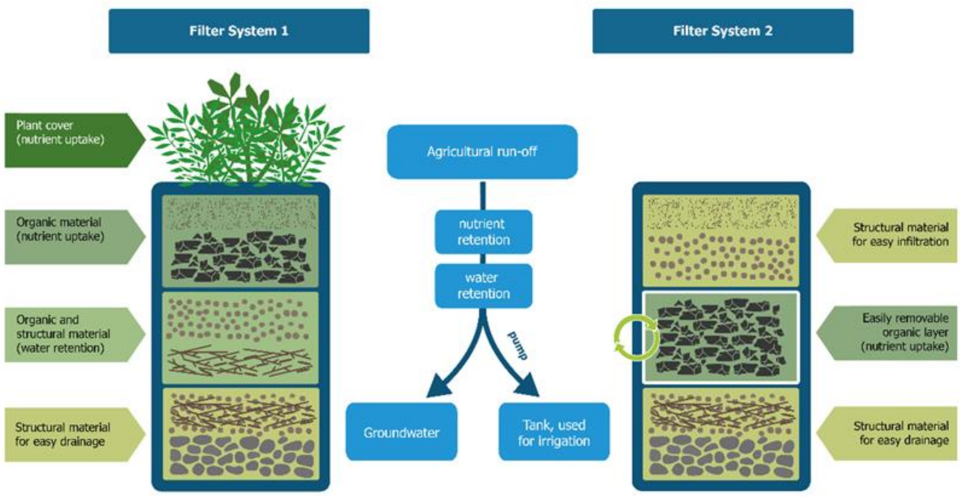


Figure 14. Bio-inspired filter system concept (alchemia-nova GmbH)

Bio-inspired multilayer filters (C2) in the Mistelbach case study are differentiated based on the substrate used in the main layer and the presence or not of vegetation.

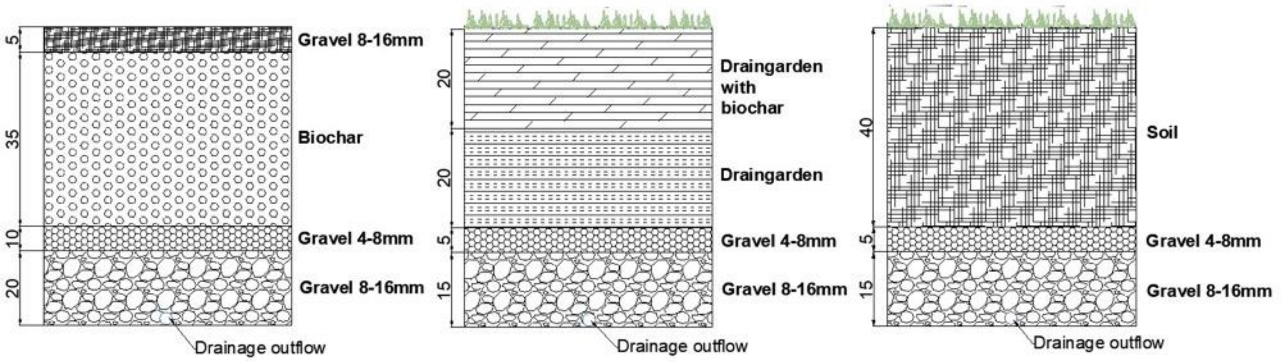


Figure 15. Layer composition (cm) of each filter: biochar, Draingarden, and soil filters in Mistelbach, Austria.

Biochar filter was an unvegetated filter material, with a 5 cm thin gravel layer on top, followed by 35 cm Biochar main layer, 10 cm gravel 4-8 mm and 20 cm of gravel 8-16 mm in the drainage layer. Biochar (0 - 2 mm grain size) was coated with $Mg(OH)_2$ during the production from Sonnenerde GmbH, Austria.

Draingarden filter was vegetated, 20 cm top layer of Draingarden mixed with 5% by mass biochar, followed by 20 cm fine Draingarden substrate without compost + 10% coarse zeolite 4 – 8 mm, 5 cm gravel 4 – 8 mm, and 8 – 16 mm gravel in the drainage bottom part.

The soil filter was vegetated. Its main layer was composed of local soil (loamy sand) 40 cm, followed by 5 cm of gravel 4 – 8 mm and 15 cm of gravel of 8 – 16 mm.

Substrate information

Draingarden® is a mixture consisting of purely mineral and organic components. The filter material is a particular substrate of the DrainGarden® system developed by Zenebio GmbH. Its composition and detailed substitutes are not made public.

Biochar is derived from grain husks, fruit sludge and wood shavings, which are heated to high temperatures (600 °C) in the absence of air and then extinguished with water (commercial name Bio-Pflanzekohle, Sonnenerde GmbH). It is used in agriculture, not as a nutrient per se but in conjunction with fertilizer, it provides an optimal habitat for desired microorganisms due to its large surface area. The biochar used in this filter is the same material as Pflanzenkohle, except it was enriched with 20% by weight with magnesium hydroxide $Mg(OH)_2$ during the production, which will be referred from hereafter as $Mg(OH)_2$-coated biochar or only biochar.

Batch sorption experiments were carried out in the Laboratory of the filter materials used in the Mistelbach and Gleisdorf sites. The results are presented in Del. 4.5

4.3.2.2. Dimensioning reasoning

The filter was designed to reduced flow and nutrient/contamination peaks for overland flow events. Overland flow is mainly caused by rain events with higher intensities, and therefore, they should be large enough to retain the amount of overland flow. The individual field had an area of 10 m², and the long-term 30min-precipitation intensity was 48.3 mm/h. Further, assuming a typical discharge coefficient of 0.47, would result in a drainage rate of 22.7 L/hm² from the field and 28.3 L/hm² directly on the filter area (without slope and assuming full infiltration) (0.8 m x 1.2 m). After one hour, the catchment's runoff load (V) is 1.45 m³. Putting the runoff load in relation to the filter surface, the calculated depth of runoff (h) is 508 mm or, accordingly, a runoff rate (Q) of 0.14 L/s. Mathematically, a filter surface area of 1.71 m² would be required, which results - with the constraints of the available surface area in mind - in a spreading height of 153.82 mm (with the filter saturated before the rain event). If the systems were sized to store the entire runoff load, it would result in uneconomically large dimensions for an experimental prototype and, thus, additional expense for installation and operation would be required. Therefore, the standard 1000 L IBC tanks were used to construct the system (1.2 m^2). Regarding the layer thickness selection, the design of a vertical flow soil filter according to ÖNORM B 2505 (2009) served as a rough blueprint.

4.3.2.3. Requirements for the system (C2)

(i) Requirements for installation

The installation splits into three parts (Figure 16): a) the catchment area, including pipes; 2) the filter array with water distribution; 3) the photovoltaic island with monitoring sensors. The catchment area can be installed either with or without vegetation. The metallic sheets that isolate the catchment area must be driven in with a heavy mallet and protective block. It is recommended to do this after a rain event as moist soil is more penetrable. The catchment area had a slope of 1%, and its dimensions were 10m long along the hill slope and 3m wide. The piping starts with the collection funnel at the very end of the catchment area. The pipes require rammed feet every 3 meters for stability.

For the array of three filters, a three-way distributor is required to split the flow of the whole catchment equally on top of the three filters. The three-way-distributor must be mounted on a stable pole and then levelled for the proper division of the water flows.

