WATERAGRI

D 6.1 System Design and Construction Guidelines

36/2023

WP 6 Sustainability and Technical Evaluation of Proposed Innovations and Measures

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No 858375.

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Work Package	6
Delivery Date (DoA)	1.3.2023
Actual Delivery Date	1.3.2023

Abstract:	UOULU assessed different WAERAGRI solutions in collaboration with solution providers based on a template. From each solution, a factsheet was designed and developed on the solution itself to guide its further uptake and development as the main output from T6.1. The solutions were divided into 2-3 groups: Decision Support Systems, End-of-pipe solutions designed to retain water/nutrients and/or recover nutrients, and solutions to test soil properties. The factsheets will be stored on the WATERAGRI homepage.

Document Revision History			
Date	**Version**	**Author/Contributor/ Reviewer**	**Summary of main changes**
8/02/2023	1	Björn Klöve	Main text
20/02/2023	2	Tamara Avellan and Syed Mustafa	Comments
24/04/2023	2	Sebastian Puculek (ULUND)	Quality review
25/04/2023	3	Rolf Larsson (ULUND)	Final review
26/04/2023	4	Björn Klöve	Final edits

Dissemination Level		
PU	Public	X
CO	Confidential, only for members of the consortium (including the EC)	
PP	Restricted to other programme participants (including the EC Services)	
RE	Restricted to a group specified by the consortium (including the EC Services)	

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Funding Scheme: Research and Innovation Action (RIA) ● Theme: SFS-23-2019
Start date of project: 01 May 2020 ● Duration: 48 months

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List of Abbreviations and Acronyms	
DSS	Decision Support Systems
n.a.	Not available

1 Overview of task

The main task of D6.1 was to report the assessment of the proposed innovation methods to retain water and nutrients. This was done considering functionality and different technical aspects for their wider implementation. The output of this evaluation are Factsheets (Appendix 2) on different solutions. The report itself provides a summary of the methods assessed.

1.1. Approach

The assessment in D6.1 intended to outline the key principles of each method in a similar, easy-to-understand format to facilitate their uptake by different stakeholders. The factsheet template with the points to be assessed was developed in a joint project meeting (March 2022) and further assessed in another (October 2022). The template included sections on introduction, design concept, technical information, costs and benefits, challenges and opportunities, references and contact information. For details, see Appendix I.

Solution providers provided information for the factsheets. UOULU then assessed the information to limit positive bias from solution providers. The factsheets were then revised 2-5 times. The methods are presented, including schematics and visual material.

2 Comparison of methods assessed

The WATERAGRI solutions were divided into decision support systems (DSS) and end-of-pipe solutions. In addition, the Water Retainer was classified as a soil amendment and a novel way of analysing soil systems. The Water Retention Curve (WRC) model was classified as a method for testing soils. Where the methods are still under development and need further field testing, this was clearly stated.

Table 1 Solution classified into type (DSS = decision support system, n.a. not available).

Solution name	Type of solution	Water retention	Nutrient recovery	Other	Expert assessment
AgriLemma Serious Game	DSS	n.a.	n.a.	A game to optimise resource allocation	Ready to be used
Data Assimilation	DSS	n.a.	n.a.	A monitoring-modelling set-up provides more accurate data for precise water management	Set-up ready, needs expertise and infrastructure
Irrigation Management Platform	DSS	n.a.	n.a.	A set-up to observe soil moisture, plant development and plan irrigation	Ready to be used
Remotely Sensed Data	DSS	n.a.	n.a.	Provides useful maps from remotely sensed data	Ready to be used

Tracer Methods	DSS	n.a.	n.a.	A smart method to understand agro-hydrology, infiltration and recharge	Ready to be used
WRC model	Soil property model	a test that can be used for assessment	n.a.	A new and fast method to understand to observe changes in porous media water retention	Ready to be used
Water retainer	soil added solution	tested in lab and field	n.a.	An organic liquid that can be sprayed on the soil to increase water retention	Ready to be used, but effect not yet fully documented
Biomembranes	end of pipe solution	n.a.	yes, but the solution under development	Biomembranes tested, but solutions not ready for application yet	Not ready for use
Filter drain pipe	end of drain pipe solution	n.a.	yes, but not known; sediments retained	Tested in field operation. Replacement needed after clogging (maybe every other month)	It can be used, but the effect is not yet documented
Multilayered filter system	end of pipe solution	n.a. or small	yes, but not known	Developed and tested in meso-scale field operation	Needs to be tested and developed further
Microfluidics	end of pipe solution	n.a.	yes, 98 % in lab pilot	Tested in lab scale set-up	Needs to be tested in full-scale systems
Farm-constructed wetlands for water retention	end of pipe solution	yes, depends on the design	see below	Depends on the design of (area, volume, outlet configuration)	Has been documented in many trials
Farm-constructed wetlands for nutrient retention	end of pipe solution	yes, see above	recovery depends on add-on technology	Nutrient removal and retention depend on the size and wetland properties	Has been documented in many cases, but not much for nutrient recovery

3 Recommendations

Based on factsheets and communication with partners, DSS systems are mostly ready for use in real applications. Most of the novel end-of-pipe solutions are still in development and not ready for use in agricultural water management. However, some have been tested at field scale or meso-scale and further developed during the project. The lessons learnt can be used to develop the methods further in the future.

4 Appendix I Template

5 Appendix II Factsheets

FACTSHEET TEMPLATE

NAME OF WATERAGRI SOLUTION

(**Max 4 pages: Fill in as relevant and delete irrelevant**)

Simplified Flowchart / Diagram / Images/Icon

Key information

- How it works or the working principle
- Target audience and user (ready to apply by farmers or further design needs)

A. **Brief Introduction** (max 250 words)**:**

i. A short introduction about the product in a nonscientific way (Easily understandable by the end-users)
ii. What are the key objectives of the product?
iii. What makes the solution innovative compared to its existing counterparts?
iv. What will the end product look like? (Physical installation, decision support system, other?)

B. **Design concept:**

i. Design criteria (layout, size, retention time, hydraulic loading rate,..)

C. **Technical information:**

i. Requirement for installation/use (e.g., land, water, equipment, minimum amount of land area required)
ii. Requirement for operation and maintenance (labour/manpower/skill/training)
iii. How to monitor performance

D. **Cost and Benefits:**

i. Cost of installation (and cost of disposal)
ii. Cost of operation and maintenance
iii. Farming benefits
- Yield etc.,
- Water retention potential/capacity (as mm for water retention solutions)
- Nutrient recovery potential/capacity (if possible as kg/ha or other units) Which nutrients are recycled through the use of the solution (e.g., Nitrogen, Phosphorus, Potassium)?
- Product/byproduct marketing (circular economy/climate change adaptation/mitigation)

iv. Environmental consequences of the product (e.g., increase/decrease in biodiversity, habitat protection, reduction/increase in GHGs, impact on air/water/soil quality, etc.)
v. Social consequences of the product (e.g. livelihood, satisfaction/wellbeing)

Please specify whether the number/information provided is site or climate-specific.

E. **Challenges and opportunities:**

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

ii. Legal requirements (e.g., labour, environmental, and water law)
iii. Policy aspect (e.g., subsidies: list any subsidies available to farmers to implement the solution; from the local/regional government in the area of implementation; please provide references if available)
iv. Evidence base and uncertainties (TRL)

F. Reference and demonstration:

i. Where to find more details?
ii. Video link
iii. Example site (page link/just example)

Contact Information

(Enter Contact information, i.e. email, website, postal address)

FACTSHEET

AgriLemma SERIOUS GAME

Key information

AgriLemma is a game to increase awareness about WATERAGRI solutions. The game engages stakeholders to test different water retention and nutrient retentions solutions considering different trade-offs involved in selecting solutions under uncertainties.

Target audience: farmers or farm managers, agricultural chambers, farmer associations, water management organizations, media, researchers, policymakers

A. Brief Introduction:

Serious games are designed to serve a purpose beyond entertainment, such as training, education, behaviour change or awareness raising. Serious games offer multiple benefits. They are attractive to play because they are fun and engaging and give players a sense of autonomy, competence and connection. Games allow us to simplify and model the complexity of the real world and allow players to experiment with their choices when doing so in the real world can be costly. Stakeholders can also understand how to adapt their choices and decisions in the face of uncertain factors such as climate change. In addition, games are engaging and provide a good learning medium compared to more traditional forms of learning such as information campaigns, websites, marketing flyers or leaflets. They are also an effective tool for communicating with the general public and stakeholders who may not have the technical knowledge and background in agricultural water management.

B. Design concept:

In the game, players take on the role of a farmer in Europe. They have their own farm with fields and can grow five different crops: potatoes, sugar beets, rapeseed, maize, and wheat. To grow crops in the field, players need resources, such as water, nutrients, workers, and seeds. In each round, farmers gain resources, trade resources, plant crops, monitor crops, discover opportunities and invest in their farm by implementing technologies. These technologies will help them retain nutrients and water, increase yields and improve the sustainability of their farm. In AgriLemma, the player's goal is to keep their farm economically, environmentally and socially sustainable.

C. Practical information:

AgriLemma can be played as a table-top board game with 4-6 players. The board game will be delivered as a downloadable Word document/PDF with all the printable game materials such as cards, graphics to stick on the board, etc. This will be made available via the WATERAGRI website along with instructions for facilitators and a list of game pieces (e.g. pawns, water cubes, game money tokens, etc.).

To conduct a gameplay session, facilitators can translate the Word document of the game deliverable into their own language and arrange the list of game pieces themselves. Furthermore, they will need to arrange a table and a few chairs. If there is interest in measuring the impact of the game, questionnaires can be deployed before and after the game to collect data about player’s awareness levels about different solutions, perception on agricultural water management, and game experience. These questionnaires can be downloaded along with the game materials.

D. Costs:

Certain costs are involved in conducting a game session. We estimate that it will cost around 20-30 euros to print all the game materials and about 20-30 euros to order additional game elements (such as pawns, cubes, game token money, etc.). The game elements can be easily arranged from existing board games (if the facilitators have access to them). Please account for additional costs or personnel hours if you plan to translate the game from English to another language.

E. Challenges

Playing games may be an unusual concept for many users/players, depending on their age or previous exposure to serious games. This method may need convincing and its added value should be made explicit and explained to players. Furthermore, as with any modelling exercise, serious games are a simplification of reality and the information in the game does not provide a fully realistic assessment of the solutions. Please refer to the WATERAGRI framework and the results of individual solutions and the underlying models used. Finally, AgriLemma is designed as a generic game that does not take into account local conditions such as soil type and weather patterns of a specific area. Users interested in applying the game to a specific geographical area are encouraged to adapt the game to their local conditions.

F. Reference and demonstration:

To access the game, please check the WATERAGRI website and the project deliverable D1.3

Contact Information

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https://wateragri.eu/

BIOMEMBRANES

Key information

Functionalized nanocellulose membranes can take up nitrate and phosphate. These membranes can be put in a water treatment unit. As the membranes are biobased, degradable materials, they can after use be added to the soil, thus returning the leached nutrients back for their original purpose providing fertilizers (nutrient recycling).

Target audience: future farmers and advisors.

A. Brief Introduction:

Biobased nutrient capture agents provide a sustainable means to diminish the nutrient load from fields by capturing these elements from agricultural drainage water. Here, a new surface - tailored nanocellulose-based membrane was designed and developed further for the purification of runoffs from agricultural areas. The aim was to design the membrane for selective nutrient capture and to configure the runoff treatment to eliminate the need for additional pumping, thereby reducing energy costs.

The biological structure opens the possibility to use the nutrient-rich membrane material after recovery for soil amendment and/or fertilization, thereby developing a full circular solution for the nutrients which otherwise could be considered pollutants impairing surrounding freshwater reserves.

In WATERAGRI, the system was tested for the first time in laboratory conditions. The nutrient uptake of the fabricated biobased membrane was ~ 8 mg for potassium and nitrate ions and ~ 11 mg for phosphate ions per gram of dry membrane.

Further testing is ongoing to increase nutrient uptake.

B. Testing and design concept:

The membranes should be used in a configuration which allows efficient removal, and at the same time, causes zero back pressure, in order to enable free flow of the runoff water and no need of extra pumping.

The system has been tested at a width of 60 cm and 2.5 m length, rolled in a spiral with a distance of 1 cm between the layers. Its performance has been assessed with 4 L/h flow rate and a hydraulic retention time of about 3.5 hours and 16 L/h, implying a hydraulic retention time of around 1 hour respectively.

C. Technical information:

The technology is still in development and detailed technical information for full-scale operation is not yet available.

No special skills are required to operate the system, but an indication of when the membranes are saturated and need to be replaced is required by assessing the nutrient concentration after treatment. Quick test indicators are available for this purpose. Otherwise, the goal is a solution that requires minimal maintenance.

