WATERAGRI

D4.2: Risk Assessment for Wetland Sediment Applications on Agricultural Land

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WP4 Nutrient Recovery from Streams

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Abstract:	This deliverable reports on Risk Assessment for Wetland Sediment Applications on Agricultural Land. The main content is a thorough and critical evaluation (literature review) of the wetland coupled agriculture and the related concerns such as nutrients, sediments and contamination risks. This will also be supported by the two case studies.

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List of Abbreviations and Acronyms

Al	Aluminium
As	Arsenic
BOD	Biological oxygen demand
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cr	Chromium
Cu	Brass
CW	Constructed Wetland
DET	Dewaterability Estimation Test
DO	Dissolved Oxygen
DOC	Dissolved organic carbon
EC	Electrical conductivity
FAO	Food and Agriculture Organization
FCW	Farm Constructed Wetland
Fe	Iron
FWS	Free Water Surface
HFCWs	Horizontal-Flows Constructed Wetlands
K	Potassium
Mg	Magnesium
$Mg(OH)_2$	Magnesium hydroxide
Mn	Manganese
Na	Sodium
NH_4-N	Ammonium nitrogen
Ni	Nickel
NO_3-N	Nitrate nitrogen
Pb	Lead
PO_4^{3-}-P	Phosphate phosphorus
SFCW	Surface Flow Constructed Wetland
SMHI	Swedish Meteorological and Hydrological Institute
TF-VFCW	Tidal Flow Vertical-Flow Constructed Wetland
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TOC	Total organic carbon
TP	Total Phosphorous
TSS	Total Suspended Solids
WR	Water Retainer
Zn	Zinc

1 Introduction

1.1 The purpose of this deliverable

Based on the overall objectives of WP4 and Tasks 1-5 within the WP, this deliverable (D4.2) summarises the outcomes of both field investigations and theoretical studies of wetlands coupled with different agricultural applications related to sediments, nutrients and pollutants and their impacts, both positive and negative.

In particular, this report presents the following:

(i) field study results from the two case study sites.

(ii) assigned activities for each partner.

(iii) knowledge base of the wetland-water-nutrients-sediment complex with analysis, evaluation and review.

This deliverable is structured as follows:

- Section 1: Purpose of the report and an overview of its objectives.
- Section 2: Realised activities from partners for D4.2.
- Section 3: Other WATERAGRI project-related work.

1.2 Objectives

With the widespread and large-scale application of constructed wetland technology, there is a strong need to further investigate the benefits and risks of direct coupling of wetland system to agricultural production activity regarding sediments, nutrients, pollutants and the water flux in both directions. A knowledge base of the wetland-water-nutrients-sediment complex with analysis, evaluation and critical review will provide answers to not only technical problems but also societal aspects (such as public acceptance level and participatory issues) as well as legal and policy level insights.

WATERAGRI D4.2 will achieve the following objectives:

A. Summary of field experiments and data analysis within WP4 and related WPs. This is to support the following point B as well.
B. A knowledge base of wetland-water-nutrients-sediment interactions in the form of a state-of-the-art report and a scientific literature review.
C. Other related measurements and activities.

2 Activities within the framework of D4.2

2.1. Brief introduction of Dewaterability Estimation Test device DET

Together with WP4's main activities, one of the tasks is the functional test of the Dewaterability Estimation Test device (DET) apparatus (within D3.3 and D4.2). The DET device consists of the DET software and the DET equipment (Figure 1). The DET equipment is currently available as a stainless-steel prototype for high accuracy and durability with main elements of slot funnel, light-emitting diode, camera, temperature and humidity sensors, light diffuser, laptop to laptop host the device software, cooling thermal paste and fan. This test aims to estimate the dewaterability of sludges, a sludge being a mixture of water and solids (speaking in simplified terms). In the WATERAGRI project, the DET apparatus measures how well a sludge can be dewatered. And this information can then be used to inform management decisions regarding the selection of dewatering technology. The testing and evaluation analyses have been described in report D3.3.