The PV Island needs to face south, and more importantly, the batteries must be placed in a water and acid-proof container high enough not to get in contact with any runoff water (about 10 cm off the ground). The levelling of the PV panels is less important than levelling the filters, but special care shall be taken in windy areas.

(ii) Requirements for operation and maintenance

The operation is automated and passively driven by gravitational forces (water catchment, distribution, and discharge) and photovoltaic (monitoring and sensors). As with nature-based solutions, the plants need weeding every 30 days, but this is not vital to the reliability of the filtration system. The 3-way distributor needs less maintenance after the first levelled installation to ensure homogeneous distribution. However, it heavily depends on the amount of water and sediments the run-off carries. The wooden feet need to be condition-checked every 30 days for rotting processes. Except for the inlet and the funnel area, where sticks, stones or sediments can lead to clogging, the catchment area and piping are maintenance-free.

(iii) Requirements for monitoring performance

Due to the remoteness of the place, a PV island provides electrical power and shelter for monitoring equipment all on one pallet. The parameters measured were water outflow quantity, soil temperature, and moisture. A hydro switch triggers the measurements inside the pipe. This switch turns on once a 15cm long water film closes the contact between two poles and gives the start signal for measurement. The monitoring runs as long as there is a water flow and stops 12h after the water stops running to monitor the hydraulic behaviour of the filters after a rain event.

Figure 16. Catchment agricultural area, view of the agricultural runoff pipe that distributes the water on top of the three filter systems, PV island, vegetated filters, and tipping counter for effluent. 09.06.2022, Mistelbach, Austria.

4.3.3. Challenges and opportunities

i. Technical limitations (durability, slopes, soil and climate)

This solution was designed for experimental purposes above the land surface, in case of upscaling, this system can be incorporated inside the soil. Deliverable 4.1 describes the bioengineering techniques that can be applied inland using filter materials we tested in Mistelbach and Gleisdorf experimental sites. With regard to this experimental setup, the slope must ensure agricultural overland flow, so >0.1% is a point of reference depending on the runoff ratio of the soil (vegetation, type of soil, porosity, duration of rain event, etc.). Slopes between 1% and 5% are represented in the implementation of Mistelbach. Steeper slopes would require more practical evidence. The ploughing direction determines the surficial hydrodynamic behaviour of the runoff and should be considered in the slope direction when planning a runoff filtration but is limited by too high flow speeds and erosional forces. Economic dimensioning of the filters contributes to ecoservices at high-intensity rain events or light rain but cannot support long-lasting rain events due to storage capacity.

ii. Legal requirements (e.g., labour, environmental, and water law)

The setup in Mistelbach operated as small-scale aboveground filters show low ecological impact. An environmental assessment is needed for big-scale implementation of the filters, especially when digging is required (subsurface installation), and the outlets are close to water bodies.

iii. Uncertainties (Technology readiness level, TRL)

As stated in point (i), technical limitations showed uncertainties in hydraulic behaviour at steeper slopes as well as different types of vegetation. The biochemical composition of the filter can be further explored for the interaction between layer thickness, medium composition and economic investment. A subsurface implementation with endemic plants would show higher practicability for a larger-scale application.

4.3.4. Methodology for Mistelbach case study system

4.3.4.1. Monitoring parameters

a) Soil probes to monitor moisture content and temperature were installed during the construction of the filter system in June 2021 at two level depths (17 cm and 30 cm for Filter 1, 2cm – 20 cm depth for Filter 2 and Filter 3, respectively (See Figure 13). These data can serve as an estimation of water retention of the filters.

Table 2. Soil probes to monitor moisture and temperature at different filter depths

SENSORS IN USE	TYPE	FILTER 1 (DEPTH)	FILTER 2,3 (DEPTH
Moisture sensor	Meter MAS-1	17 cm and 30 cm	2 cm and 20 cm
Temperature sensor	PT1000	17 cm and 30 cm	2 cm and 20 cm
Tipping counter	UGT 0.1 L Polycarbonate		

b) Tipping counters were installed in the outlet of each filter system to collect the agricultural runoff effluent. The effluent samples were analysed in the laboratory for PO_4-P, NO_3-N, and NH_3-N using the photometry method (DR1900 Hach LANGE), pH, EC, and temperature using WTW 3320 multiparameter. For influent, installing a tipping counter was impossible due to the three-way distributor.

4.3.4.2. Tracer study

A tracer experiment using saline water was carried out from 12 – 14th May 2022 on all three filter systems (biochar, Draingarden, soil filters). A 1000 L water tank was brought into the field by the farmer to perform the tracer tests and placed uphill in the catchment area so water could be led to the systems by gravity. Because there was not enough pressure to mimic desired flow, influent loading was done manually using a bucket with a valve in its bottom, directing the water in the perforated distribution pipe situated on top of the filter. Each filter system was first wetted with fresh water until there was continuous water running from the effluent (around 50 L). The tracer experiment method followed was similar to previous methods on similar systems (Langeragraber, 2003). The tracer influent was prepared on-site, spiking tap water with NaCl until it reached an electrical conductivity of 25 mS/cm. Each filter received 50 L of tracer solution for 10 minutes. Following the tracer application, the filter was loaded with 50 L of fresh tap water; one, two, and three hours after the tracer application, a total of 150 L of fresh water. The electrical conductivity of each effluent filter system was measured continuously every 10 minutes for 48 hours, and data were stored automatically (Figure 17). Tracer results are shown in Section 3.3.5.

Figure 17. Tracer experiment on 12.05.2022, three EC meter probes were placed in effluent cells and measured for 48 hours the effluents' electrical conductivity.

4.3.5. Preliminary results and conclusions

The installation of the systems was completed in May-June 2021. Bi-weekly site visits were performed until September 2021 in order to collect water samples and analyse the nutrient concentration in the filter inflow and outflow. Unfortunately, adverse climatic conditions and challenges with sampling prevented the collection of the water needed for the nutrient analysis in monitoring season 2021. Therefore, the experiment was repeated in the vegetative season in 2022, and which results are shown in the following sections.

Activities carried out in 2022 in Mistelbach, Case study II, Austria:

- Re-optimization of the run-off collection system and drainage filter system – April 2022.
- Tracer tests using NaCl solution on all three filters.
- Flow measurements (tipping bucket), effluent sampling, and water quality analyses for nitrate, phosphate, and ammonia during the monitoring period April 2022-September 2022.
- Moisture and temperature in the drainage system at rainfall events.

Precipitation data

Precipitation data from the Mistelbach pilot site are presented in

Figure 18. It is important to point out two details: a) not every rain event produces runoff, and b) the rainfall data presented below are mean values of the Mistelbach area, not of the exact experimental location.