The nanocellulose membrane material has been produced in sheets (length 10 m, width 30 cm, thickness ~25 µm) of uniform and functionalized for enhanced affinity using roll-to-roll (R2R) manufacturing. The membrane production method is based on casting a water-based suspension of nanocellulose, thus enabling R2R production on a pre-industrial scale.

The membrane production method is green and up-scalable and can therefore be produced at VTT in different scales and configurations.

D. Costs and Benefits:

As the method is still under development and new configurations are still to be tested, we cannot yet provide estimates of the cost of installation, operation and/or maintenance. However, most probably, no costs of disposal will be applicable.

For the farmer, the innovation provides a sustainable means to minimize the environmental impact of cultivation with decreasing risk of impairing the water quality in the surrounding ground and freshwater bodies. In addition, the recovered nutrients can safely be returned to the fields.

The social consequences are related to environmentally sounder agriculture (for the farmer, and increased wellbeing for the people in the environment due to less input of nutrients to the freshwater bodies and consequently lower eutrophication). Moreover, if /when the biomembrane production is scaled up to commercial level, it will create new entrepreneurship and job opportunities in the green sector.

E. Challenges and opportunities:

The technology is still in development and test programme on-going, thus statements on technical limitations cannot be given. The current TRL level is 6-7.

However, no legal requirements are foreseen. Depending on the region, it is possible that farmers can apply for subsidies or investment support for such environmentally benign installations.

F. Reference and demonstration:

https://www.vttresearch.com/en/ourservices/cellulose-films-and-coatings

Contact Information

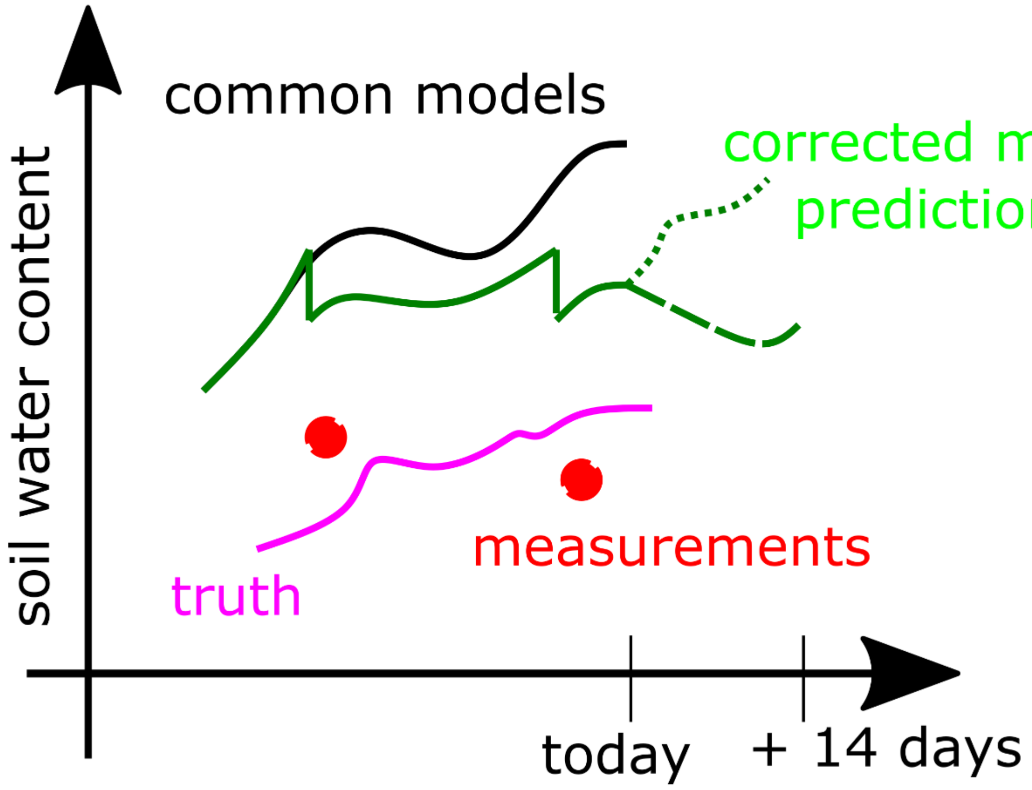
Membrane development: Alexey Khakalo, VTT, Finland, alexey.khakalo@vtt.fi

Pilot tests and technical details on process implementation: Stevo Lavrnić, University of Bologna, Italy, stevo.lavrnic@unibo.it

Bioavailability of recovered nutrients: Nóra Hatvani, Bay Zoltan Nonprofit Ltd for Applied Research, Hungary. nora.hatvani@bayzoltan.hu

FACTSHEET

DATA ASSIMILATION



Concept of Data Assimilation System

Key information

In data assimilation, on-line field observations are communicated to a mathematical model to improve its performance to provide more accurate predictions on e.g. soil water content. The set-up presented here provides forecasts at plot and regional scale for the next 14 days. The approach can be used to predict crop yield and soil water content for climate resilient agriculture and to optimize irrigation schedules

Target audiences: Advisory Services, Farmers, Decision Maker, General Public

A. Brief Introduction:

The data assimilation system is designed to provide the best possible predictions of crop and soil conditions (e.g., soil water content, groundwater levels) at the plot and regional scale for the next 14 days. Simulations of integrated terrestrial system models are combined with measurements to reduce model uncertainty. The innovation of the data assimilation system is to support near real-time decision making in agricultural watersheds. The system, i.e., the code, can be used by advisory services to provide long-term quantitative support to farmers and decision makers. Results, such as estimates of conditions for agricultural fields or watersheds, e.g., predictions of soil water content, groundwater levels, crop biomass trends, and expected yields, can be provided by the advisory services online in form of maps, tables, and graphics. Farmers and the general public could then in turn use this information to optimize irrigation schedules, for example.

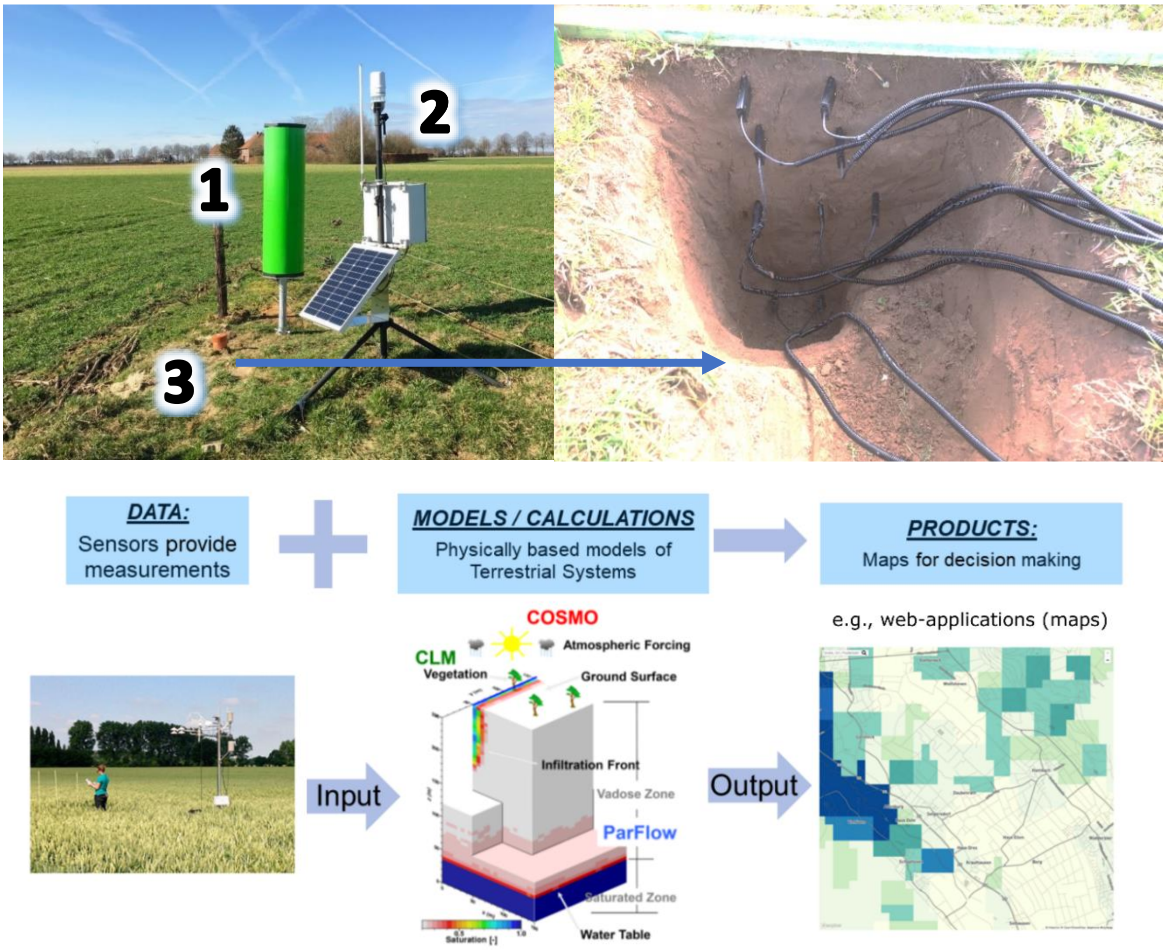


Fig. 1: From real-time observations to model predictions and visual products. (A) Instruments on an agricultural plot. 1: Cosmic Ray Neutron Sensor, 2: All in one Weather station (ATMOS-41), 3: Sensors in different depth of the soil. (B) Soil water and temperature sensors installed in different depths. (C) Workflow: On-site measurements are the input data for physically based models. The simulation output will be used to support decision making in agricultural business.

B. Design concept:

Spatially varying inputs such as precipitation, land use, crop types, meteorological conditions and hydro(geo)logical properties are used to numerically calculate the water, energy, carbon and nitrogen cycle of the terrestrial systems of interest. Weather data are measured directly in the field, e.g., on an agricultural plot, stored in a geodatabase, and harmonized in near real-time. Short- to medium-term weather forecasts are used to predict hydrologic, crop, carbon, and nitrogen conditions and fluxes for selected crop types for the next two weeks. The simulated states of terrestrial systems, e.g., soil water content, are corrected by observations of soil water content in near real time via data assimilation. This continuous combination of simulations with observations reduces the prediction uncertainty. Prediction of variables important for decision making, such as soil water content, crop conditions, and groundwater levels, can be provided via a cloud interface, including their uncertainty.

C. Technical information:

A meteorological station is needed to measure the variables that drive the physically based models. This can be, for example, an eddy covariance station that measures land-atmosphere exchange fluxes, soil heat fluxes, and typical meteorological variables at best 10-minute (at least 1 day) resolution. Soil moisture and soil temperature should ideally be measured at different depths, e.g., 0.01 m, 0.05 m, 0.20 m, 0.5 m and 1.0 m A wireless sensor network would allow collection of relevant information in near real time. Trained experts take care of the design of the integrated terrestrial systems model, the model maintenance (including hardware and software maintenance) and the visualization of the results. The integrated models for e.g., agricultural plots or regions, can be built with open source (e.g., Community Land Model/ParFlow) or commercial (e.g., HydroGeoSphere) codes/modeling software.

D. Costs and Benefits:

Costs include the infrastructure needed to collect plot-specific or local data for modeling and to run a terrestrial model continuously. The instruments, e.g., an eddy-covariance station and a wireless sensor network should be continuously maintained by a technician. Collected data must be checked for completeness and realism. Instruments may stop operating in the field, e.g., due to intrinsic failures or external conditions (weather, damage). Periods without measurements (gaps) must be filled with information from neighboring weather stations, which can increase costs. In addition, there are costs for the development of the terrestrial system model by a specialist and the necessary access to computer resources. Clearly, the benefit to stakeholders, particularly advisory services, is the option to provide forecasts for specific agricultural areas with a high spatial resolution. Model outputs can also be adapted to local needs, making the outputs more reliable and providing quantitative and long-term decision support to farmers.

E. Challenges and opportunities:

The nature of the meteorological variables (atmospheric forcings) limits the possible forecast period, i.e., the time span for which forecasts can be made with reasonable reliability. For example, weather forecasts can only describe a general trend for the next 10 days and are relatively reliable only for the next 5 days. Therefore, extending the forecast period beyond 14 days with reasonable reliability (seasonal forecasts) is only possible to a limited extent, but soil moisture contents and groundwater levels have a longer memory which opens the doors to also make predictions for longer time scales. The data assimilation system is based on a stochastic modeling approach that clearly allows predictions with lower uncertainty for the next 14 days and, in turn, to increase the handling time in agricultural operations. These predictions can be useful, for example, to start optimizing irrigation schedules ahead in time. Costs and possible yield loss during drier periods can be reduced and precision agriculture is an option.