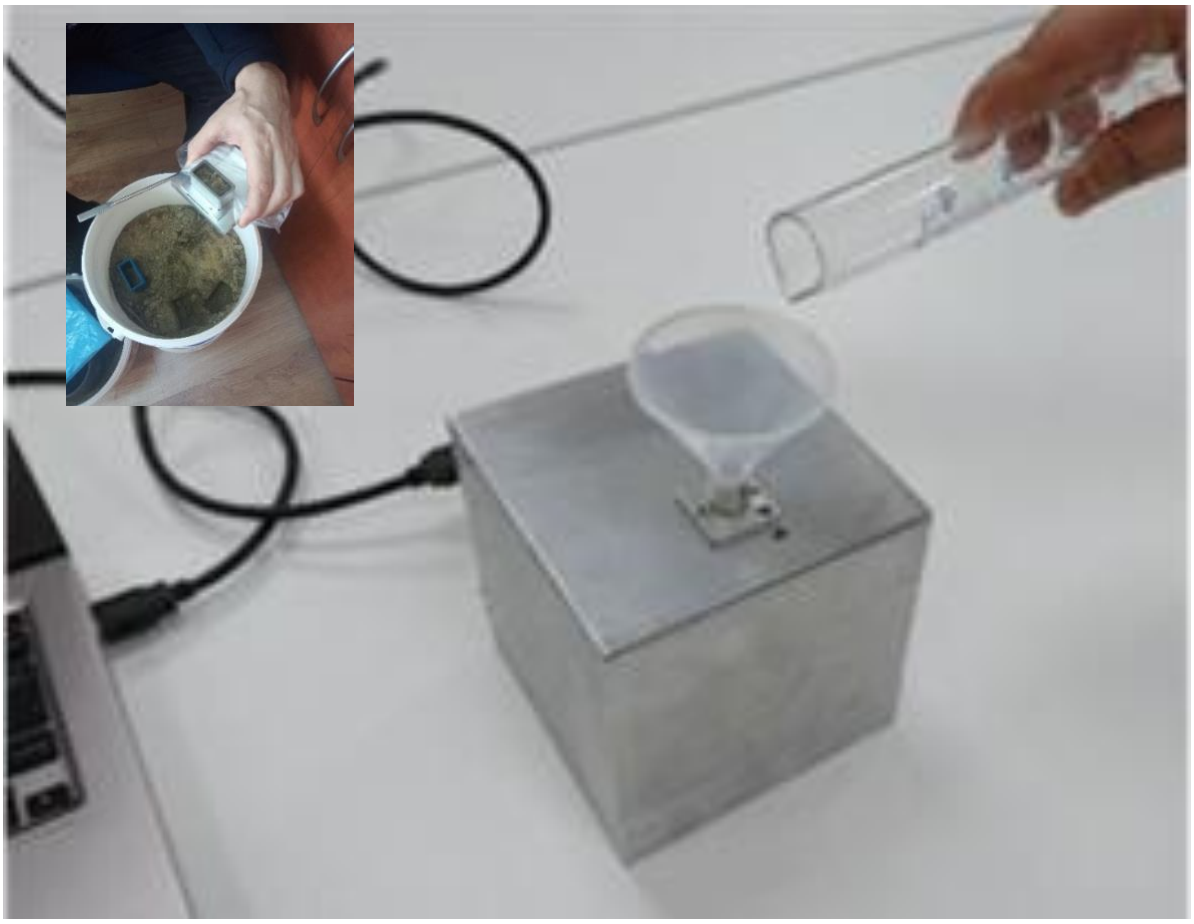

Figure 1. Dewaterability Estimation Test in the WATERAGRI Project.
https://www.youtube.com/watch?v=h2TxSo3v6D0&t=31s&ab_channel=WATERAGRIProject

2.2. Continued field data collection and analysis from, Farm constructed wetlands for nutrient recovery (C1)

As part of the Roadshow Concept, described in Task 8.2, Open Days are envisioned as events designed to demonstrate to a farmer community all the benefits of implementing individual and combined WATERAGRI solutions by showcasing them to the farmers first-hand at our test site locations. The first presentation of a test site location was given online during the 1st WATERAGRI Consultation Workshop on 5th October 2020. Gustaf Ramel (the owner of Gårdstånga Nygård company) was responsible for demonstrating the construction of dikes, wetlands, and reservoirs at Gårdstånga Nygård (Sweden).

As one of the farmer partners of WATERAGRI, Gårdstånga Nygård (GN) is a limited company operating agricultural activity on 200 ha of organic and 800 ha of conventional farmland. It is located in the municipality of Eslöv, northeast of Lund, Sweden, and is vulnerable to droughts. The C1 Farm constructed wetlands for nutrient recovery have been set up with a field plot for experiments. The experimental field includes key dikes, wetlands and reservoir interventions, with semi-automatic water level control in the reservoir. The detailed experimental setup and the location of plots for sampling are shown in Figure 2. The field comprises 64 parcels (each is 12 m × 12 m). In the experiment, three variables were tested (four replicates each): irrigation with water that passed through the wetland, water retainer product and phosphorus. There are 16x4 parcels and 4 controls. The harvest in 2021 was spring barley, and in 2022 it was winter wheat. The quantity and quality of harvests were analysed by an external organisation via GN.