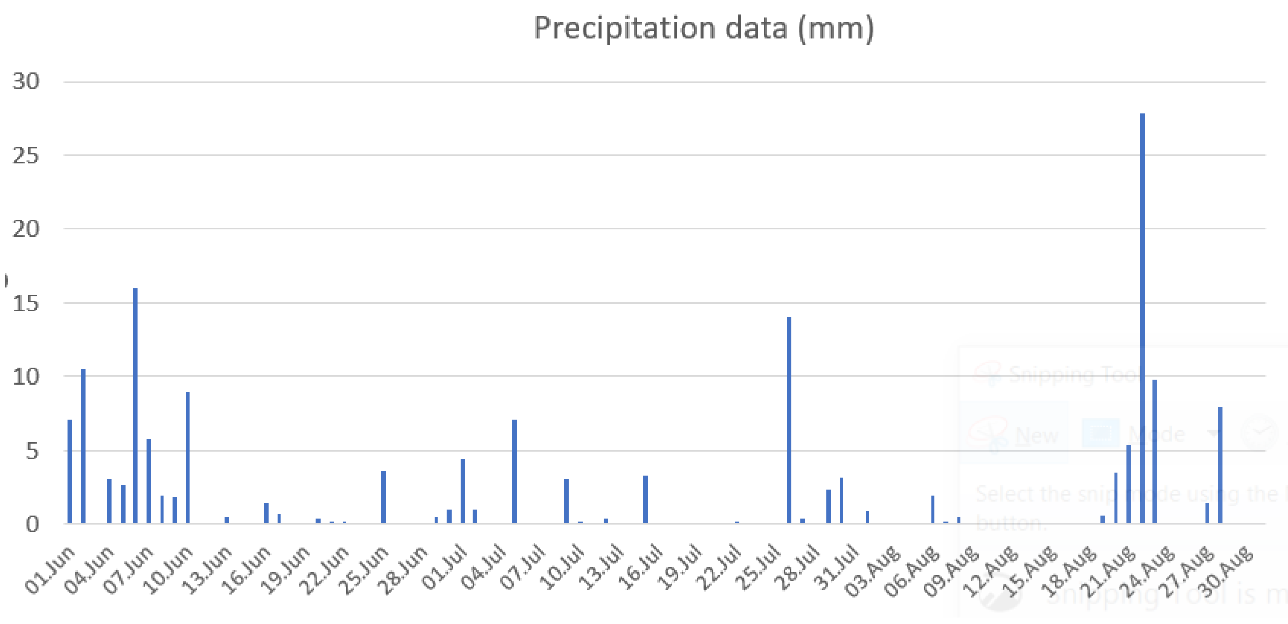


Figure 18. Precipitation (mm) per day during the period June – August 2022 in the Mistelbach area (Data source: visualcrossing.com).

4.3.5.1. Filter's Water content results

Biochar as water retainer (B6)

Considering that on the 12th-14th, the May tracer experiment was performed, during which 250 L of water passed through the system, we exclude these days from data analyses. Monitoring started on 15.05.2022 and lasted until 15.09.2022. Table 2 shows the measurement of effluent volumes in litres at the outlet of the filters by day. The monitoring system only logs data when a rain event results in a runoff reaching the filters, which means there was no water output on the missing days.

Table 3 shows there were only three significant rain events in 2022 monitoring periods on days (17.5, 05.07, 28.08) where all three filters had output on the same day. The rest of the days, Draingarden and soil filters had minor dripping after a runoff or no water output. Biochar drained more water compared to other filters in general. However, it also has less than five-litre output, whereas the other filters have none.

The data shows there was not enough rain to produce agricultural runoff in the region during the summer, and there were prolonged dry and hot periods between the rain events. Since the monitoring system is designed to be switched on when there is flowing water into the system, it was not possible to measure the moisture values of the filter during the dry periods.

Data received from the moisture sensors shows that both measurement points from the biochar filter remained over 40% humid all the time. This percentage was capped by the measurement range of the sensor (0-40%).

Values from the Draingarden filter indicate that the bottom sensor was saturated during the duration of the experiment, and higher sensors measurements ranged between 25-40%.

Table 3. Effluent data collected per day in L from tipping counter each filter

Date	Biochar effluent (L)	Draingarden effluent (L)	Soil total (L)
17/05/2022	62.9	42.4	40.8
18/05/2022	4.3	5.2	3
19/05/2022	0.9	1.2	0.3
20/05/2022	0.3	0.3	0
21/05/2022	12.6	0.1	0
22/05/2022	1.1	0.2	0
23/05/2022	0.2	0	0
24/05/2022	0.2	0	0
27/05/2022	0.2	0	0
28/05/2022	0.4	0	0
29/05/2022	0.3	0	0
30/05/2022	0.1	0	0
09/06/2022	5.4	0	0
16/06/2022	0	0	6.5
17/06/2022	0	0	0.1
22/06/2022	0.9	0	0.1
23/06/2022	2	0	0
25/06/2022	17.5	0	3
26/06/2022	2	0	0
05/07/2022	129.4	89.8	58.3
06/07/2022	4.5	1.9	0.1
01/08/2022	1.8	0	0
02/08/2022	1.9	0	0
21/08/2022	0.5	0	0
22/08/2022	17.2	0	0
23/08/2022	15	0	0
24/08/2022	2.7	0	0
25/08/2022	0.9	0	0
28/08/2022	28.9	7.9	3.4
29/08/2022	1.9	0.5	0
01/09/2022	0.6	0.1	0
02/09/2022	0.2	0	0
04/09/2022	0.2	0	0
05/09/2022	0.2	0	0
06/09/2022	0.3	0	0
10/09/2022	0.2	0	0
11/09/2022	2.5	0	0
12/09/2022	3.7	0	0

Moisture values from the soil filter ranged between 43% highest and 12% lowest. The points on the graph illustrate the logged measurements during the rain event on a given date (Figure 19). In the beginning, the filters were wet because of the tracer tests carried out on 12-14th May 2022, this explains the highest value of moisture content at the starting point. After that, both trendlines are decreasing during dry periods and increasing significantly, only corresponding to major rain events.