F. Reference and demonstration:

Websites:
https://wasser-monitor.de/
https://adapter-projekt.org/wetter-produkte/vorhersagen-parflow-clm-deutschland-und-nachbargebiete.html

Peer-reviewed journal publications:

Kurtz, W., He, G., Kollet, S. J., Maxwell, R. M., Vereecken, H., & Hendricks Franssen, H.-J. (2016). TerrSysMP–PDAF (version 1.0): a modular high-performance data assimilation framework for an integrated land surface–subsurface model. *Geoscientific Model Development*, *9*(4), 1341–1360. https://doi.org/10.5194/gmd-9-1341-2016

Li, D., Hendricks Franssen, H.-J., Han, X., Jiménez-Bello, M. A., Martínez Alzamora, F., & Vereecken, H. (2018). Evaluation of an operational real-time irrigation scheduling scheme for drip irrigated citrus fields in Picassent, Spain. *Agricultural Water Management*, *208*, 465–477. https://doi.org/10.1016/j.agwat.2018.06.022

Nerger, L., & Hiller, W. (2013). Software for ensemble-based data assimilation systems—Implementation strategies and scalability. *Computers & Geosciences*, *55*, 110–118. https://doi.org/10.1016/j.cageo.2012.03.026

Reichle, R. H. (2008). Data assimilation methods in the Earth sciences. *Advances in Water Resources*, *31*(11), 1411–1418. https://doi.org/10.1016/j.advwatres.2008.01.001

Strebel, L., Bogena, H. R., Vereecken, H., & Hendricks Franssen, H.-J. (2022). Coupling the Community Land Model version 5.0 to the parallel data assimilation framework PDAF: description and applications. *Geoscientific Model Development*, *15*(2), 395–411. https://doi.org/10.5194/gmd-15-395-2022

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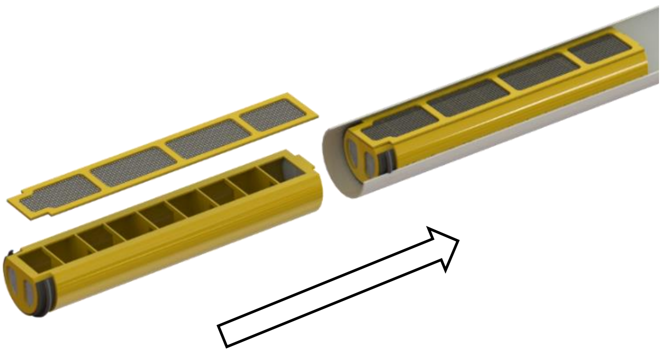
FILTER DRAIN PIPE



Key information

This technology provides a filter structure that can be inserted to a drainage pipe outlet to retain nutrients from subsurface agricultural drainage water. The structure can be reused by filling it with new filter material each time the filter is saturated, and the loaded filter material can be used directly as fertilizer.

Target audience: researchers, farmers, farm schools.

A. Brief Introduction:

The filter system is an in-pipe cartridge filter system developed by lchemia-nova to retain nutrients from subsurface agricultural drainage water. The structure is inserted at the end of the existing drainage pipe. It is currently being tested at field scale in Gleisdorf, Austria. The main advantages of this experimental prototype are that the structure is easily inserted/removed in the existing drainage pipe, the structure can be reused again by filling it with new filter material every time that the filter is saturated, and the loaded filter material can directly be used as fertilizer.

B. Design concept and experimental set-up:

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. Drainage water flows through a filter structure and exits it. The cartridge filter structure is made using a 3D printer. The structure has the precise dimensions to fit tightly in drainage pipe.

The performance of such system in terms of nutrient retention is investigated in a real drainage pipe in Gleisdorf at an organic farm. Two cartridges are inserted in the drainage pipe. Dimension of each cartridge were: 700 mm long, 74.5 mm radius, 149 mm height, and volume of 8 L. The cartridge structure was filled a substrate media like biochar which can retain P and N present in drainage water. To ensure sufficient hydraulic conductivity, the multi-layer filter consisted of 4-8 mm zeolite in the first structure, and MgOH coated biochar produced by cherry seeds. Previously tested biochar tested was too fine for this kind of solution. The filter was removed after 32.8 m3 of water had passed through the filter (over 110 days). During periods of intense rain-event there was overflow and sedimentation was observed on top of the filter as well as inside. The results of some sampling points showed that effluent concentrations decreased passing from influent, effluent of 1^{st} structure, to final effluent after the 2^{nd} structure. But this was not observed continuously.

Prior to this application, the biochar was tested in laboratory to assess sorption properties of the material. Sorption curves for PO_4, NO_3, NH_3 were determined with a range of inlet concentrations varying from 0 to 25 mg/L. Biochar did not arrive the saturation point at these concentrations. Columns experiments are currently being carrying out at Boku to assess nutrient capacity of zeolite and biochar under different flow rates.

Fig. 1. Cartridge, location at drain pipe exit, and the experimental set-up.

C. Technical information:

Information about the subsurface drainage water treatment solution:

i. Requirement for installation/use.
The solution is placed in a drainage pipe (KG160). The outlet must be accessible for insertion and unmounting filters. Also the drainage pipe must be straight to allow to allow to insert the required number of filters.

ii. Requirement for operation and maintenance
Periodic monitoring (once a month) of the drainage pipe to treat possible hydraulic (clogging) or overflow issues (i.e., heavy rain event can lead to washout of fine sediments from soil, that may clog filter or water meter). Exchange of filter medium, once the filter is saturated. No special skills are required to maintain the system if it works properly, short instructions are sufficient training for maintenance.

D. Costs and Benefits:

i. Cost of installation, materials and equipments:
- filter structure 3D-printed: 72 € /unit
- Sieve front and back 3D-printed: 70 € /unit
- Other materials: coupling sleeve, lid for drainage pipe, rope, tube clamp: 130 €
- Substrate costs: Biochar coated with MgOH (1500 € / m^3), zeolite 4-8 mm costs
- Working time (up to 2h), 3D-printing of one filter + preparational work (8h of which 6h are printing time)
- Watermeter costs
- Water analyses equipments, reagents, and working time costs.

ii. Farming and environmental benefits:

- Product/by-product marketing (e.g., circular economy, climate change adaptation/mitigation, reduction in disposal costs)
- Filters are printed with bio-based plastics (PLA) and can be shredded and reused for further printing.
- No additional land area is occupied, which leads to habitat protection

iii. Environmental consequences:
- 3D-printing needs electricity - overall input would be cheaper with injection moulding - but needs high amount of production pieces
- When using biodegradable plastics, potentially produced microplastics through surface scratches or similar are also harmless.

iv. Social consequences:
- Through easy handling more individuals can be reached and inspired to care (more) about water usage and nutrient recovery locally

E. Challenges and opportunities:

i. Possible degradation of PLA through exposure to water flow. Local drainage pipe must be accessible without risks
ii. Biochar / charcoal is reported to bind phosphorus. The period of exchanging filter media is to be assessed and optimized based on local conditions (inflow, fertilizer use, etc.)
iii. This in-pipe cartridge could provide a niche solution in addition to other forms of filter media enclosure

F. Reference and demonstration:

Reports and Deliverables of WATERAGRI project:

i. Deliverable 4.3 Description of development of drainage solutions
ii. Deliverable 4.7 Progress report on the development of the nutrient recovery solutions
iii. Deliverable 4.5 Advanced use of biochar for nutrient retention
iv. Deliverable 5.3 Data collected from Case Study facilities.
v. Project Website: https://wateragri.eu/wateragri-solutions/

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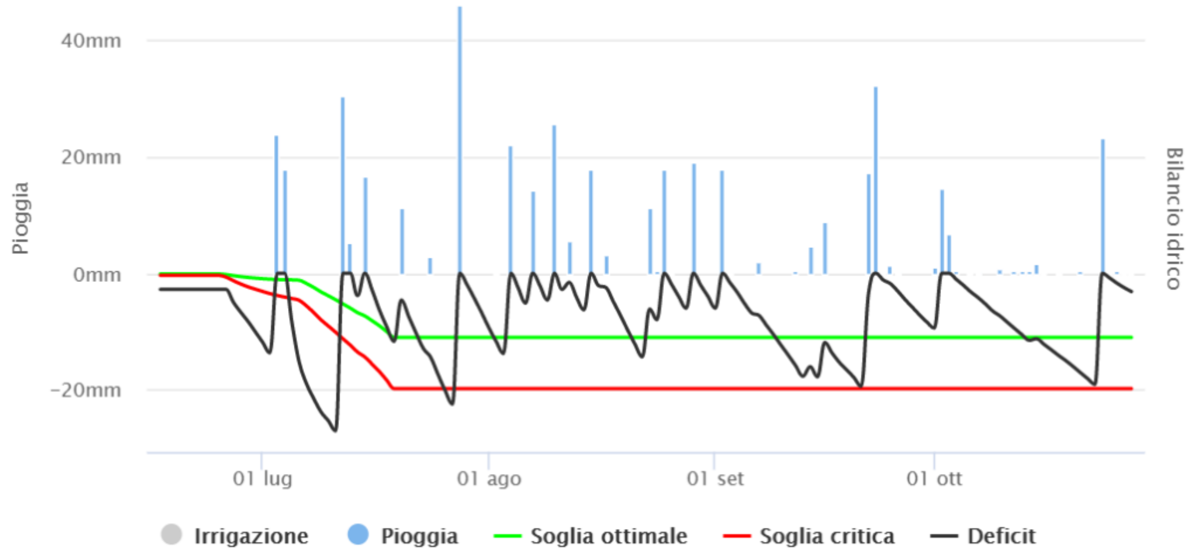
IRRIGATION MANAGEMENT PLATFORM



Key information

The Irrigation Management Solution is an online platform developed by Agricolus that uses information from soil monitoring and remote sensing products to estimate irrigation needs for optimal irrigation scheduling in agriculture. The solution helps farmers, agronomists and consultants manage irrigation scheduling and crop stress in real time, ensuring optimal production while reducing water use, energy consumption and environmental impact.

Stakeholders: farmers, advisors, consultant.

A. Brief Introduction:

The irrigation management solution developed estimates irrigation requirements for optimal irrigation scheduling. It integrates remote sensing, geographic information systems and global positioning systems to increase the operational utility and spatial resolution of the crop simulation and water balance model. Irrigation outputs include daily information on crop water status and irrigation requirements, as well as temporal patterns of soil moisture levels compared to upper (optimal soil moisture status to be achieved with irrigation) and lower (onset of stress when irrigation is mandatory) thresholds. Additional data outputs from the model include phenological phase, crop coefficient and water stress coefficient.

B. Design concept:

The Precision Irrigation solution is based on calculating the soil water balance. The soil water balance requires input of hourly weather data, soil characteristics, crop development stage and irrigation rates applied to the field, which you enter in the "WORK" section.

The outputs of the model include the water deficit, which expresses the amount of water (mm) required to bring the soil back to field capacity, i.e. the amount of water held in the soil after excess water has been drained by gravity.

The model provides the critical threshold, which expresses the amount of water (mm) below which water stress starts to occur at that particular phenological stage. The optimum threshold expresses the amount of water (mm) that must be replenished in the soil to avoid water stress. The model suggests irrigation every time the water deficit falls below the critical threshold and the amount suggested corresponds to the millimetres needed to bring the soil back to the optimal threshold.

C. Technical information:

The installation and activation of the irrigation management system requires an installation of a physical or virtual weather station. Monitoring and management of the precision irrigation system after installation is fully automated and does not need on-site support.

D. Costs and Benefits:

Farming benefits include:

- Yield increase, non-reduction in the face of constraints (climatic, economic, etc.), stability of yield over time, etc.,
- Water retention potential/capacity estimation (if possible as mm for water retention solutions),
- Nutrient recovery potential/capacity assessment (if possible as kg/ha or other units; provide information about the kind of nutrients recovered/recycled/reused e.g., nitrogen, phosphorus, potassium)
- Product/byproduct marketing (e.g., circular economy, climate change adaptation/mitigation, reduction in disposal costs)

The cost of the Agricolus Precision Irrigation system is 360 EUR per year of subscription. The benefits of using an irrigation management system are many, leading to optimized use of water input and minimized water wastage. Furthermore, soil with an adequate moisture level leads to a higher content and retention of nutrients and organic matter, which will lead to greater soil fertility and higher crop quality and quantity. In addition, optimized utilization of water resources will lead to an adaptation of the farm and farming system to ongoing climate change.

E. Challenges and opportunities:

One of the biggest issues is the training the users to change their working habits and make optimal and efficient use of the proposed solution.