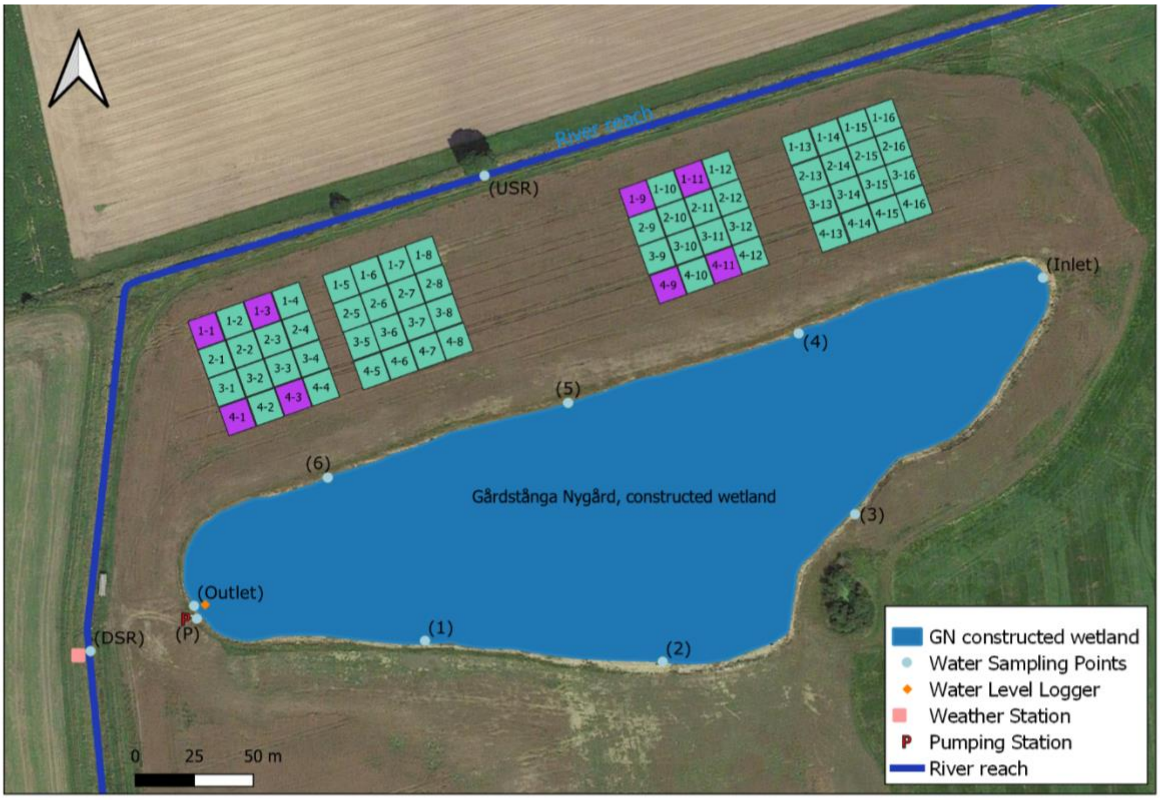

Figure 2. Gårdstånga Nygård scheme. Small experimental field with 64 parcels, next to the new Farm Constructed Wetland. North and west of the wetland is the Rödabäck river which feeds the wetland. (The markers: USR, Inlet, 1-6, Outlet, P, and DSR are locations for water sampling points).

Besides the soil sampling for nutrients and pollutants analysis, a monthly water quality sampling program has also been carried out (The water sampling points are marked in Figure 2). Three categories of element samples were collected and analysed during the period of 2021-06-11 and 2022-11-30, with 15 samplings in total. The three categories are Physical (pH, Redox, DO, TSS, Salinity, EC, Resistivity, TDS, Turbidity); Mineral (Al, As, Cu, Ni, Pb, Zn, Co, Cr, B, Cd, Ca, Fe, Mg, Mn, Na) and Organic matter and nutrients (TOC, DOC, TP, TN, NH4-N, NO3-N, K, BOD, COD).

The results of the first step analysis of these elements are discussed and presented in WATERAGRI D4.1 and D5.3, except for variations of TSS and TDS, which are discussed here in this paragraph.