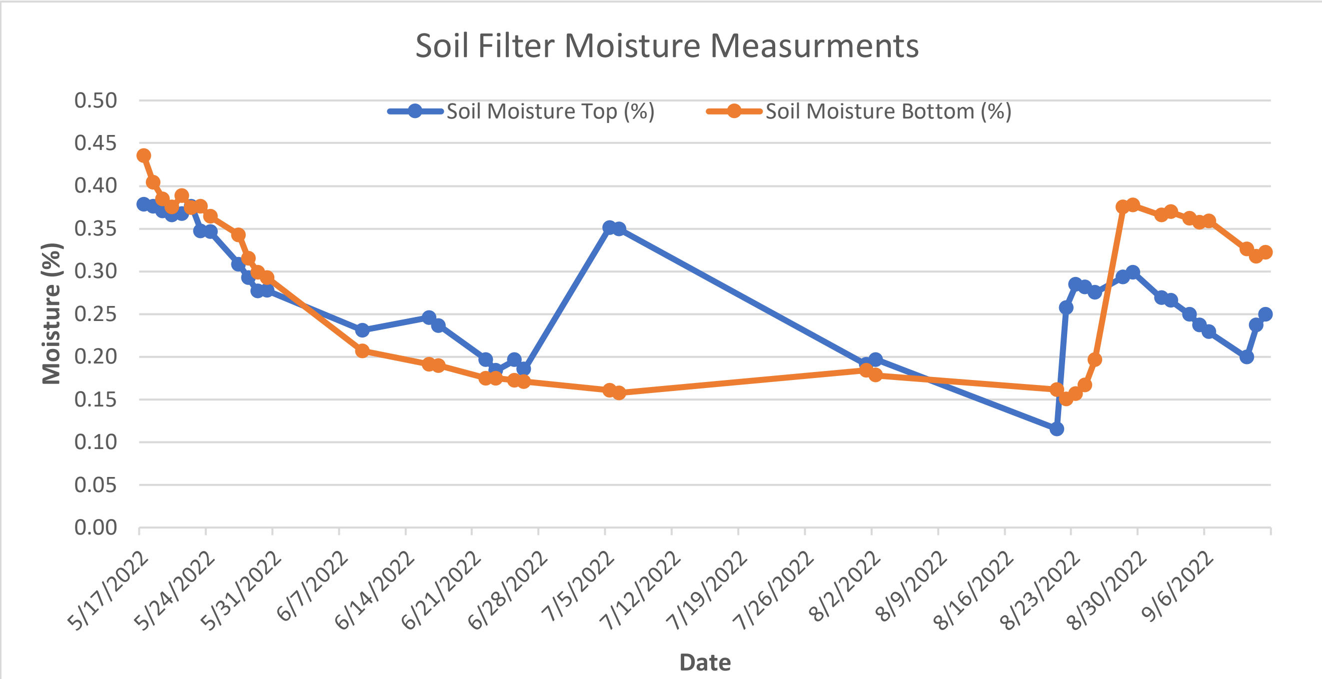


Figure 19. Soil moisture content (%) measured from sensors in two filter depths.

The oven-drying method water content of the filter substrates at the end of the monitoring period

At the end of the experiment, the water content of the substrates was determined on a gravimetric basis with the oven drying method. Gravimetric water content (θ) is the mass of water per mass of dry soil (filter). It was measured by weighing a soil (filter) sample (M_{wet}), drying the sample to remove the water, and then weighing the dried soil (M_{dry}). $\theta=(M_{wet}-M_{dry})/M_{dry}$.

Substrate samples from the primary layer were taken in triplicates, at three different depths, on 6th December 2022 when ICB filters were emptied. The samples were brought to the laboratory to determine water content by oven-drying them at 105°C for 24 hours.

The results of moisture content for Soil and Draingarden filters are presented in Figure 20. The results show that the moisture content of the soil filter was 14%, for the upper layer of the Draingarden filter was 23-26%, and the second layer of Draingarden had a moisture content of 19-28%. Biochar was the most moisture material by qualitative check, as well as from the sensor's measurement, biochar moisture values were higher than 100% (120%-160%).

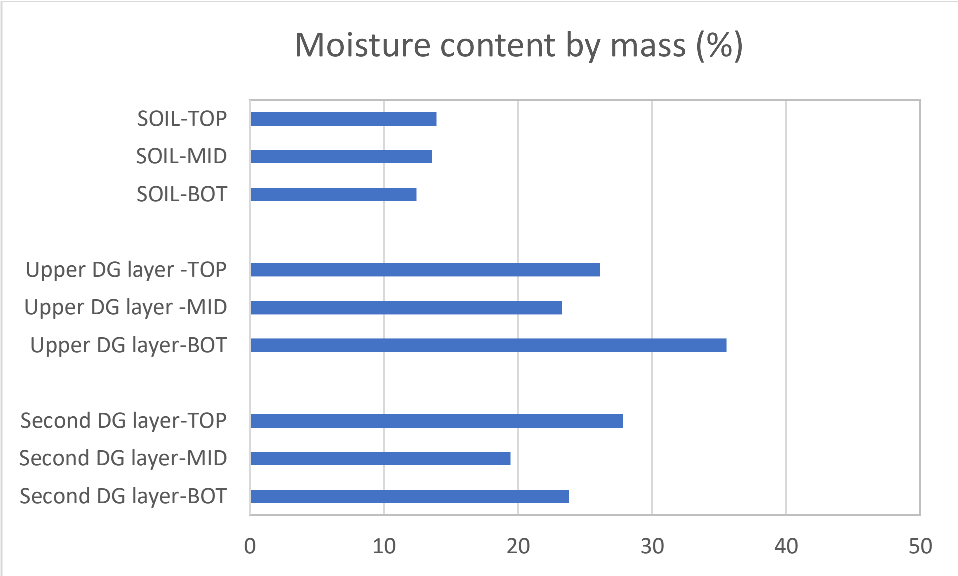


Figure 20. Substrate moisture content data which were collected from the main layer at different depths (every 10 cm) at the end of the experiment. Samplin: 06 Dec 2022. (Gravimetric water content by mass $(M_{wet}$-$M_{dry})/M_{dry}*100)$.

4.3.5.2. Tracer tests

The tracer mass recovery (M/M0) results were plotted versus the time (Figure 21). Total tracer mass recovery was 90% for the soil and biochar filter and 115% for the Draingarden filter. Mass recovery higher than 100% is usually attributed to experimental error or background electrical conductivity data in the system (which, in this case, were deducted anyway).

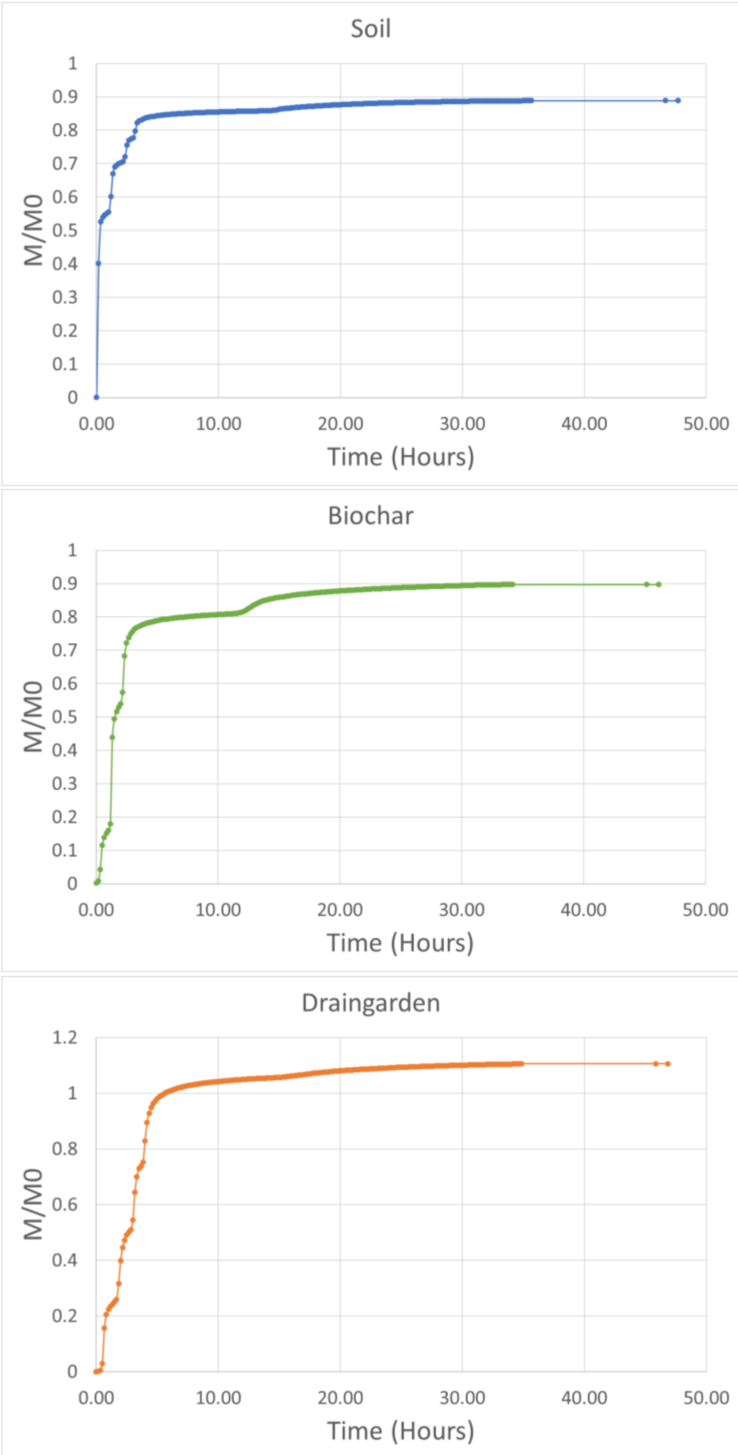


Figure 21. Tracer data results of the three systems in the Mistelbach pilot case study, Austria. 1) Soil filter, 2) Filter containing biochar in the mean layer, 3) Filter containing Draingarden material in the main layer.