F. Reference and demonstration:

More details and major technical information are available at www.agricolus.com

Contact Information

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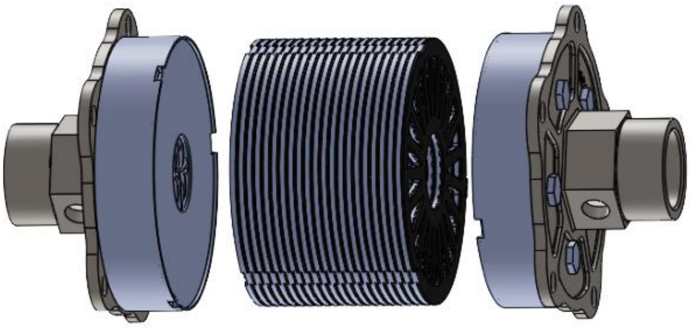
Microfluidics



Key information

This solution uses microfluidic networks and adsorbent microbeads to recover nutrients from wastewater. Through the intricate positioning and isolation of particles in the absence of turbulence in microchannels, microfluidics offers enhanced nutrient recovery in micro-confinement. The method has been tested in the laboratory for the treatment of agricultural runoff.

Target audience: Future farmers, advisors and consultants.

A. Brief introduction:

A microfluidic system is being developed by Eden Tech for the in-situ recovery of nutrients from agricultural runoff. These nutrient recovery systems are based on microfluidic networks inscribed on CD sized disks that can capture nutrients from waste streams. In WATERAGRI, the solution is being developed based on the technical recommendations obtained from the analysis results for agricultural runoff water samples from Italy, Hungary, and Poland. The system has been validated in lab scale for the recovery of the adsorbent microbeads capable of recovering nutrients. The treatment solution be connected to drainpipe outlets after initial treatment systems and needs electricity for pumps to circulate the water through the system.

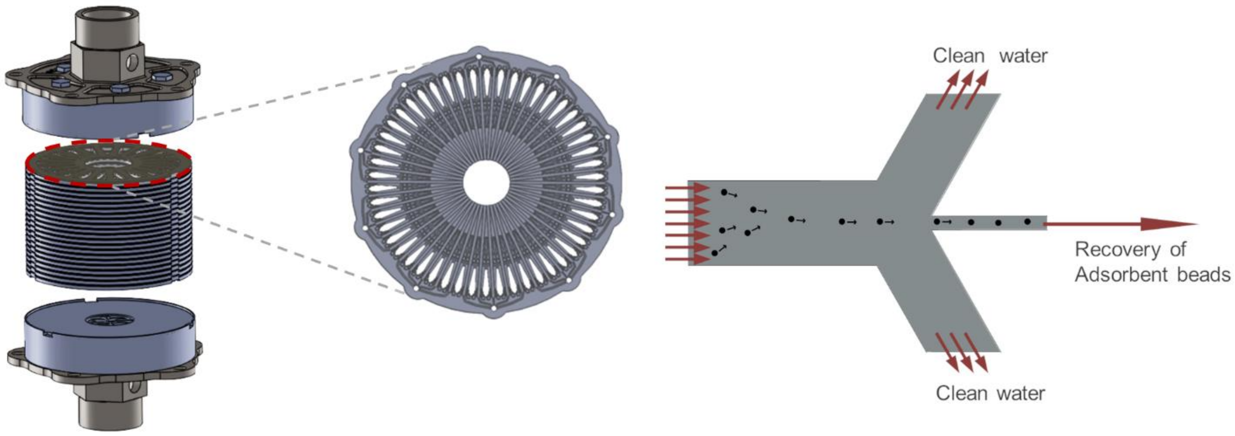


Fig. 1 Operation principle.

B. Design concept:

The Microfluidic system can recover nutrients providing a continuous process with *in-situ* recovery and regeneration of adsorbents without the need of change of cartridges or stopping the process. It is composed of filtrating discs, about the size of a CD, stacked in groups of 10s and 100s, depending on the clients' needs with a capacity of processing up to 1000L/sec of water. The discs are engraved with networks of microchannels, organized into smart energy microfluidic grids. One cartridge is composed of stacked CDs of varying numbers, combined to create a miniaturized factory. When treating low-concentration nutrient solutions, the process can be sped up by enclosing the adsorbent and contaminants in microchannels, resulting in substantially quicker adsorption kinetics. The surface-to-volume ratio in microchannels is also greatly raised, which increases the active trapping rate while keeping the overall size of the device compact. When compared to the similar bulk procedures, the amount of adsorbent utilized is also greatly reduced.

Each microfluidic CD core has a diameter of 10 cm and a thickness of 1 mm. The first step of nutrient recovery from agricultural runoff involves prefiltration to remove any suspended particles and organic materials. Followed by the careful selection of commercially available adsorbent microbeads based on the target nutrient. These microbeads are mixed with the contaminated water followed by circulating the water through a series of micrometer-sized channels, a scale where fluid flow is highly controllable. Our system for isolating microbeads involves the manipulation of water through a series of micrometer-sized channels. The device efficiently guides the microbeads for collection at a significantly higher concentration, up to 1,000,000-fold. After concentration the microbeads are further processed for recovery, regeneration and recirculated through the system.

C. Technical information:

The microfluidic system makes use of commercially available adsorbent microbeads to adsorb the nutrients in microchannels, which is known to enable process intensification thereby enhancing the adsorption kinetics. These adsorption microbeads are then isolated and concentrated utilizing a microfluidic network engraved on the CDs. This isolation of microbeads from the water is done by utilizing a combination of inertial microfluidics technology and obstacles within the microfluidic channels. This ensures high separation while operating at large volumes of water. The laboratory tests carried out demonstrated a separation efficiency of >98% while operating at 100L/min. Thanks to its compact nature, it can be easily deployed, either retrofitted into existing facilities or incorporated into the design of brand-new plants. The system requires an external pump to circulate agricultural wastewater. The system consists of a prefiltration cartridge, a microfluidic stacked CD cartridge, and a regeneration agent reservoir.

D. Costs and Benefits:

The solution is made available by providing the technology as a service, known as Product as a Service (PaaS). Customers subscribe to the product and pay recurring fees. With PaaS, products are offered in subscription models that are offered with services attached, which results in a lower initial cost and no installation fees. This reduces the clients' CAPEX and OPEX. The initial cost is minimal, and the end-user gains access to the advantages of the technology, without the burden of complex maintenance.

Our nutrient recovery system provides financial benefits to future farmers, utility companies and other stakeholders. The recovered nutrients can be marketed, or farmers can reuse them as a pure and effective fertilizer, produced from resources that would otherwise be wasted. If scaled up, this might make a significant contribution to lowering agricultural carbon footprint and nutrient loading into rivers while also providing an extra income stream for wastewater treatment plants.

E. Challenges and opportunities:

The method has not yet been tried out in field scale for treatment of agricultural runoff. The system required electricity.

F. Reference and demonstration:

Solution website: https://eden-microfluidics.com/eden-cleantech/

Project website: https://wateragri.eu/wateragri-solutions/

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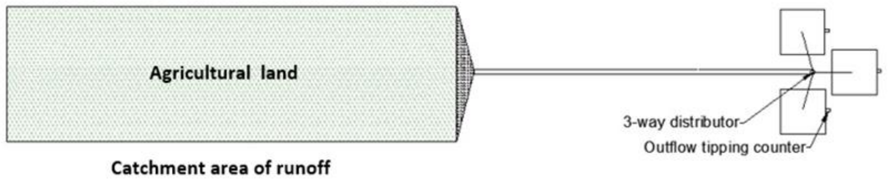
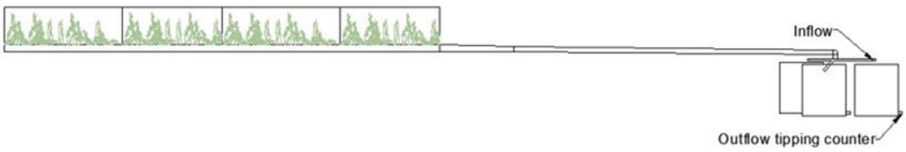
MULTI-LAYER FILTER SYSTEM





Key information

The water treatment system is a multi-layered drainage system designed to retain water and nutrients from agricultural runoff (overland flow). It has been tested as an experimental prototype in the WATERAGRI project.

Target audience: future farmers, farm schools.

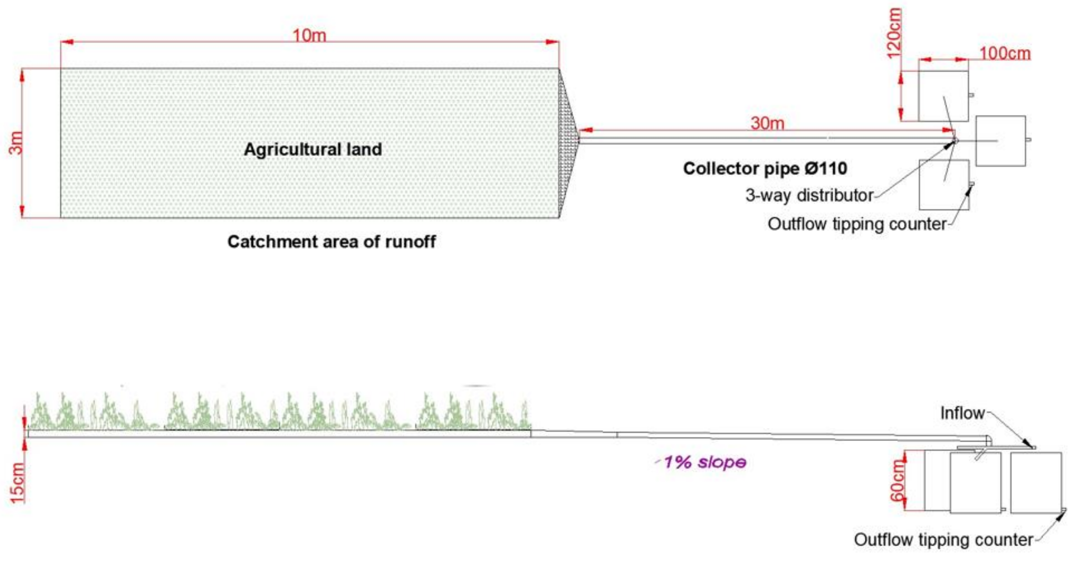
A. Brief Introduction:

Alchemia-nova has in collaboration with BOKU developed a multi-layer vertical filter system to treat agricultural runoff. The drainage filter system consists of three IBC tanks (1.2 m^2) cut on top installed in parallel and filled with different substrates to mimic a vertical flow filter system. The filters differed in terms of substrate used in the main layer and presence of vegetation: biochar/unvegetated, draingarden/vegetated, soil and vegetated, respectively. The bio-inspired filter was designed to work as a water retainer and a nutrient retainer addressing agricultural surface run-off and tested on the slope of an agricultural field in Mistelbach, Austria. 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 require little maintenance apart from harvesting the plants yearly and changing the biochar when it is saturated with nutrients.

B. Design concept and experimental set-up:

Three vertical-flow multi-layer systems operating in parallel, were constructed above ground in three IBC tanks in June 2021, in an agriculture land in Mistelbach and received surface runoff from a 30 m2 cropped land having an inclination of 1% (Figure 1). Each system had a surface area of 1.2 m^2 and 65 cm height composed of different layers of substrates. Filter 1: was unplanted filter (with biochar in the main layer); Filter 2: a vegetated filter system (with Draingarden® substrate + biochar). Filter 3: vegetated system with local soil as reference.

Surface agricultural run-off infiltrated vertically through the system (vertical flow) and outflow is measured with a tipping counter, connected to a PLC datalogger and PV panel. In terms of parameters measured: ammonia, nitrate, orthophosphate, pH, EC, temperature, soil moisture in two depths of the filter system, were monitored. The systems are designed according to the Austrian guideline for vertical flow wetlands ÖNORM 2505.