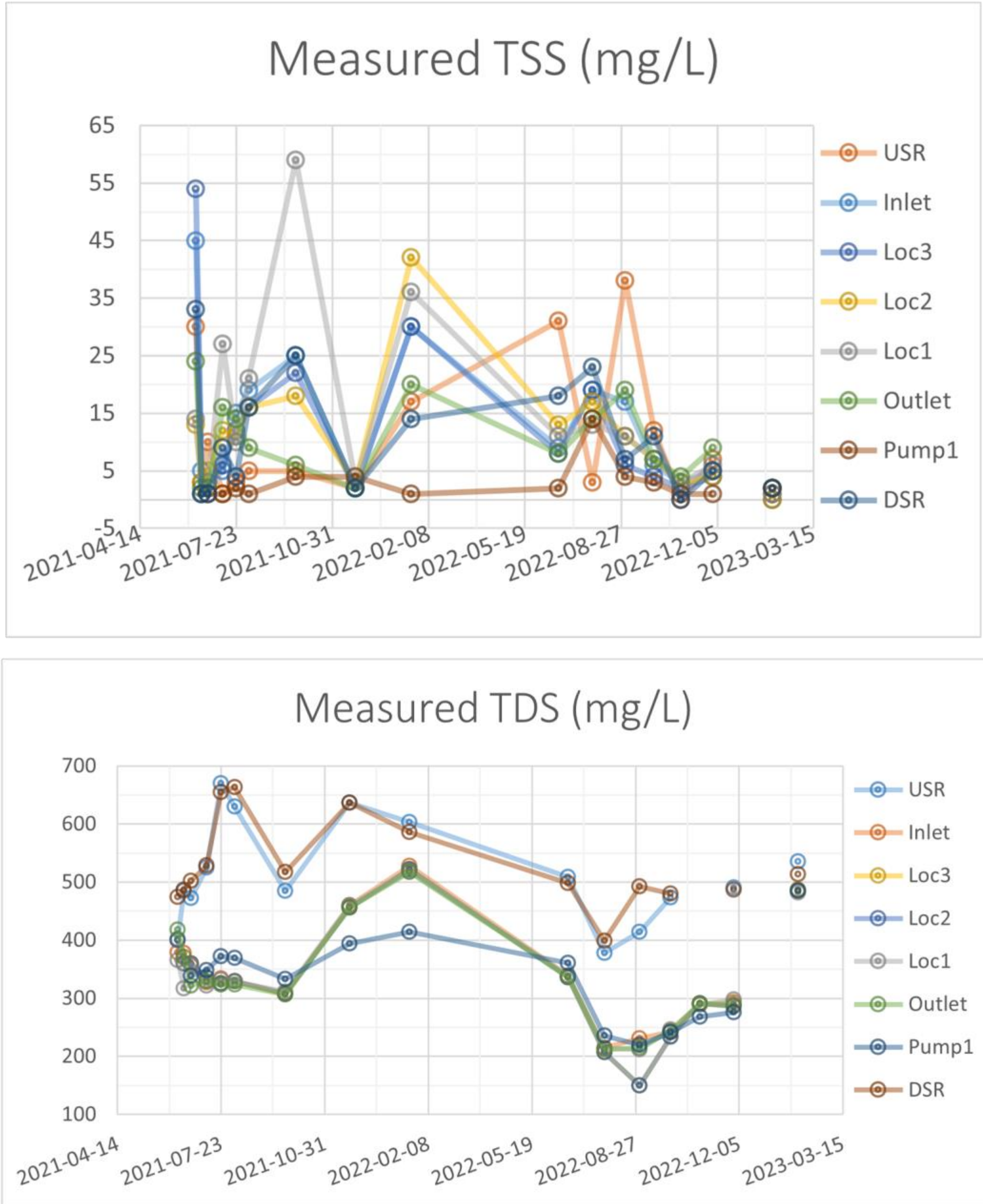

Figure 3. Variation of TSS and TDS (Total Dissolved Solids) at different locations (from upstream point to downstream point) during the sampling period.

The temporal variation of TSS and TDS (Total Dissolved Solids) at different locations during the sampling period shows the largest interval in terms of amplitude. The TSS have a clear decreasing trend during the sampling period, with a few (seasonal) fluctuations, whereas TDS's decreasing trend and the variations are not as large as TSS for the same period. On the other hand, the decreasing spatial trend from upstream to downstream is clearer for TDS, as shown in Figure 3. This means that TSS is more sensitive to seasonal flow fluctuations and that the newly constructed small-scale wetland at GN has already demonstrated a good function in reducing the TDS content along the flow direction downwards.

2.3. Literature review

2.3.1 Selected Swedish case reports

Since the C1 experiment is carried out in Sweden, a knowledge base of the wetland-water-nutrients-sediment complex in a summary report based on Swedish conditions is highly relevant. A literature search found that the national organisation *Svenskt Vatten* (*Svenskt Vatten* is owned collectively by all Swedish municipalities) has a comprehensive collection of information in the form of statistics and reports for the Swedish water sector. Two recently published reports, “Sludge spreading on arable land - the importance of humus content” (Svenskt-Vatten, 2021), and “Recycling of nutrients from sewage” (Svenskt-Vatten, 2022), see Figure 4, gave in-depth analyses of current practices and conditions in nutrients use and re-use.

Figure 4. Two recent Swedish publications on nutrient recovery and re-use.

In the English summary of Report Nr 2021-9 (Svenskt-Vatten, 2021), it is stated that the most important buffering factor for tackling extreme weather conditions is the soil’s organic matter, and an easy way to promote this is the supply of root sludge to the arable land. The original hypothesis was to test the function of this idea, analysing the long time series with harvest data from the two field trials with sludge dispersal on arable land in southwestern Skåne that have been going on since 1981, together with meteorological data on precipitation, where the evapotranspiration was calculated from data obtained through estimates for the region. However, the report did not make it clear whether the above hypothesis was confirmed or not.

This field experiment-based study also considered the effects of future climate change. The conclusions and results are based on the three pre-defined hypotheses:

- The positive moulding effect of sludge is especially important in dry growing seasons.

- Harvests are less consistent due to moulding, both within the field and between years.
- Significant carbon sequestration occurs, which means that the amount of greenhouse gases in the atmosphere is reduced.

After the implementation of the study, the report found the following three main conclusions:

1. The hydrological (water balance) models that have been used do not provide unequivocal results in understanding whether increased soil content through sludge application can favour plants during dry periods. However, there were tendencies for increased yields with higher water availability in the sludge-treated lines for spring-sown crops in Igelösa (A village some kilometres from the WATERAGRI case study site).