Tracer tests with NaCl revealed the systems had fast peaks. The fast peaks, low peaks, and pronounced tailing generally indicate the occurrence of non-equilibrium flow behaviour (Canga et al., 2016, Pugliese et al., 2017). The preferential flow could be attributed to the impact that 'freeze-thaw-dry' atmospheric conditions had on the filter systems for two years, which could lead to the formation of cracks or preferential pathways. Even so, the filter reduces the peak discharge, which can be considered a good measure for temporary water retention.

4.3.5.3. Nutrient retention

The bio-inspired multilayer filters were monitored from 12.05.2022 to 14.09.2022. Physico-chemical results and effluent concentrations for PO_4, NO_3-N, and NH_3-N are shown in Table 4 and Figure 22, respectively. The monitoring period started with performing tracer tests from 12^{th} -14^{th} May, where each system was flushed with around 250 L of tap water (50 L to wet the system, 50 L of tracer, and 150 L of fresh tap water). This amount of water is reflected in higher PO_4 (2 mg/L) and NH_3-N (30 mg/L) effluent concentrations for Draingarden and soil filters compared to successive sampling dates effluent concentrations, probably related to P and N leaching from the system. On the opposite, the biochar filter did not show these high values. Electrical conductivity values were also higher compared to background values (1 mS/cm) because of the added NaCl tracer. pH values were higher for the biochar filter (average pH 9.47) and lower for Draingarden and soil filters (pH 8.09, and pH 8.08, respectively).

Results from effluent concentrations for PO_4, NO_3-N, and NH_3-N show some variability over time; concentrations ranged between 0.06 to 3 mg/L, with an outlier for NH3 of (30 mg/L). All three filters behaved similarly for PO_4 retention with effluent concentrations below 0.5 mg/L. For NO_3-N, Draingarden and biochar filter had some variability, with soil retaining better NO_3-N. Except for the initial outliers, all three filters had effluent NH_3-N concentrations at or below the detection limit (0.01 mg/L). The collected data are limited to conclude the nutrient retention performance of the systems; this is due to no frequent agricultural runoff in the monitoring seasons 2021 and 2022 to serve as influent for the bio-inspired filter systems with biochar, Draingarden, and soil filters. Background electrical conductivity values of the filter systems were around 0.8-1 mS/cm. The electrical conductivity values were higher from 12.05.2023 because NaCl tracer experiments were carried out, and the filter systems took time to return to background electrical conductivity values (Table 4). Biochar filter had higher pH values (average 9.47) compared to Draingarden and soil filters (8.09 and 8.08, respectively). The next step in this setup will be the schematic drawing of field-embedded systems, also applying bioengineering techniques to guide the water to the system. The outcome of this work is presented in **Deliverable 4.1.**

Table 4. Electrical conductivity and pH data of effluent samples, Mistelbach case study. Influent was able to be collected only three times.

Date of sampling	Electrical conductivity (mS/cm)				pH			
	Inf.	Biochar	Draingarden	Soil	Inf.	Biochar	Draingarden	Soil
12/05/2022	-	3.90	6.85	4.58		8.95	8.07	7.54
14/05/2022	-	5.00	5.83	3.14		9.73	8.50	7.99
20/05/2022	-	3.28	2.43	0.82		9.71	7.98	7.37
27/05/2022	-	3.28	2.42	0.80		9.77	7.98	8.81
03/06/2022	-	2.77	2.41	0.80		9.80	7.82	8.64
09/06/2022	0.26	2.26	2.39	0.85	7.95	9.54	7.89	7.72
24/08/2022	0.16	1.20	no water	no water	8.62	9.91	no water	no water
14/09/2022	0.32	1.14	0.78	0.82	8.5	8.37	8.407	8.469

Figure 22. Effluent concentrations over time for PO_4, NO_3-N, NH_3-N, Mistelbach pilot study case (The visit dates where no effluent was found are not shown).

4.4. Gleisdorf (C2) – Case study 8.3, Austria

4.4.1. Introduction and goals

The goal of the Gleisdorf case study was to find a small-scale solution for agricultural subsurface flow. While in Mistelbach agricultural runoff was studied, in Gleisdorf, the multilayer filter concept was used but in a horizontal flow approach.

4.4.2. Site description and prototype location

Near Gleisdorf/Styria/Austria (47.117587511658, 15.7889951203452), a subsurface drain water filter prototype was installed (Figure 23 and Figure 24). The respective subsurface drainage is laid out at a depth of around 70 cm and collects water from approximately 1ha of slightly sloped organic farmland. The filters are inserted in the last 2m of the main collection branch, just before the water is discharged into a bordering stream. The inclination of the drainage pipe is estimated to be 7% (Figure 24). The organic farm is cultivated with potatoes and fertilised in spring with organic fertilizer.

Figure 23. Site location, Gelisdorf, Austria III. The prototype was inserted in the drain pipe collector.

4.4.3. Design concept, construction, and technical information

The system is designed to mimic a horizontal flow filter system but at a small scale and is inserted in the drainage pipe at the outlet (Figure 24). Drainage water flows through a filter structure and exits it. The cartridge filter structure is made using a 3D printer, and its final model was developed after producing different 3D printed structures (Figure 25). The drainage filter structure was designed based on site-specific parameters. The structure has precise dimensions to fit tightly in a drainage pipe. The system was installed in Spring 2022 and monitored in Summer 2022, and the monitoring campaign will also follow during Spring-Summer 2023.

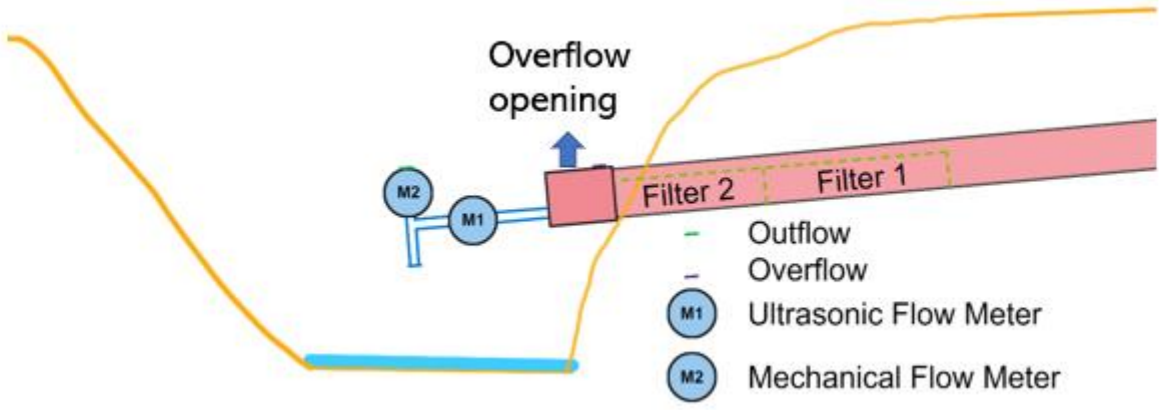


Figure 24. Schematic design of the two filter prototypes installed in the Gleisdorf drainpipe. Filter 1: zeolite 4-8 mm, Filter 2: Biochar from cherry seeds, M1 and M2 Ultrasonic and Mechanical flowmeters.