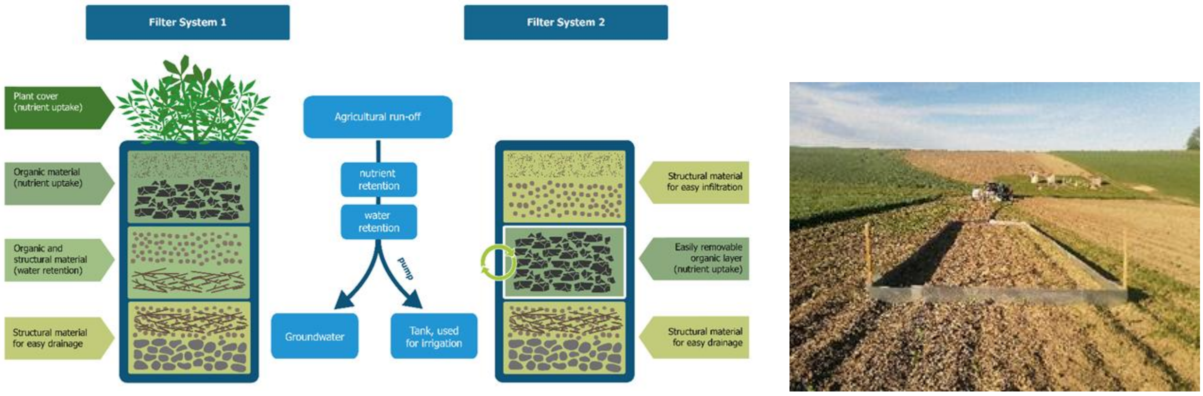


Figure 1 Drainage design (top), drainage filter system concept (left), and photo of the catchment area 26.05.2022 *(right)*

The long-term mean rainwater event-related 30-minute precipitation intensity of I30 = 48.3 mm/h was used as the basis for the design. Since the test field area is very small (30 m² - 3 m x 10 m), it was assumed that it contributes completely to the runoff event after only a short period of time. Therefore, a precipitation duration of 1 h was chosen, which results in a design precipitation (N) of 48.3 mm. A discharge coefficient (B) of 0.47 and a design precipitation (N) of 48.30 mm/h results in a drainage rate (QA) of 22.70 l/h*m² in relation to the experimental field or 48.30 l/h*m² related to the precipitation directly falling on the soil filter.

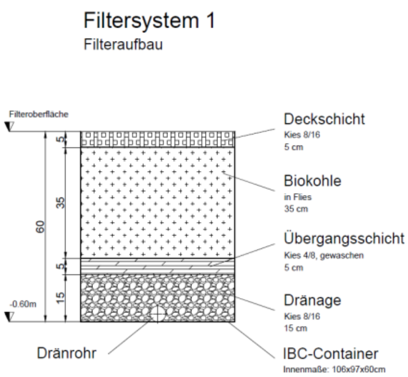
The filter surface area was assumed to be 0.8 m x 1.2 m and the catchment area of the field was therefore reduced to 10 m x 1 m per filter. After one hour, the runoff load (V) of the whole catchment is 1.45 m³. Putting the runoff load in relation to the filter surface, the calculated depth of runoff (h) is 508 mm or accordingly, a runoff rate (Q) of 0.14 l/s.

Regarding the selection of the layer thickness (Di), the design of a vertical flow soil filter according to ÖNORM B 2505 (2009) served as a rough blueprint.

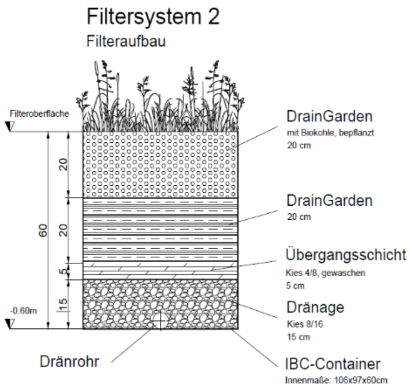
Table 1 Filter design details

BIOCHAR FILTER – LAYERS	LAYER DEPTH (cm)
Not Vegetated	no
Gravel 8-16 mm	12
MgOH coated biochar	30
Geotextile rabbit grille	-
Gravel 8-16 mm	20

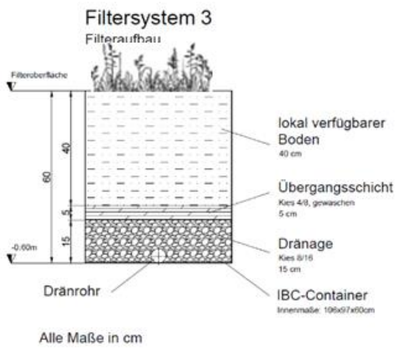
Note: Geotextile/rabbit grille (0.3m) was placed to easily remove the biochar.



DRAINGARDEN FILTER – LAYER COMPOSITION	LAYER DEPTH (cm)
Vegetated	yes
Draingarden substrate	20
Draingarden® substrate (fine, without compost) + 10 vol% coarse zeolite	20
Gravel 4-8 mm	5
gravel 8-16 mm	15



SOIL FILTER – LAYER COMPOSITION	LAYER DEPTH (cm)
Vegetated	yes
Soil (from the site)	40
Gravel 4-8 mm	5
Gravel 8-16 mm	15



C. Technical information

Requirements for installation:

The system has not been tested in a full-scale setup. In the trial, the pipes that collect surface runoff from the end of the catchment area require rammed feet every 3 meters for stability. The 30 m long PVC collects the surface runoff, and a three-way distributor is used to divide the influent (surface runoff) on top of each filter system that operates in parallel. For the array of three filters, a three-way distributor is required to equally split the flow of the whole catchment to the three filters. It is important to clean and level the ground where the filters will stand to ensure homogenous water distribution and infiltration through the filter. When placing the pallets, a stable concrete slab should be placed beneath to distribute the weight better, especially on soft soil. The three-way distributor needs to be mounted on a stable pole which is previously rammed into the earth and then leveled for the proper division of the water flows. The PV island needs to face south, and more importantly, the batteries in a water and acid-proof container high enough not to get in contact with any runoff water (about 10 cm off the ground). Leveling of PV island is not very important as it is for the filters, but special care shall be taken in windy areas.

(iii) 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 also shows low maintenance, although this is heavily dependent on the water and sediments carried by the run-off. The wooden feet need to be condition-checked every 30 days for rotting processes. Except of the inlet, where sticks, stones or sediments can lead to clogging, the catchment area and piping are maintenance free.

(iv) Requirements for monitoring performance

Due the remoteness of the place a PV-island provides electrical power as well as shelter for monitoring equipment all on one pallet. The parameters measured were water outflow quantity, soil temperature and moisture. The measurements are triggered by a hydro switch inside of 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 if there is a water flow (surface runoff resulting after a rain event) and stops 12h later if there is no more water.

In the trial tests, the monitoring of the filter system is carried out through

a) Probes to monitor soil moisture (Meter MAS-1) and temperature (PT1000) were installed at two level depths (17 cm and 30 cm for Filter 1, 2cm – 20 cm depth for Filter 2 and Filter 3 respectively.
b) Use of tipping counters (UGT 0.1 L Polycarbonate) in each filter system's outlet. Effluent samples collected are analysed in laboratory for PO_4-P, NO_3-N, NH_3-N, pH, EC, and temperature.

D. Costs and Benefits:

i. Cost of operation and maintenance

Fixed installation cost is €686 – €764 per system. However, upscaling requires an in-ground filter system; therefore, other cost estimations apply. The operation and maintenance costs of these pilot scale filter systems relate to the travel costs to the remote site and are usually higher than the cost to maintain the system with low requirements. Water analyses can also be considered to monitor the retention of nutrients in the filter.

ii. Farming benefits:

The proposed system has the potential that if upscaled, may provide water retention capacity and nutrient recovery potential. The recovered nutrients (phosphorus, and nitrogen) can then be recycled by using the saturated biochar filter as fertilizer. Moreover, the system has the benefits of being a climate change adaptation approach in capturing agricultural surface runoff.

iii. Environmental and social consequences

In the medium to long term, better management of water resources in agriculture can contribute to the water security of the region´s ecosystems and communities. The results of the multi

E. Challenges and opportunities:

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

The system assumes overland flow, so for the Austrian case the slope must ensure runoff with >0,1% as 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 plowing 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. An economic dimensioning of the filters can cope with high-intensity rain events or light rain but cannot support long-lasting rain events due to storage capacity.

ii. Legal requirements

The setup in Mistelbach operated as small-scale above-ground filters show low environmental impact. An environmental assessment is needed at big scale implementation of the filters, especially when digging is required (subsurface installation) and the outlets are close to water bodies. The effluents leaving the system should not cause any environmental problems (high concentration of nutrients). In practice, the technical assessment of the extent of the contamination is naturally carried out by experts. The area type classification of the ÖWAV Rule Sheet No. 35 on rainwater treatment represents an important guideline.

iii. Evidence-base and uncertainties (TRL)

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 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.

As stated in point E(i). technical limitations showed uncertainties in hydraulic behaviour at steeper slopes. The biochemical composition of the filter layers leave room for experimentation and for the interaction between layer thickness, medium composition, and economic investment as such. A subsurface implementation would show higher practicability for a larger scale application.

F. Reference and demonstration:

i. Public reports of WATERAGRI project:
   a. Deliverable 4.3 Description of the development of Drainage Solutions
   b. Deliveragle 4.5 Advanced Use of Biochar for Nutrient Retention
   c. Deliverable 4.7 Progress report on the development of the Nutrient

ii. Video link: https://www.youtube.com/watch?v=6LtD0pbzEkc

iii. Project website site: https://wateragri.eu/wateragri-solutions/

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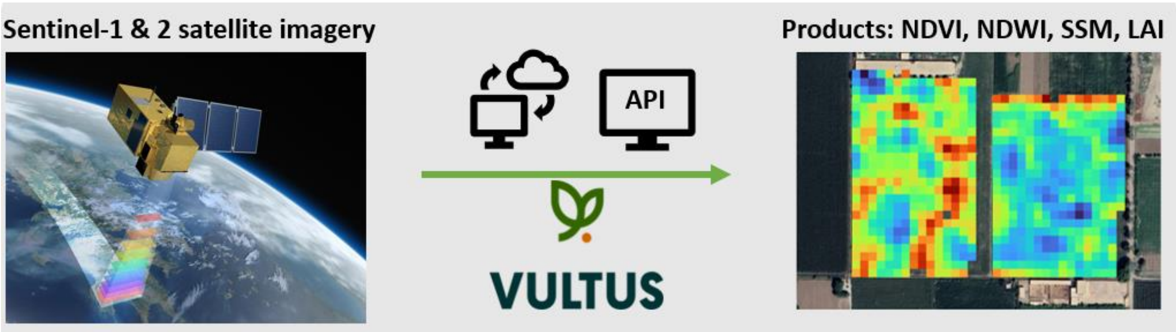
REMOTELY SENSED DATA



Key information

The remote sensing product takes into account the different agricultural crops, topography and soil types of the fields to develop our products for precise fertilisation and irrigation.

Target audience: farmers and advisor services

A. Brief Introduction:

Remote sensing data, especially satellite imagery, are now widely used for monitoring land cover change, agricultural and forestry management, and urban development. For agricultural water and nutrient resource management, VULTUS has developed and implemented a remote sensing processing pipeline to obtain biophysical parameters of vegetation and soil, such as various vegetation-related indices (Normalised Difference Vegetation Index NDVI, Normalised Difference Water Index NDWI, Leaf Area Index LAI, etc.) and soil surface moisture (SSM), using optical and microwave remote sensing observations from Sentinel-1 and Sentinel-2 satellite imagery. These data are valuable for monitoring and managing water surpluses and shortages and for improving nutrient recycling in agricultural catchments.

B. Concept:

The concept is a fully automated pre-processing chain through its Application Programming Interface (API) to provide fully geo-referenced and parameterised (calibrated and in physically meaningful units) spectral data to end users in WP3 and WP5 (Figure 1). Satellite images are searched and filtered based on the required date and then the processing engine is deployed in a cloud architecture and automatically performs calibration, correction, cloud removal and analysis based on different monitoring methods using satellite imagery and outputs the products of LAI, NDVI, NDWI, SSM. Users can access these products through our API platform.

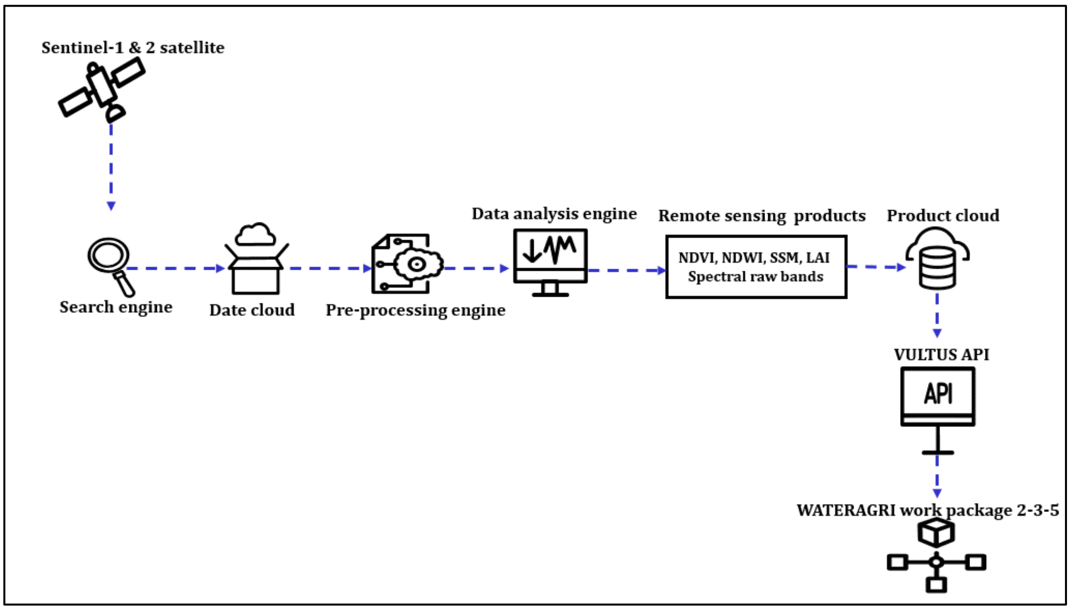


Figure 1. Design and workflow of VULTUS remote sensing pipeline.