2. The application of digested sludge gives an increased variation in yield, both between years and within fields. This variation is eliminated by fertilisation with N-P-K.

3. Digested sludge provides significant carbon storage. Down to a depth of 40 cm, an average of 35 % of the sludge has been stored as carbon in the soil at Igelösa, while the corresponding figure is lower for Petersborg (outside of Lund), 18%, which can be explained by the difference in clay content (26 and 14% respectively).

In the second report Nr 2022-6 (Svenskt-Vatten, 2022), A detailed description was given of new technologies for nitrogen recovery from wastewater together with a comparison of the nitrogen recovery methods with other ways of producing nitrogen fertiliser in terms of climate impact and costs. The report also includes a brief review of potassium and sulphur recovery opportunities and a status update on phosphorus recovery methods.

In this literature review-based study, both Swedish and international publications were included. The report warned that there is a risk that even the minor nitrogen recycling of sludge in Sweden today will be stopped if sludge use on arable land is to be banned at the same time as the requirement for phosphorus recycling is introduced. The most interesting phosphorus recovery methods involve sludge incineration and recovery from ashes, which means that the nitrogen content is lost during the incineration. Some alternative methods for phosphorus and nitrogen were also discussed. For instance, several technologies for nitrogen recovery from rejected water are available at full scale. The technology that has been implemented to the greatest extent is ammonia stripping. The technology is particularly interesting if recovery at a wastewater treatment plant can be combined with large-scale production of nitrogen fertiliser from other sources, such as at the VEAS in Oslo, or if a solid nitrogen product can be produced, such as with the so-called Eco:N technology that is currently being trialled. Contact membranes are another technology available on a full scale in Germany and being evaluated on a pilot scale at RecoLab in Helsingborg. The technology provides similar consumption of chemicals and energy as ammonia stripping.

It is summarised that ammonia stripping and contact membranes are the techniques for nitrogen recovery from rejected water that is applied on full scale and have a similar and relatively high consumption of chemicals and energy. Other methods have been tested for wastewater streams like reject water, including thermal strip-ping of ammonia with further chemical reaction with gypsum or distillation to ammonia water. Evaporation and distillation are also developed techniques that can potentially recover nitrogen.

2.3.2 Literature review

There are lots of examples of constructed wetland (CW) applications worldwide in wastewater treatment and reuse (Dell'Osbel et al., 2020), pollutant removal (Ebrahimi et al., 2021), nature conservation (Everard et al., 2012) as well as multi-purpose ecological and environmental restoration (Shingare et al., 2019, Gupta et al., 2021, Nan et al., 2020). There are also emerging and tangible technologies and applications developed in parallel, such as nature-based solutions (Abrahams et al., 2017), stormwater control (e.g., low-impact development) as described by (Alihan et al., 2018) and blue-green infrastructure concept for a sustainable society (Bell et al., 2019, Gulbaz and Kazezyilmaz-Alhan, 2017, Hager et al., 2019, Zhang and Chui, 2019). However, there is a strong need to further assess the benefits and risks of direct coupling of wetland systems to agricultural production activity regarding sediments, nutrients, pollutants and the water flux in both directions. In this

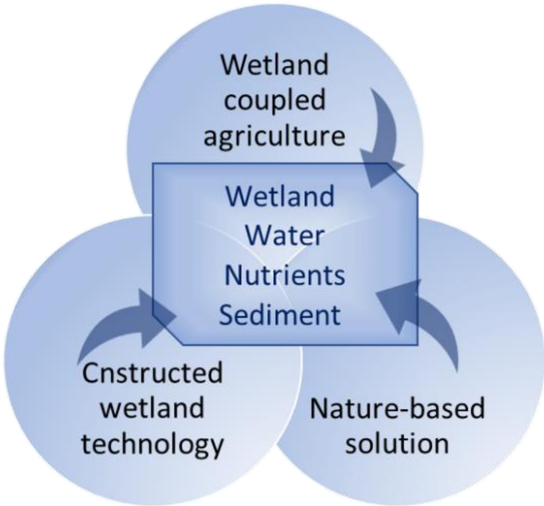

Figure 5. Inter-relation of wetlands coupled to agriculture activities.