The performance of such a system in terms of nutrient retention is investigated in a real drainage pipe in Gleisdorf at an organic farm. Two cartridges were inserted into the drainage pipe. The dimension of each cartridge was: 700 mm long, 74.5 mm radius, and a volume of 8 L. The cartridge structure was filled with a substrate media like biochar which can retain P and N present in drainage water. To ensure sufficient hydraulic conductivity, the multilayer filter consisted of 4-8 mm zeolite in the first structure and $Mg(OH)_2$-coated biochar produced from cherry seeds. Previously tested biochar was too fine for this kind of solution.

The nutrient concentration in the drainage flow was assessed for influent, effluent after the first structure, and effluent after the second structure (i.e., final effluent). Results from the first monitoring year, 2022, are presented in this deliverable. The data for the 2023 season will be shown in the updated version of deliverable **D5.3 Data collection**. A Master' student is currently doing column experiments at BOKU to quantify filter adsorption capacity under different flow rates. This data will support filter optimization in the monitoring year 2023 and arrive at better conclusions regarding the filters' nutrient retention capacity.

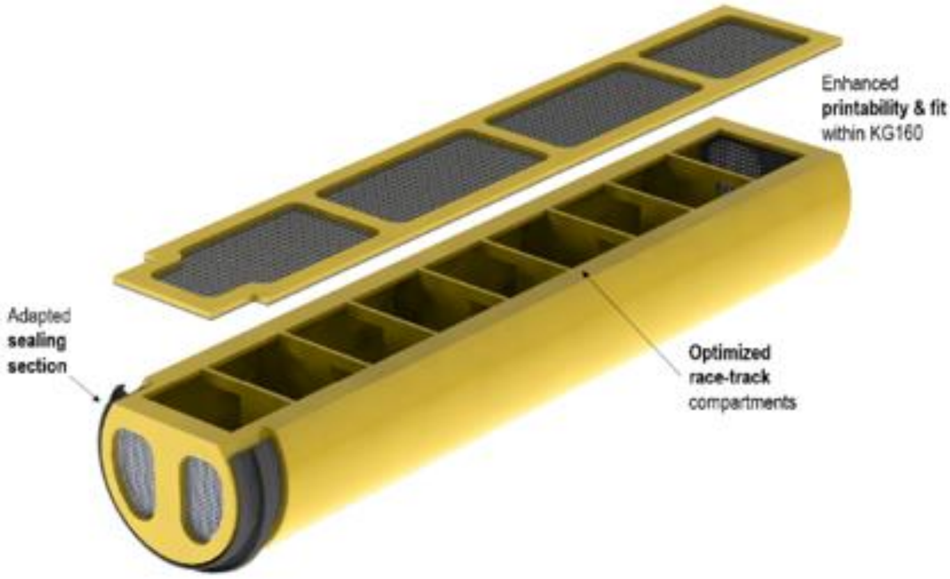


Figure 25. Prototype filter structure designed and produced by alchemia-nova (ALCN), inserted in the subsurface drainage pipe (Gleisdorf, Austria).

4.4.4. Challenges and how they were solved

The drainage pipe system is in a remote agricultural area. Flow measurements have been a challenge because of local conditions and the fact that the proposed structure is inserted in the drainage pipe. Two water meters (an ultrasonic and a manual water meter) were installed in the outlet area of the filters by narrowing the drainage pipe into a 50 mm diameter pipe. The overflow was noticed in the first trials, where both structures were filled with biochar (0-2 mm). A reason for overflow was the flowmeter configuration, which was modified, and a second reason for overflow could be the limited hydraulic conductivity of Biochar due to the fine grain size. To limit the overflow, if caused by the hydraulic conductivity of the filter materials, we decided to try in the second trial:

Zeolite 4-8 mm in the 2/3 length of the structure to increase the hydraulic conductivity, and fine grain $Mg(OH)_2$ biochar in the 1/3 of the structure. Flow experiments were done prior to the field test regarding the maximum conductivity of the systems before having overflow.

Meanwhile, $Mg(OH)_2$-coated biochar originating from cherry seeds, thus resulting in a larger grain size (0-4 mm), was ordered and produced, especially for the experiment by Sonnenerde GmbH company. The grain size of this biochar was higher (0-4 mm) than the previous $Mg(OH)_2$ biochar also used in Mistelbach (0-2 mm).

Following up, third trial experiments were undertaken with zeolite 4-8 mm in the first structure and biochar (0-4 mm) in the second. We hoped by changing the source of biomass from which biochar is produced, we could address the P leaching issues noticed from the use of the first biochar. The results of this configuration are presented in this deliverable. The results of the fourth trial (2023) will be presented in the updated version of deliverable Del. 5.3.

4.4.5. Methodology

The monitoring plan lasted from April 2022 to September 2022 and included measurements of outflow water volume, pH, and nutrient concentrations (PO_4^{3-}, NO_3-N, NH_3-N). The drainage water samples were collected and transported for analysis in the laboratory of ALCN with spectrophotometric assays (DR Lange 1900 photometer kits). The same methodology as for the Mistelbach case study was followed for chemical analyses (See Section 3.3.4).

Activities completed during 2022 in Gleisdorf:

- Installation: Spring 2022, Monitoring period: April 2022-September 2022.
- Inflow samples were analysed for: pH, EC, and PO_4^{3-}, NO_3-N, and NH_3-N concentrations.
- Effluent after each structure: pH, PO_4^{3-}, NO_3-N, NH_3-N.

4.4.6. Preliminary results and conclusions

Sorption tests of the filter materials

Prior to the field application, the substrates of zeolite and biochar were tested in the laboratory to assess the sorption properties of the material. Sorption curves for PO_4^{3-}, NO_3-N, and NH_3-N were determined with a range of inlet concentrations varying from 0 to 25 mg/L. Biochar did not arrive at the saturation point at these concentrations; see results in Figure 26. The sorption curve for PO_4 shows that biochar from cherry seeds adsorbs more P compared to fine biochar. Zeolite is the least effective for PO_4 retention and retains 90% of NH_4-N at 50 mg/L inlet concentrations. Column experiments are currently being planned at BOKU through a master's student to assess the nutrient capacity of zeolite and biochar under different flow rates.