C. Technical information:

In order to access the VULTUS API, users must install the Postman platform. In addition, users must contact VULTUS to create an account on the VULTUS platform and obtain an access token to register the fields or polygons of interest. Therefore, the basic requirement for the user is to know how to use the Rest API and Postman.

The requirements for remote sensing information are the Sentinel-1 and Sentinel-2 images..

D. Costs and Benefits:

The cost of providing the VULTUS API is 200 SEK / .19 EUR per API request. This includes all cloud computing, cloud storage and related personnel costs associated with maintaining the VULTUS API.

Results from the remote sensing pipeline, such as NDVI, can be used as an indicator of crop health and further integrated into fertiliser calculations to help farmers improve yields and reduce fertiliser use. Other products, such as NDWI and SSW, are important parameters that can be used for sustainable water retention and management practices. All products in the pipeline can be used directly or further developed to advise on agricultural practices, irrigation management and landscape changes resulting from socio-economic development. The ultimate mission of the VULTUS platform is to help users reduce greenhouse gas emissions and increase biodiversity in their agricultural practices.

E. Challenges and opportunities:

VULTUS does not provide an application front-end / user interface for the VULTUS API. This means that VULTUS relies on partners to integrate the VULTUS API into their partner platform to provide data to farmers and growers. Currently, we have a technical limit of no more than 1,000 hectares of field at any one time on our platform. Theoretically, it has the potential to reach 5,000 hectares. As more users join the VULTUS platform and provide us with more feedback from the field, we will be able to provide more accurate and reliable products in return.

F. Reference and demonstration:

Kandekar, V.U., Pande, C.B., Rajesh, J., Atre, A.A., Gorantiwar, S.D., Kadam, S.A., & Gavit, B. (2021). Surface water dynamics analysis based on sentinel imagery and Google Earth Engine Platform: a case study of Jayakwadi dam. Sustainable Water Resources Management, 7:44.

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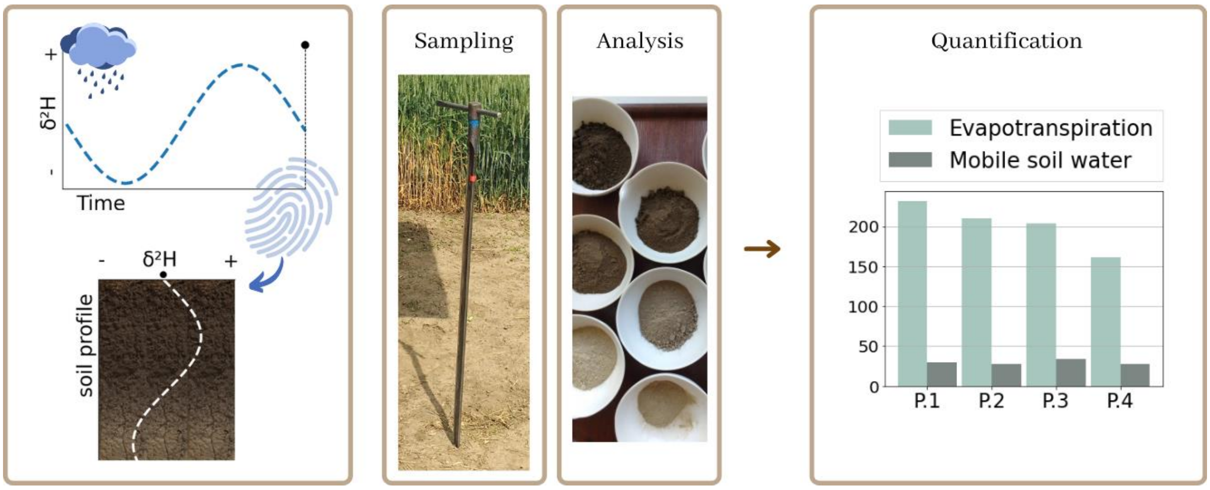
TRACER METHODS



Key information

Stable water isotopes (δ18O and δ2H) are used as a tool to assess water flow and retention in soils. Pore water isotope ratios can also be used to calibrate flow and transport parameters in physically based models to improve accuracy in studies of subsurface water movement or surface-vegetation-groundwater interactions.

Target audience: researchers

A. Brief Introduction:

Tracer methods can provide valuable information on the water transport in soils. The isotopic composition of oxygen and hydrogen isotope in precipitation water varies throughout the year, which depends on factors such as temperature and water vapor sources. These changes have a pronounced sinuosity with a minimum and maximum value in winter and summer in the climates covered by the project (i.e., Boreal, Continental and Pannonian). This isotopic signal ($\delta^{18}O$ and $\delta^{2}H$) can also be followed and observed in soil water in the vertical direction, as precipitation water pushes water from previous precipitation events downwards. Depending on the soil type, climatic characteristics and sampling timing, one or two peaks might still be observable in vertical soil profiles. It is, therefore, possible to track the movement of water and quantify the water flux in the soil. Soil water flux below the root zone basically equals the potential groundwater recharge, which is essential for renewing groundwater resources. By means of a water balance, other inputs and outputs, such as evapotranspiration, can be estimated.

One of the main advantages of this method is the ease of quantifying average water fluxes in fields that are difficult to access or have little data available by carrying out a single sampling campaign. It is also an advantage over other complex methods that require more resources, time and expertise, such as process-based models.

B. Design concept:

In order to use this simple method, a soil core is extracted and divided into 5 - 10 cm subsections. Soil samples are stored in sealable, inflatable and leak-tight bags, the isotopic composition of the water is analyzed, and the water content is determined. The isotopic signal of soil water can be compared with that of precipitation water to identify winter or summer peaks, considering the accumulated precipitation and isotopic composition. The volume of water per m^2 in the subsections [mm] has to be related to the elapsed time [yr] to obtain the water flux. Other hydrological processes can be estimated by performing a water balance, e.g. evapotranspiration.

Sampling recommendations indicate the best sampling time and depth intervals according to soil type and climate (check WATERAGRI simplified model).

C. Technical information:

This straightforward method requires soil profile samples, analysis of oxygen and hydrogen isotopes ($\delta^{18}O$ and $\delta^{2}H$) and determination of soil water content.

Detailed procedure:

i. Sampling campaign:
   a. Soil core sampling down to 60 - 150 cm or even deeper if possible, divide and store samples every 5-10 cm. Repeat the soil core sampling in the same plot to obtain a composite sample.

b. The soil samples are disturbed and placed into a sealable, inflatable and leak-tight bag (usually a plastic Ziploc® bag or laminated Al-bags)

ii. Analysis of isotopic composition (if using a laser-based isotope analyser):

a. The bags are filled with dry air for three days to reach isotopic equilibrium in the head-space.

b. Analysis of the isotopic composition of soil water ($\delta^{18}O$ and $\delta^{2}H$) using a laser-based isotope analyser (e.g. Picarro L2140-i).

iii. Analysis of gravimetric water content by drying the soil samples to determine the weight loss corresponding to the water content. To determine volumetric water content (θ_w) if soil bulk density is known or can be assumed. Based on the soil type, residual water content (θ_r) can also be estimated.

iv. Comparison of the temporal variation of the isotopic composition of soil water with precipitation and identification of a common period or peak.

v. Peak-shift method to quantify water flux (mm/yr): Sum of the water content in the identified soil interval ($z_{t+T} - z_t$), in mm, divided by the elapsed time T, in yr [Eq. 1].

$$q_{(z,T)} = \frac{1}{T}\sum_{i=0}^{m}(\theta_w - \theta_r)(z_{i+1} - z_i) \qquad \text{[Eq. 1]}$$

D. Costs and Benefits:

- Costs related with materials for sampling and analysis of measurement of oxygen and hydrogen isotopes ($\delta^{18}O$ and $\delta^{2}H$) and water content.
- Farming benefits: Provides information on the hydrological processes occurring in the field (e.g., infiltration, soil water retention, evapotranspiration). It can help to achieve a more sustainable management of water resources if appropriate solutions are adopted, reducing the extra costs of irrigation water or drainage infrastructure.
- Environmental and social consequences: In the medium to long term, better management of water resources in agriculture can contribute to the water security of the region's ecosystems and communities.

E. Challenges and opportunities:

Challenges:

- In sandy soils or soils with a high dispersivity it may be complicated if not impossible to differentiate a peak, and therefore the method could not be applied.
- Very heterogeneous soils can pose a challenge, due to a greater need for sampling to cover areas with different fluxes, or due to the presence of horizontal flows that divert water or preferential flow bypassing the soil profile, resulting in greater uncertainty.

Opportunities:

- Several periods with different rates can be identified in the soil, depending on soil properties, precipitation characteristics and sampling time.
- It can be used to compare the effect of different management practices in the water retention capacity of soils.
- Isotopic composition of precipitation water can be gained onsite, using the data from the nearest location available in WISER portal (GNIP-IAEA) or from prediction tools (https://isotope.bot.unibas.ch/PisoAI/).

TRL: Applicable solution

F. Reference and demonstration:

Boumaiza, L., Chesnaux, R., Walter, J., and Stumpp, C. (2020) Assessing groundwater recharge and transpiration in a Nordic humid region dominated by snowmelt using vadose zone depth profiles. Hydrogeology Journal 28, 2315-2329, https://doi.org/10.1007/s10040-020-02204-z

Canet-Marti, A., Morales-Santos, A., Nolz, R., Langergraber, G., and Stumpp, C., 2022. Quantification of water fluxes and soil water balance in agricultural fields under different tillage and irrigation systems using water stable isotopes. Soil & Tillage Research, *submitted*

Canet-Marti, A., Morales-Santos, A., Nolz, R., Langergraber, G., and Stumpp, C., 2021. Hydrological processes and water flux quantification in agricultural fields under different tillage and irrigation systems using water stable isotopes. EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-11039, https://doi.org/10.5194/egusphere-egu21-11039.

Leibundgut, C., Maloszewski, P., Külls, C., 2009. Tracers in Hydrology. JohnWiley & Sons Ltd, Chichester, UK.

Stumpp, C., Bruggemann, N., Wingate, L., 2018. Stable Isotope Approaches in Vadose Zone Research. Vadose Zone Journal 17.

Vadibeler, D., Stockinger, M.P., Wassenaar, L.I., Stumpp, C., 2022. Influence of equilibration time, soil texture, and saturation on the accuracy of porewater water isotope assays using the direct H2O(liquid)-H2O(vapor) equilibration method. Journal of Hydrology 607.

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WATER RETAINER

Icon

Key information

Water Retainer is an organic soil conditioner liquid that can be added to the soil surface. Water Retainer changes the physical properties of the soil, making it more resistant to drought. The product is biodegradable and ready to use in agricultural fields, horticulture and home by professional gardeners.

Target users: farmers, advisory services.

A. Brief Introduction:

Water Retainer is applied to the soil by surface spraying. It can be sprayed with most pre-emergent herbicides. Water Retainer is easy to apply using any type of sprayer.

In the WATERAGRI project, the product was tested in a soil physical laboratory and in a field trial. The measurements show that the product has an effect on soil water retention. The product is designed to reduce the effects of drought. A field-scale study has been carried out which indicates changes some in soil physical parameters. The effect on crop yield has not been scientifically documented.

B. Design concept:

The product can be applied at the time of sowing, either by spraying on the soil surface or dissolved in irrigation water. The Water Retainer can be mixed with water-soluble pesticides or pre-emergent herbicides that are applied by spraying, so no additional operational costs are required for application. The recommended minimum dosage is 10 litres per hectare, diluted 20-100 times depending on the spraying technique.

The effect of Water Retainer lasts for 3 months as it biodegrades during this period. The application can be repeated if necessary and possible. (See also 'Challenges and opportunities' below for this option).

C. Technical information:

The technical principle of the water retain as tested in WEATERAGRI show changes in soil water retention for different soils tested in laboratory at University of Salford, UK (see reference).

D. Costs and benefits:

The cost of purchasing the Water Retainer product (75-90 EUR/hectare, net price) and delivery.