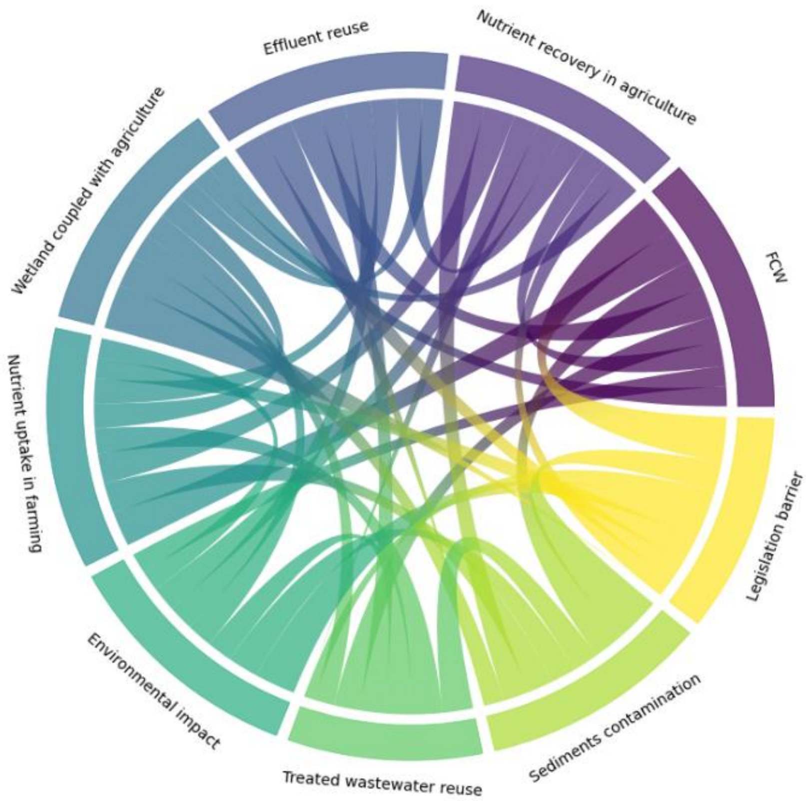

Figure 6. Chord-diagram illustrating inter-dependences of search keywords.

review study, the authors particularly focus on the inter-relationship of nature-based solutions, constructed wetlands and agriculture concerning the wetland-water-nutrients-sediment nexus. This simplified inter-relation is illustrated in Figure 5.

A scientific literature review article: for the international perspective, a scientific literature review has been carried out based on the most relevant international publications of the last 20 years. The title of the resulting review article will be “Risk Assessment for Wetland Sediment Applications on Agricultural Land: A Critical Review”.

Compared to Figure 5 showing the nexus relationship, the inter-relationships of the associated keywords are more complex, showing multiple connections and interactions. A graphical relation map as a chord diagram is shown in Figure 6 where the “legislation barrier”, for instance, is impacting all other aspects.

The literature search with relevant keywords relating to the wetland and agricultural activity has identified the following aspects as the most relevant and crucial for the current risk assessment of Farm Constructed Wetlands (FCW): The most relevant paper using the concept of farm-constructed wetlands (FCW) exclusively is one by (Carty et al., 2008). A more frequently used term is integrated constructed wetland (ICW), which usually comprises more than one wetland cell (Harrington and McInnes, 2009, Scholz et al., 2010, Everard et al., 2012, Mustafa et al., 2009, Ludwig and Hession, 2015). In some countries like Italy, drainage ditches are often regarded as farm-constructed wetlands (Dollinger et al., 2015). In Sweden, the FCW has been less relevant since the main focus has been on nutrient uptake and heavy metal removal (Davidsson, 2003),(Jordbruksverket, 2004).

1) Wetland nutrient recovery in agriculture.

In recent years, many research studies on wetland nutrient recovery have been carried out (Xia et al., 2016, Rosolen et al., 2015, Uwimana et al., 2018b, Magwaza et al., 2020, Yamanaka et al., 2017, Banaszuk et al., 2020, Zubair et al., 2020, Qin et al., 2021, Bonanno et al., 2013, Francisco et al., 2014, Craft et al., 2018, Schweizer et al., 2018, Rosemarin et al., 2020, Hopple and Craft, 2013, Adegbeye et al., 2020). However, specific applications in agriculture and farming land are much less studied both internationally and in Sweden (Magwaza et al., 2020, Banaszuk et al., 2020, Cui et al., 2020, Abbott et al., 2018, Costantini et al., 2020, Adegbeye et al., 2020). Wetland nutrient recovery in, in general terms, is very commonly practised in Sweden, but much less so for agricultural products (SFA, 2023), (Tonderski, 2002),(Marmolin, 2009).

2) Wetland treated effluent reuse in agriculture.

(Ofori et al., 2021) used a benefit-drawback analysis approach for treated wastewater use for crops and other agricultural products and found it beneficial provided the use is optimised for local conditions. Even wastewater-based vegetable production was reported with some success ((Inyinbor et al., 2019). A quantitative study on nitrogen and phosphorus removal rate was applied and reported by (Dal Ferro et al., 2018) and (Andreo-Martínez et al., 2017) with promising results which can be expanded to other similar areas. However, this kind of reuse has legal difficulties, especially in Sweden. The food security concern related to treated effluent reuse in agriculture (especially crops) is strictly regulated in Sweden. Constructed wetlands are covered by habitat protection according to the Ordinance 1998:1252 on area protection according to the Environmental Code (SWEPA, 2014). Within a habitat protection area, conducting any activity or taking any action that may harm the natural environment is prohibited. Therefore, anyone planning to conduct an activity or take action within a habitat protection area must first assess whether it may harm the natural values of the habitat. If there is a risk of damage to the natural environment, the County Administrative Board must seek a dispensation from the habitat protection regulations. If there are special reasons, a dispensation from the prohibition may be granted in individual cases.