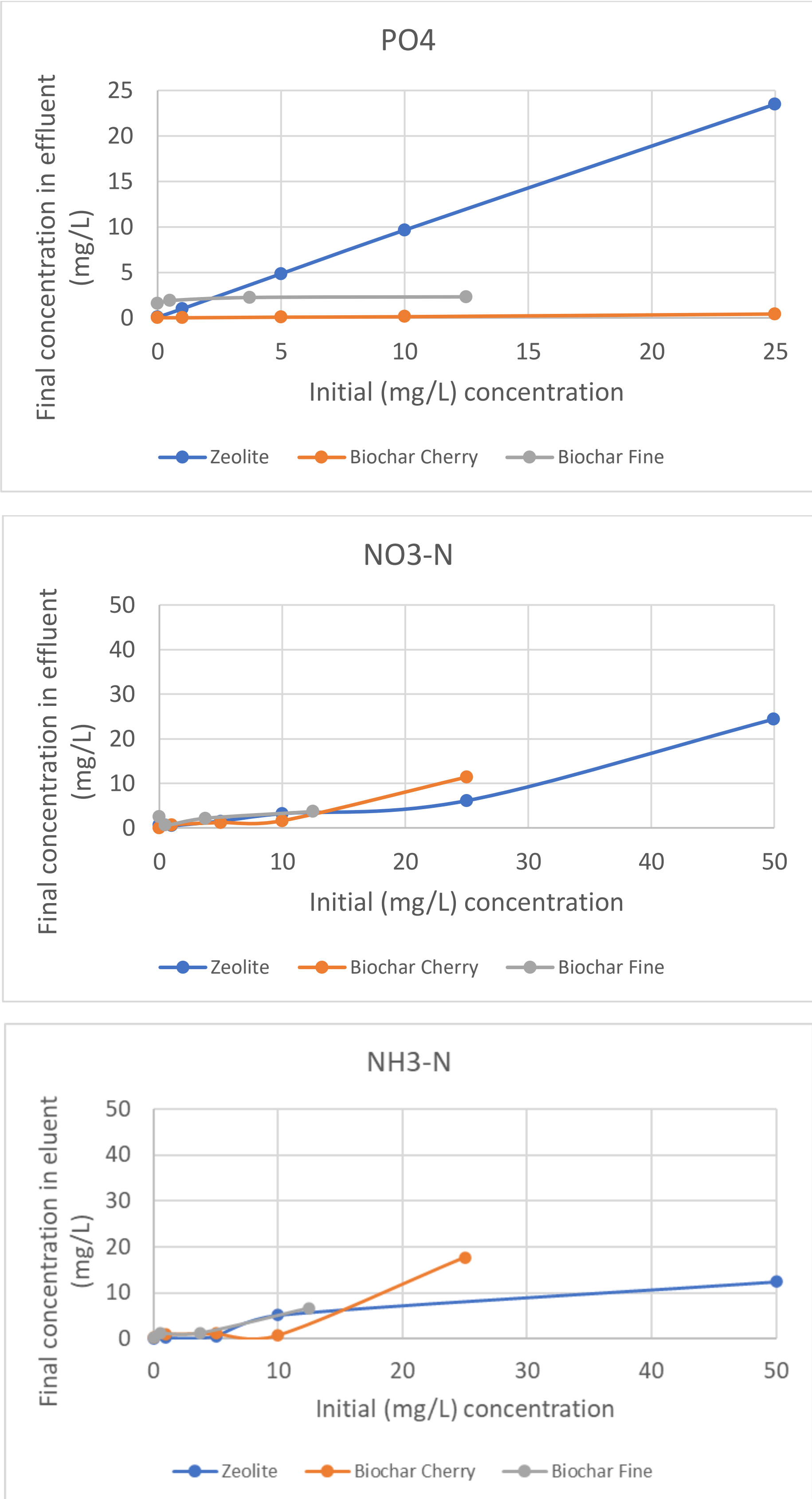


Figure 26. Sorption results performed in the laboratory of ALCN for Zeolite coated $Mg(OH)_2$ biochar from cherry seeds and $Mg(OH)_2$-coated biochar finer texture of the same material as the one used in Mistelbach.

Nutrient monitoring of the drainage filter structure

The results of nutrient concentrations in the influent, effluent 1 after the first structure and effluent 2 after the second structure for the period 13.09 - 13.11.2022 are shown in Figure 27. The first filter inserted in the pipe had zeolite 4-8 mm, and Filter 2 had $Mg(OH)_2$-coated biochar from cherry seeds. Effluent after the second structure had almost always lower concentrations compared to the effluent of the first structure, indicating nutrient retention in filter 2 consisting of biochar. However, the Influent concentrations, which were generally low for all nutrients (0.02-0.08 mg/L for PO_4, 0.4-1.2 mg/L for NO_3-N, and 0.1-0.15 mg/L NH_4-N), were lower than the effluents sometimes indicating some leaching of PO4 and N from the filter materials.

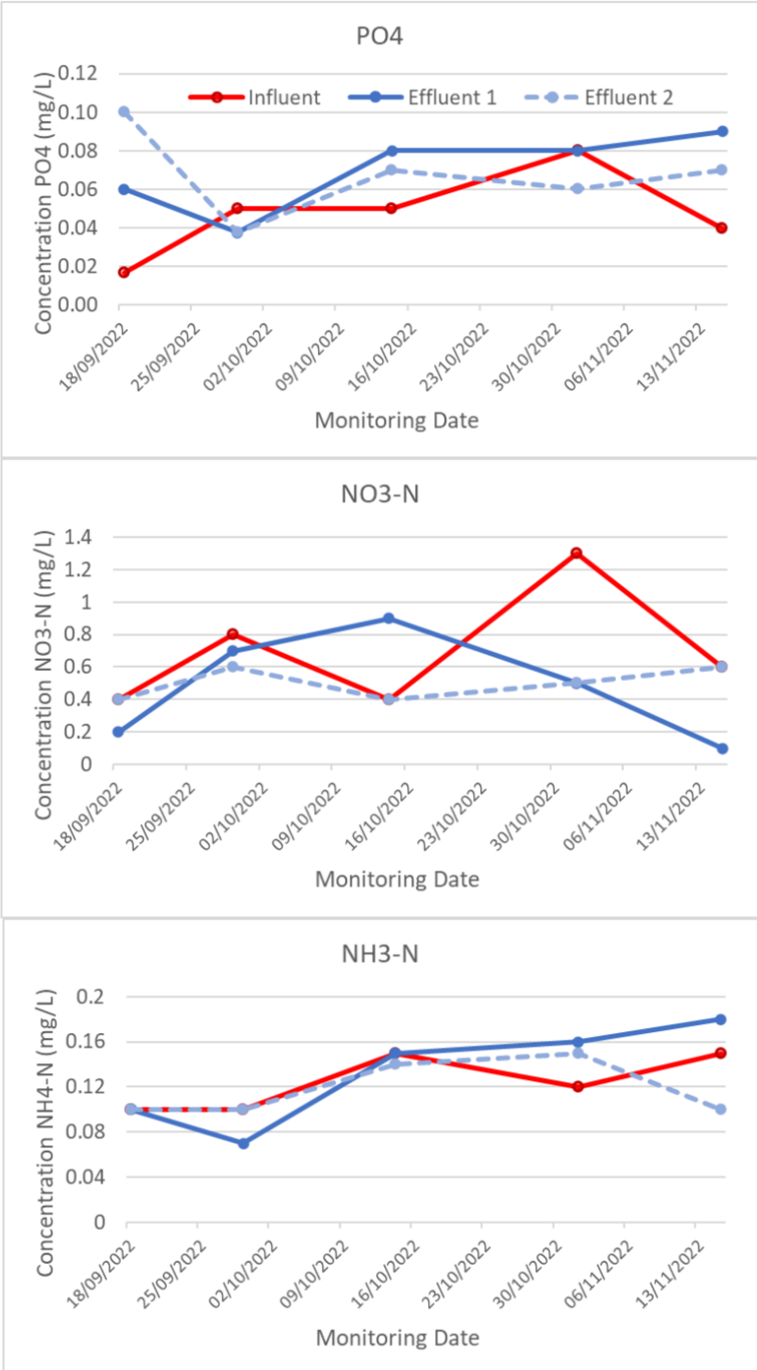


Figure 27. Influent and effluent concentration results of 3rd trial drainage filter system, Gleisdorf pilot case study. Monitoring of 3rd trial started on 7 July, but there was no water in the drainage pipe until 18.09.2022