Utilizing the product in fields without irrigation can result in extended endurance of crops during drought periods and better yield.

E. Challenges and opportunities:

The product is biodegradable and registered for use in organic farming. The product is hygroscopic, so in the case of treating fields where plants are growing, it has to be taken into account that the liquid shall be washed off after the treatment from the surface of the plants by 2-2.5 mm irrigation or rain, to avoid localized dehydration of the plant tissues. The product developer report also other agronomic benefits, but we have not tested these or found information that support these potential benefits.

F. Reference and demonstration:

https://waterandsoil.eu/index.php/elementor-3085/?lang=en
https://waterandsoil.eu/index.php/elementor-3206/?lang=en

https://www.youtube.com/watch?v=lzJZdWxKhZM
https://www.youtube.com/watch?v=lqnAOi-KWnU

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WATER RETENTION CHARACTERISTICS MODEL

Key information

The Water Retention Curve Model represents a new type of soil water retention curve model based on interfacial physics. It describes the relationship between soil water content and soil suction for unsaturated soil conditions. The presented model provides the subsurface hydrology modeller with a reliable and convenient tool and the end user with an accurate assessment of the water retention effect on the soil water retention capacity.

Stakeholders: scientists, modellers.

A. Brief Introduction:

A number of mathematical models have been proposed and adopted to describe and represent the water retention curve of soils. However, to date, most of these models are either purely empirical or too complicated and ineffective to be used to evaluate water retention agents and directly quantify their influence on soil water retention capacity. The water retention properties model adopted for WATERAGRI aims to address these challenges. The model is developed based on the concept of interfacial physics.

B. Technical information:

Soil water retention characteristic depends on the soil nature and pore structure. Using the water retention characteristic model above to assess the effect of water retainer agent usage added into either soil or water directly, the model has been modified to integrate a standalone function, which is to quantify the water retainer effect. The modified model is in the form below:

$$P_c = e^{\gamma C_{WR}}\left(\lambda\left[\frac{1}{\alpha}(\exp(\alpha S_w)-1)-\frac{1}{\beta}(\exp(\beta(1-S_w))-1)\right]-m(1-S_w)^n\right),$$

where γ is a constant and C_{WR} stands for the usage (concentration) of the water retainer.

The mathematical formula can be directly used to fit the measurement water retention curves of soils, which use or are applied with the water retainer agents.

Theory:

There are three different water phases co-exists in unsaturated soils, they are the bulk water in fully occupied pore space, the water vapor in the empty pore space and the water film on the empty pore walls. The model describes and assess the three phases in terms of their respective states using classic physical interfacial theory. It gives out an explicit mathematical expression for the state of the three phases, which establishes a state equation for the soil water retention characteristics at different water contents or pore water saturation, from fully dry to fully wet. The state equation is further modified to evaluate the effect of the use of water retainer agent on soil retention curve.

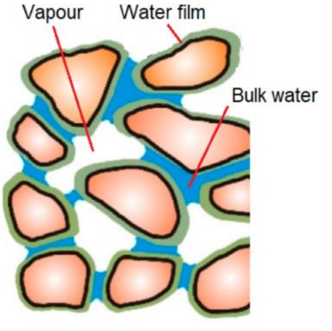


Fig. 1 Three respective water phases, i.e., bulk water, vapour and water film, which are coexists in the pores of unsaturated soils as illustrated in the figure below.

The three phases have their respective pressures at a certain state of water saturation degree, which can be described as below:

- For the bulk water phase

$$P_w = \frac{\lambda}{\alpha}(\exp(\alpha S_w) - 1),$$

Where P_w is the pore water pressure, S_w is the pore water saturation, α is a constant relating to the water interaction with soil particles at their interface, λ is a constant relating to the initial water film when bulk water starts to accumulate in pore space due to capillary condensation.

- For the vapour phase

$$P_v = \frac{\lambda}{\beta}(\exp(\beta(1 - S_w)) - 1),$$

where P_v is the pore vapour pressure, β is a constant relating to the vapour interaction with soil particles at their interface.

- For the water film

$$P_f = m(1 - S_w)^n,$$

P_f is the pressure of water film on empty pore walls, m and n are two constant parameters.

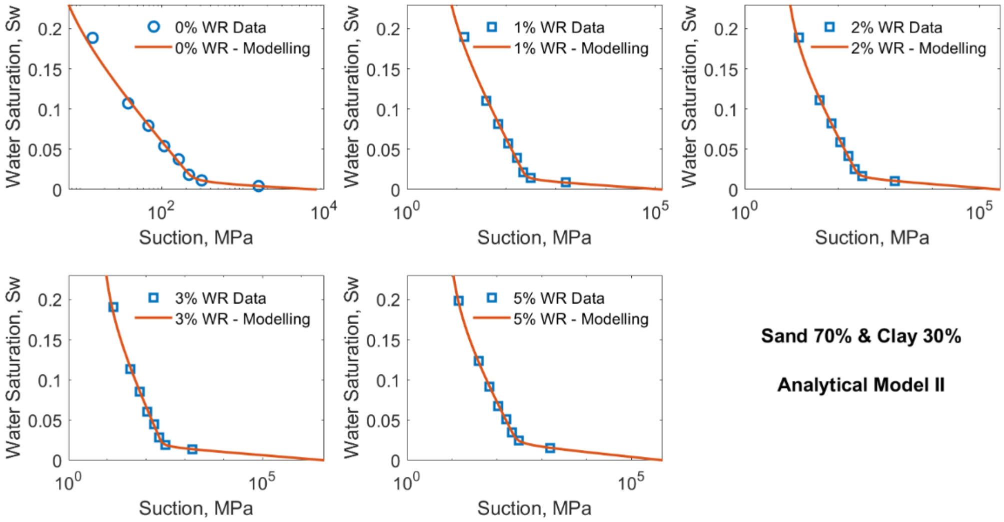
Soils under unsaturated states displays a suction on free water outside, known as the soil metric suction or capillary pressure P_c, which can be defined mechanically as below:

$$P_c = P_w - (P_v + P_f)$$

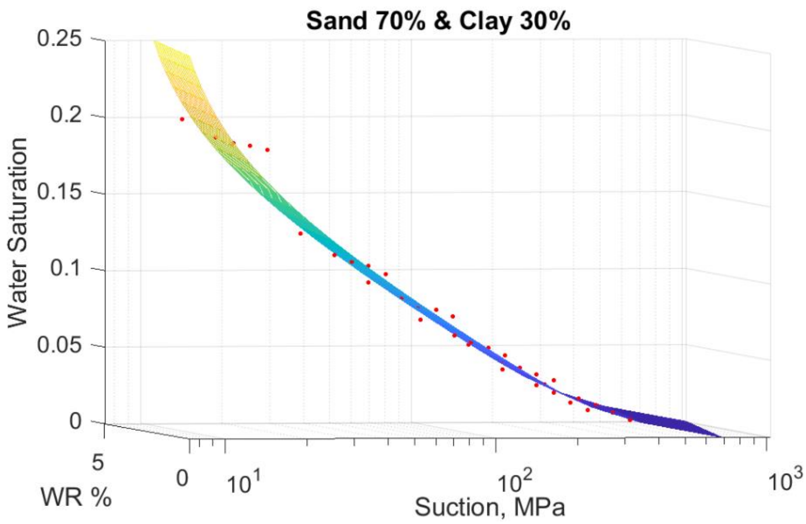
Substituting the phases' pressure above generates:

$$P_c = \lambda\left[\frac{1}{\alpha}(\exp(\alpha S_w) - 1) - \frac{1}{\beta}(\exp(\beta(1 - S_w)) - 1)\right] - m(1 - S_w)^n$$

This equation defines the soil water retention characteristic and represents the water retention curve.



The represented individual water retention curve for a soil of different water retainer (WR) percentage



The 3D presentation for the water retention characteristic at different suction and water retainer percentage

C. Costs and Benefits:

The model can be easily used by any researchers of fundamental knowledge of unsaturated soil physics and curve fitting.

D. Challenges and opportunities:

Wider test and implementation will help for further development for both the underlying theory for the unsaturated soil physics and hydrology modelling for real world challenges.

E. Reference and demonstration:

Further information about the concept of the water retention characteristic model and its development can refer to:

- Yu Wang, S.M. Grove, M.G. Anderson, 2008, A physical-chemical model for the static water retention characteristic of unsaturated porous media, Advances in Water Resources, 31: 723-735.
- Yu Wang, X.Y. Wang, M. Scholz, D.K. Ross, 2012, A physico-chemical model for the water vapour sorption isotherm of hardened cementitious materials, Construction and Building Materials, 35: 941–946.

The description for the water-vapour sorption isotherm and water retention characteristics (WVSI-WRC) model can be found on: https://www.youtube.com/watch?v=tyYyK9TYdXQ

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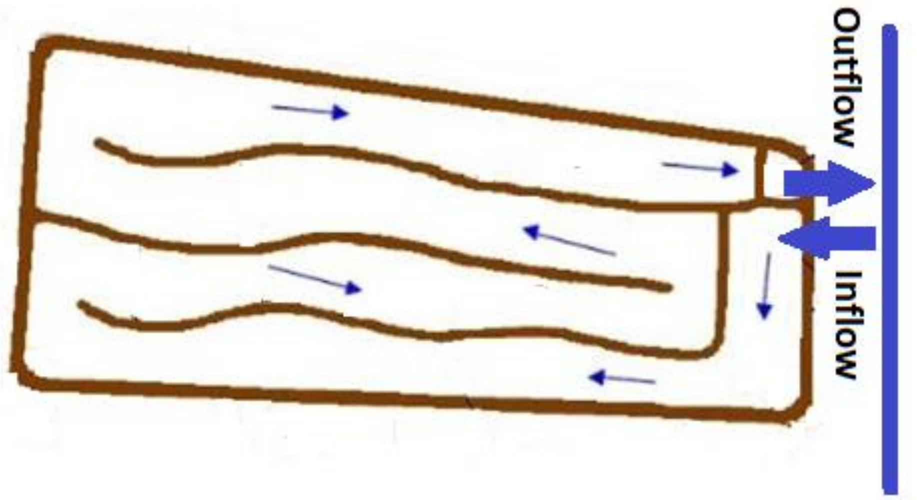
FARM CONSTRUCTED WETLANDS FOR NUTRIENT RETENTION



Key information

A Farm Constructed Wetland has the ability to retain and reduce nutrients from the inflow through various biogeochemical processes as the water passes through.

Target audience: farmers, general public.

A. Brief Introduction:

Farm Constructed Wetlands (FCW) is a type of Nature Based Solution (NBS) which can be used for retaining and reducing nutrient concentrations in water affected by agriculture. Phosphorous (P) is mainly retained by sedimentation of particles to which P tends to be adsorbed. Nitrogen (N) is mainly retained through biochemical processes (nitrification-denitrification) as bacteria convert mineral N to gas which returns to the atmosphere. Nutrients are also, to some extent, taken up by plants growing in the wetland, or accumulated in the soil.

The objective of FCW for nutrient retention is to reduce the eutrophication effects of agricultural drainage water or water affected by agriculture on downstream watercourses, lakes and sea. Another potential benefit of FCW is the possibility for managing the flow of water through farmland. Wetlands can thus be used to save water in order to use it for irrigation when needed, and to provide temporary storage during intensive rain events in order to reduce peaks and associated downstream problems. This aspect of FCW is covered in a separate factsheet.

The innovative aspect of FCW for nutrient retention is the fact that it is an NBS which provides a number of ecosystem services as beneficial side effects, and that it can deal with variable flows typical of agricultural drainage water, also managing variable fluxes of different contaminants.

The wetland should be designed to be optimal for local conditions and the specific case/farm. Important parameters, among others, are the size of the catchment area which generates the inflow to the FCW, the expected inflow nutrient concentrations and target outflow concentrations, as well as hydraulic retention time of the system.

B. Design concept:

There are a few important **design criteria** which follow logically from the nutrient retaining mechanisms. A deeper part, around 2 meters, near the inlet with low velocities might be useful in order to let particles settle to the bottom. Also, certain parts with depths of 0.1 – 1.0 meter can provide areas which are favorable for vegetation development, both submerged and emergent species. The plants have dual functions providing a substrate for denitrification bacteria as well as taking up nutrients when they grow. The former process (denitrification) is dominant, while the latter process (plant uptake) depends on removal of plant material in order to give substantial net effects. In case of high nitrate load, too low concentration of DOC (Dissolved Organic Carbon) can be a limiting factor, resulting in less than maximum nutrient (N) removal efficiency.