3) Wetland coupled with agriculture.

From a historical perspective from the 18th century, (Güldner and Krausmann, 2017), used an index-based method for organic farming analysis and concluded that organic farming could introduce some instability in nutrients exchange. The trend of combining wetlands with agricultural production is increasing worldwide. A public policy design study in a region of France with wet grassland was reported by (Hardy et al., 2020), where a so-called Agri-Environmental Scheme (AES) was introduced to farmers as an incentive for increased biodiversity, although the acceptance level by the farmers must be improved in order to resolve a number of contradiction and/or dilemmas in environmental development. A Canadian research study coupling wetlands with agriculture was carried out by (Brunet and Westbrook, 2012), where the transport of nutrients, bacteria and salt were quantified under field conditions and compared to natural spills. These results could be a good reference base in comparison with European conditions, such as the historical review study carried out by (Güldner and Krausmann, 2017). For a larger area in India, (Singh and Sinha, 2019) performed a detailed land use/land cover (LULC) analysis connected to hydrology. An SWMM model-based simulation of horizontal subsurface flow in constructed wetlands was carried out by (Alihan et al., 2018), where hydraulic/hydrologic parameters were studied for a series of storm events. A vegetable crop production combined with wetland soil nutrient transport was given by (Solaiman et al., 2019). For a quick analysis method, (Rebelo et al., 2019) proposed a wetland hydro-geomorphic unit system to quantify the ecosystem service in a multi-wetlands case. We strongly suggest using a unified framework to quantify the ecosystem service benefits linked to general agriculture and farming activities.

4) Nutrient uptake in farming.

Many general studies on nutrient uptake in farming practices were found by literature search (Dai et al., 2021, Xia et al., 2016, Semida et al., 2019, Pooniya et al., 2021, Uwimana et al., 2018a, Marandure et al., 2020, Cardinal et al., 2014, Marella et al., 2021, Wielemaker et al., 2019, Vroom et al., 2020, Vundavalli et al., 2015, Temmink et al., 2017, Mazhar et al., 2021, Mishra et al., 2019, Campling et al., 2021, Adamtey et al., 2016, Konrad et al., 2019, Szymczak et al., 2020, Biernat et al., 2020, Knook et al., 2020, Dungait et al., 2012, Higgins et al., 2019, Martin et al., 2020, Branca et al., 2021, Jew et al., 2020, Kour et al., 2020, Güldner and Krausmann, 2017, Ávila et al., 2021, Costantini et al., 2020, Collins et al., 2021, Gordon et al., 2021, Alavaisha et al., 2019, Adegbeye et al., 2020). Most of these authors described both advantages and disadvantages (advantages are often related to economic gain and increased income, whereas the disadvantages are mostly related to environmental concerns and ecology) of farming, such as crop-based farming like rice or fish farming. (Biernat et al., 2020) discussed the organic farming system with a focus on TN in a European context related to the EU-Nitrate directive and found that organic farming systems often fail to meet the requirements of given environmental standards for water protection in the EU, calling for integrated approaches. In Sweden, such activities are often focused on restoration rather than uptake. The most common purposes in Sweden are to achieve 1) conversion of nitrate to nitrogen gas by denitrification process, 2) plant nutrient uptake in the wetland by plants or vegetation and 3) fixation of nutrients in sediments for a long-term purpose (Marmolin, 2009). This is considered an effective way to reduce nutrient transport to recipients (Sonesten, 2004), (Rosemarin et al., 2020).

5) Treated wastewater reuse in farming.

Treated wastewater reuse in farming might be an alternative in many parts of the world with severe water shortages and scarcity. A review article, (Inyinbor et al., 2019) discussed detailed benefits, risks and challenges in wastewater irrigated vegetable production in such areas. In a similar study, (Anastasis et al., 2017) examined various elements concerning vegetable growth, such as pharmaceutical compounds and other hazardous pollutants. (De Corato, 2020) presented a circular economic review about on-farm composting and compost-based tea application for soil and plant improvement through the so-called virtuous reuse of agricultural waste, which is considered less controversial since it is not treating edible crops directly. The author claims that "compost can be indeed virtuously used for recovering degraded soils, restoring soil fertility by C-sequestration, and reducing the use of chemical inputs and the negative environmental impacts" although no further evidence was provided. There are rarely similar reports from Sweden due to the concern of high risks associated with hazardous pollutants. Most of the literature found are examples from areas where water shortage is a main challenge. (Saliba et al., 2018, Bedbabis et al., 2015, Qadir et al., 2010, Natasha et al., 2021, Hanjra et al., 2012, Sou/Dakouré et al., 2013, Grundmann and Maaß, 2017, Kumar et al., 2014, Rosemarin et al., 2020).

6) Sediment contamination risks in wetlands.