Preliminary conclusions: The drainage system (Gleisdorf): zeolite 4-8 mm and $Mg(OH)_2$ coated biochar from cherry seeds has the potential to be a good combination to fulfil the hydraulic properties and retention properties that a filter should have. The period of exchanging filter media is to be assessed and optimized based on local conditions (inflow, fertilizer use, etc.).

5. Conclusions from UOULU and Austrian systems

The solutions proposed by the WATERAGRI project have a great potential for nutrient recovery and, therefore, can help to mitigate the negative effects of water pollution by agricultural non-point sources. Recovery of nutrients from agricultural water is a necessity, and if their reuse can be performed, it could certainly contribute to the overall circularity of agricultural production.

Drainage systems and bio-inspired multilayer filter systems, which were studied and presented in this deliverable, are nature-based solutions for agricultural water treatment. Tests were and still are being performed in Sweden and Austria to enhance their performance and propose innovative ways for nutrient recovery. These systems contain natural substrates (biochar, Draingarden, zeolite) that can potentially be used as fertiliser or soil amendment once they are saturated by capturing nutrients present in agricultural water. Moreover, agricultural water rich in nutrients can be directly used for crop irrigation and, in that way, reduce the use of artificial fertilisers.

The activities performed on these solutions were at a satisfactory point at M36, even though some of them were challenged by the lack of monitoring data due to the lack of precipitations. This version provides activities and results performed until M34 (February 2023).

In Finland, two agricultural sites (Tyrnävä and Ruukki) were selected with controlled drainage (CD) as study sites just south of UOULU. At Tyrnävä, CD is used for improved water retention for potato farming. At this site, we have observed soil moisture and groundwater levels since 2021. We also use the HGS model to assess drainage. At Ruukki experimental farm, hydrology is studied to understand and limit nutrient leaching and greenhouse gases by CD. At Ruukki also, automation is developed and used in CD.

Key findings, Finland

- Based on a water balance simulation for the region, the water deficit and irrigation needed were estimated. Soil moisture and groundwater data were obtained from the Tyrnävä site, and HydroGeoSphere (HGS) modelling was explored as a tool to analyse CD effects on water retention. With CD, water retention can be achieved.
- At Ruukki, the spring melting of winter-accumulated snow and frost was responsible for most of the peak discharge rates over the years and provided a significant portion of the field’s annual discharge (averaging 62% of annual total discharge). The discharge rate for these melting periods could get as high as 100 $m^3\ ha^{-1}\ day^{-1}$ (plot 4, 2019) or 108 $m^3\ ha^{-1}\ day^{-1}$ (plot 4, 2021), and GWTL showed saturation in the field.
- Soil frost measurements revealed that frost only reached -30 – 50 cm depth underground, thus, 50 cm or more of soil depth above the drainage pipes was never frozen, allowing water to enter the drainage pipes. During winter, the control wells were open, thus, discharge and leaching occurred.

- The nitrogen load in subsurface discharge waters increased upon increasing peat depth. The proportion of NO_3-N fluctuated under different conditions and was the main driver for TN load/concentration changes. The discharge concentration of NH_4-N and N_{org} was mostly stable and low. The water quality result suggests that N, dissolved P, and TOC loads transported through subsurface drainage pipes from a shallow peat field are lower than from a thick peat soil where the drainage pipes have been installed in the peat.

In Austria, two types of filter systems were tested (Section 3.4 and 3.5). The first set of bio-inspired multilayer vertical-flow filters (biochar, Draingarden, local soil) was installed in Mistelbach and received agricultural runoff and was monitored in the summer of 2021 and summer of 2022. The second type of filter received subsurface drainage water and consisted of two 3D printed structures filled with zeolite and biochar, respectively, which were inserted in a drainage pipe in Gleisdorf and were monitored from summer 2022 until September 2023. These systems (Mistelbach and Gleisdorf) can capture nutrients present in agricultural runoff or drainage water. Biochar material in laboratory sorption experiments showed potential for nutrient retention at high concentrations. The results from the pilots do not definitely support lab results due to a lack of heavy precipitations that could produce enough agricultural runoff (Mistelbach) and/or drainage subsurface water (Gleisdorf).

However, with the data produced, we could at least show that certain nutrients (PO_4-P and NO_3-N) could be retained from the filters of Mistelbach and Gleisdorf.

Key findings

- Bio-inspired multilayer filter system (Mistelbach): The monitoring of effluent nutrient concentrations showed that the filters could be potential solutions, but careful selection of biochar should be made because they may have phosphorus in their composition that is leached at the initial stages of operation. Batch sorption experiments in the lab showed that the coated biochar retains phosphorus and nitrogen better at high inlet P and N concentrations, probably due to $Mg(OH)_2$ coating than at low phosphorus concentrations. Tracer tests with NaCl revealed the systems had fast peaks indicating non-homogeneous flow behaviour. The preferential flow could be attributed to the impact that 'freeze-thaw-dry' atmospheric conditions had on the filter systems for two years, which could lead to the formation of cracks or preferential pathways. Even so, the filter reduces the peak discharge, so it can be considered a good measure for temporary water retention. In terms of nutrient uptake, the dataset collected is limited to concluding the nutrient retention performance of the system; this is due to also lack of agricultural runoff produced in the monitoring seasons 2021 and 2022.
- Drainage system (Gleisdorf): zeolite 4-8 mm and $Mg(OH)_2$-coated biochar from cherry seeds can be a potential good combination to fulfil the hydraulic properties and retention properties that a filter should have. The period of exchanging filter media is to be assessed and optimized based on local conditions (inflow, fertilizer use).

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7. Appendix

7.1. Documenting pictures of Study site 8.ii – Mistelbach, Austria

Pictures from the 1st year: implementing and monitoring, June – September/October 2021

04.05.2021 During the Installation phase, Case study: Mistelbach, Austria.

12.05.2021 During the filling phase of the three systems with filter material, Mistelbach, Austria


26.05.2021 Installation of the catchment area with dimensions: 3 x 10 m, using 1.5 mm thick and 2 m long steel plates.

Pictures from the 2nd year of operation, April – September 2022

12.05.2022 Start of the monitoring period for 2022 and 1st day of tracer experiment.



09.06.2022 The funnel that collects runoff at the end of the catchment area is cleaned from the soil sediments.

09.06.2022 Top view of the filters, from left to right: unvegetated biochar filter, vegetated soil, and vegetated Draingarden filter.

24.08. 2022 Site visit collector of runoff funnel before and after cleaning, and the last date of the monitoring period for Mistelbach. Filters were emptied on 6 December 2022.