As a rule of thumb, given by the Swedish Board of Agriculture, the hydraulic retention time of the wetland should be minimum two days. The design should ascertain that the flow of water is well distributed over the whole area. Since some of the nutrients are captured in the vegetation itself, it might be needed to provide access for machinery which can harvest the plants after a few years. In order to speed up the process of making the wetland mature and efficient, it is necessary to introduce vegetation in a newly constructed wetland.

The actual design of a wetland for nutrient reduction should be made by experienced consultants.

C. Technical information:

The **requirement for construction** of a Farm Constructed Wetlands (FCW) for nutrient retention is primarily accessible land, preferably with soil of lower quality so that it does not affect negatively agricultural production. Also there should be land nearby where the excavated soil can be moved. Part of this soil can be used in order to construct embankments of the system. The equipment needed is excavation machinery. A more detailed investigation and design is necessary to take into account local topography and the need for special structures at inlet and outlet.

Operation and maintenance of the FCW would normally not require any manpower or skills more than what is available on a farm. With an interval of a couple of years it is necessary to harvest the wetland vegetation which captures and holds nutrients in the biomass.

Monitoring of the FCW involves checking the status of the vegetation, as well as observing the flow patterns in the wetland. Any sign of preferential flow (short-circuiting) should lead to increased monitoring, and preventive actions if necessary. The even flow of water over the whole wetland area is crucial for achieving the desired nutrient removal efficiency.

Performance of a FCW depends on a multitude of factors, reflecting external conditions such as loading climate, as well as internal conditions i.e. the wetland itself. Therefore, estimates of performance have to be made on a case-to-case basis. Some performance data for a specific wetland are found in the reference given at the end of this document.

D. Costs and Benefits:

The **cost of construction** of a Farm Constructed Wetlands (FCW) is dominated by the cost of excavation and transport of removed soil. On a farm it is normally possible to shift the soil within the property, and therefore the excavation costs dominate. Typical rough estimates for Sweden (2022) mention a cost of 100 00 – 200 000 SEK/ha. Subsidies (90%) can be received, see section E.

Cost of operation and maintenance are usually quite low. Depending on the design of inlet and outlet there will be no or only limited actions necessary to regulate the flow. Maintenance involves supervision of the dam structure and harvesting vegetation as necessary. In Sweden also these costs are subsidized at 5000 – 8000 SEK/ha.

The direct **farming benefits** of wetlands for nutrient retention are limited. The gains are to be found in positive side effects, such as increased possibilities for recreation, fishing, and hunting.

The **environmental consequences** of a constructed wetland are beneficial. It would normally contribute to increased biodiversity. Moreover, these systems become semi-natural after a certain period of time, meaning that flora and fauna start to regulate themselves and no interventions from that point of view are needed.

The **social consequences** of a constructed wetland are beneficial. It offers a variation in the landscape, a demonstration site that can be used for teaching or research activities, and a possibility for increased leisure activities. Depending on the accessibility of the land, these positive effects may affect the general public or the landowner only.

E. Challenges and opportunities:

The potential **technical limitations** for Farm Constructed Wetlands (FCW) are few. The main restriction concerns the soil type. If the soil has high hydraulic conductivity it will be necessary to line the wetland with an impermeable film. A small slope from the inlet towards the outlet point is necessary in order to enable water flow. These systems are usually long-term solutions and can be used for several decades.

The **legal requirements** vary from country to country. In Sweden the construction of an FCW is considered to be a "water activity" (Swedish*: vattenverksamhet*). This requires a permit from the Environmental Court for wetlands with area > 5 ha, while for wetlands with area < 5 ha only a report to the County Board is required.

Sometimes it is possible to get **subsidies** for the construction of wetland. Also in this case procedures vary between countries. In Sweden it is possible to apply for construction or restoration of wetlands. Normally the subsidy would cover 90 % of the costs. At present (November, 2022) there are three programmes, which support wetlands. Swedish national funding is available from LONA (https://www.naturvardsverket.se/lona) or LOVA. Support from EU is funneled via the Swedish "*Landsbygdsprogrammet*". It should be noted that, in order to get subsidies in Sweden, it is necessary that the wetland is designed to fulfil its environmental objectives.

Evidence-base for using wetlands for nutrient retention is solid (TRL 9). However, the actual efficiency in the amount of removed P and N is rather difficult to predict with high accuracy.

F. References and demonstration:

Lavrnić S., Braschi I., Anconelli S., Blasioli S., Solimando D., Mannini P. and Toscano A. (2018) Long-term monitoring of a surface flow constructed wetland treating agricultural drainage water in Northern Italy. Water 10(5), 644. https://doi.org/10.3390/w10050644

Lavrnić S., Alagna V., Iovino M., Anconelli S., Solimando D., Toscano A. (2020) Hydrological and hydraulic behaviour of a surface flow constructed wetland treating agricultural drainage water in northern Italy. Science of the Total Environment 702, 134795. https://doi.org/10.1016/j.scitotenv.2019.134795

Lavrnić S., Nan X., Blasioli S., Braschi I., Anconelli S., Toscano A. (2020) Performance of a full scale constructed wetland as ecological practice for agricultural drainage water treatment in Northern Italy. Ecological Engineering 154, 105927. https://doi.org/10.1016/j.ecoleng.2020.105927

The short video "Wetlands in the WATERAGRI Project – Lund University" gives an introduction to wetlands with a focus on nutrient reduction.
https://www.youtube.com/watch?v=TpemgfRuCaE

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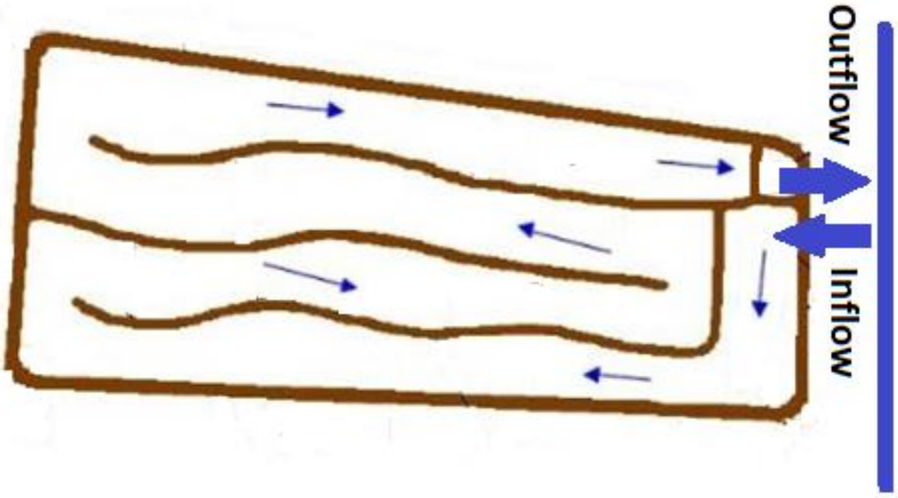
FARM CONSTRUCTED WETLANDS FOR WATER RETENTION



Key information

A Farm Constructed Wetland provides temporary water storage and can be used to provide water for irrigation. As it can retain water, it can also be used to lower flow peaks.

Target audience: farmers, general public.

A. Brief Introduction:

Farm Constructed Wetlands (FCW) is a type of Nature Based Solution (NBS) which can be used for retaining and reducing nutrient concentrations in water affected by agriculture. The aspect of nutrient retention is covered in a separate factsheet.

For water retention, runoff waters are directed to the wetland and this water can be used later for irrigation when needed. The FCW can provide temporary storage during intensive rain events, which may reduce flood peaks and associated downstream problems. Additionally, during the storage, water infiltrates into the ground and therefore it can increase water content of the surrounding areas and contribute to groundwater recharge.

The innovative aspect of FCW for water retention is, in comparison with tanks or pumping of groundwater, the fact that it is an NBS which also provides a number of ecosystem services as beneficial side effects, and that it can deal with variable flows typical of agricultural drainage water.

The wetland can be designed in different ways depending on local conditions and the relevant objectives for the specific case/farm. However, it should be noted that wetlands for water retention would normally be Free Water Surface (FWS) wetlands.

B. Design concept:

FCW should be designed based on a) the irrigation needs and b) an estimation of economically optimal size, i.e. volume considering:

a) the irrigation needs depend on the crops grown in the farm and the typical maximum water deficit plus safety margin based on annual climate variations and the accepted risk level.
b) the optimal size depends on the one hand on costs of construction and operation of the wetland and on the other hand on crop prices and the increased yield.

These above considerations would lead to a design value of the volume (m^3) of the wetland.

From a water retention point of view, the actual design geometry (layout) of the wetland is of no relevance. However, there are usually constraints in the availability of land along with supplementary ecological and social objectives which affect the design.

C. Technical information:

The main requirement for construction of FCW is primarily accessible land, preferably with soil of lower quality so that it does not affect negatively agricultural production. Also there should be land nearby where the excavated soil can be moved. Part of this soil can be used in order to construct embankments of the system. The equipment needed is excavation machinery. A more detailed investigation and design is necessary to take into account local topography and the need for special structures at inlet and outlet. Especially, if water is to be retained for peak flow reduction, a basic structure for flow control should be included. If the inflow to the wetland is expected to have a high load of coarse particles, it is beneficial to have a deeper settling area near the inlet, which will simplify sediment removal.

Operation and maintenance of the FCW would normally not require any manpower or skills more than what is available on a farm. The wetland will gradually fill with sediments which need removal depending on the amount of erosion. Also vegetation which grows in the wetland might need removal from time to time to allow sufficient water storage.

The **monitoring** of the FSW wetland could be kept at a minimum of checking the water level on a staff gauge. In order to have better control of actual water volumes stored, as well as inflow and outflow, recording gauges could be installed. Moreover, water level in the aquifer can be monitored through piezometers.

D. Costs and Benefits:

The **cost of construction** of a FWS wetland is dominated by the cost of excavation and transport of removed soil. On a farm it is normally possible to shift the soil within the property, and therefore the excavation costs dominate. Typical rough estimates for Sweden (2022) mention a cost of 100 00 – 200 000 SEK/ha. Subsidies (90%) can be received, see section E.

Cost of operation and maintenance are usually quite low. Depending on the design of inlet and outlet there will be no or only limited actions necessary to regulate the flow. Maintenance involves supervision of the dam structure and harvesting vegetation as necessary. In Sweden also these costs are subsidized at 5000 – 8000 SEK/ha.

The **farming benefits** of wetlands for water retention must be evaluated for each case, depending on climatic conditions as well as crop type and market situation. One important aspect of the decision process related to the investment in a wetland, is to consider the potential risk of drought based on climate change projections.

The **environmental consequences** of a constructed wetland are beneficial. It would normally contribute to increased biodiversity as well as retention of nutrients. In order to optimize these processes, the design has to include relevant aspects. See also the separate Factsheet on Farm Constructed Wetland for Nutrient Retention. Moreover, these systems become semi-natural after a certain period of time, meaning that flora and fauna start to regulate themselves and no interventions from that point of view are needed.

The **social consequences** of a constructed wetland are beneficial. It offers a variation in the landscape, a demonstration site that can be used for teaching or research activities, and a possibility for increased leisure activities. Depending on the accessibility of the land, these positive effects may affect the general public or the landowner only.

E. Challenges and opportunities:

The potential **technical limitations** for FWS wetland are few. The main restriction concerns the soil type. If the soil has high hydraulic conductivity it will be necessary to line the wetland with an impermeable film to ensure water for irrigation. A small slope from the inlet towards the outlet point is necessary in order to enable water flow. These systems are usually long-term solutions and can be used for several decades.

The **legal requirements** vary from country to country. In Sweden the construction of an FWS wetland is considered to be a "water activity" (Swedish*: vattenverksamhet*). This requires a permit from the Environmental Court for wetlands with area > 5 ha, while for wetlands with area < 5 ha only a report to the County Board is required.

Sometimes it is possible to get **subsidies** for the construction of wetland. Also in this case procedures vary between countries. In Sweden it is possible to apply for construction or restoration of wetlands. Normally the subsidy would cover 90 % of the costs. At present (November, 2022) there are three programmes, which support wetlands. Swedish national funding is available from LONA (https://www.naturvardsverket.se/lona) or LOVA. Support from EU is funneled via the Swedish "*Landsbygdsprogrammet*". It should be noted that, in order to get subsidies in Sweden, it is necessary that the wetland is designed to fulfil some environmental objectives besides the retention of water.

Evidence-base for using wetlands for water retention is solid (TRL 9), and uncertainties are only related to local circumstances and the outcome of a cost-benefit analysis in the particular case.

Reference and demonstration:

The short video "Wetlands in the WATERAGRI Project – Lund University" gives an introduction to wetlands with a focus on nutrient reduction.
https://www.youtube.com/watch?v=TpemgfRuCaE

For more information see for example the European NWRM Platform.
http://nwrm.eu/measure/basins-and-ponds

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