Wetland sediments are generally considered an uncertain risk factor due to a lack of detailed analysis of their chemical and biological effects. In Sweden, The County authorities consider them sludge. It is important to investigate in more detail to provide a more reliable interpretation. (Bemanikharanagh et al., 2017) concluded that contaminants such as PAHs are generally high in a middle east large-scale wetland system. This result was confirmed by (Torghabeh et al., 2020), related to an earlier study by (Alhashemi et al., 2011). Metal and heavy-metal contamination were found in natural wetlands reported by (la Torre M. Catalina et al., 2018), suggesting a long-term accumulation process. Furthermore, severe problems with organochlorine pesticides (OCPs) in connection with aquaculture activity were reported by (Buah-Kwofie et al., 2018) and (Kumar et al., 2011), suggesting carefulness in using such pesticides. On the other hand, successful efforts to manage the contaminations by cyanobacteria were reported in a constructed wetland system (Zhong et al., 2011). Tracer and index-based sedimentological investigation can also be found in (Torghabeh et al., 2020), indicating a highly varying enrichment of many elements in wetlands. On the other hand, in the mangrove wetland system case (see Xue et al., 2009), the mangrove-derived organic matter in sediment cores from the mangrove wetland was quantified and compared with the conclusion that organic matter preserved in the sediments was not predominantly composed of the mangrove-derived organic matter. This was also confirmed by (Kinimo et al., 2018), (and Jeppe et al., 2017). The corresponding impact on groundwater was studied by (Mendes et al., 2020) and for an urban environment (Bell et al., 2019). For a lake-coupled wetland case, (Morales-García et al., 2020) investigated the metal contamination and other risks of heavy metal for pollution source control, which was considered crucial for large wetland areas in cities like Mexico City.

7) Environmental impact of wetland effluent reuse in agriculture.

Treated wastewater reuse has always been controversial due to the risk of contamination. (Ofori et al., 2021) compared benefits and drawbacks in crop-based agriculture and general farming practice where wastewater was used, their most important conclusion was the risks of emerging effects from different elements. In comparison with the World Health Organization (WHO)'s approach to microbial risk assessment in pathogen reduction, (Licciardello et al., 2018) proposed a tertiary treatment approach to be practised for crop production. A quantitative study of engineered nanomaterials (ENMs) was done by (Liu et al., 2018) to quantify the impact of wastewater effluent when used in agriculture. In a similar case of using the ash of energy crops as food crop fertiliser, (Bonanno et al., 2013) concluded that biomass ash from constructed wetlands can be considered as a potential fertiliser rather than hazardous waste, despite the findings that metal concentration in ash is much higher compared to what is found in normal plants.

8) Legislative barriers in wetland sediment recycling on agricultural fields.

There is a common interest in Sweden to convert wastewater to resources in a circular economy thinking (Finnson, 2021), (Börjesson, 2018), (Naturvårdsverket, 1999). In cases where landowners in Sweden receive compensation for establishing a wetland, an agreement is usually drawn between the landowner and the counterpart representing the state. Normally, this would be a municipality or the local water council. In such an agreement, the landowner is committed to abiding by certain terms regarding both construction and operation of the wetland. If the agreement is violated, the landowner might forfeit the financial subsidies. (Gómez-Baggethun et al., 2019) provided an in-depth analysis of land use policies on ecosystem services within the Danube Delta area and concluded that benefits from ecological restoration policies are apparent but not enough to meet future challenges without policy support.

3 Other WATERAGRI-related work

3.1 Reports from the Swedish case site

Relating to assessing the recovery and reuse of nutrients from eutrophic water bodies for growing, various experiments and field studies have also been carried out at GN to support developing and evaluating other WATERAGRI solutions, as described above. A detailed report is given in the WATERAGRI D4.1 "Description of Developed Wetland Technologies", Chapter 3.

A summary of the most important findings from Chapter 3 (D4.1) is summarised below:

Productive wetlands in a general context: There is an opportunity to combine the objective of reducing local and regional eutrophication with another objective: increasing farm production with no extra input from fertilisers. Such an increase in farm production could be achieved by using wetland water for irrigation. Growing plants to produce food or energy is thus a palatable option. However, it takes careful planning and consideration of several factors. Such aspects are:

- Suitable plants
- Demands on the operation of the wetland and possible consequences for other objectives
- Legal requirements for such activities
- Commercial aspects
- Legal aspects are essentially national in character, and the suitability of plants is basically a function of geographical/climatological data.

Considerations regarding Edible plants and Energy crops - Swedish context: *Legal aspects* **-** Constructed wetlands are covered by habitat protection according to the Ordinance 1998:1252 on area protection according to the Environmental Code (SWEPA, 2014). Within a habitat protection area, it is not allowed to conduct any activity or take any action that may harm the natural environment. Therefore, anyone planning to conduct an activity or take action within a habitat protection area must first assess whether it may harm the natural values of the habitat. If there is a risk of damage to the natural environment, the County Administrative Board must seek a dispensation from the habitat protection regulations. If there are special reasons, a dispensation from the prohibition may be granted in individual cases. *Commercial aspects* - The possibilities for selling leafy greens grown in surface water from agricultural lands, such as water mint, are limited. It is difficult to control the purity of the water. The risk of flooding and contamination of the plants is high, while the requirements of the Swedish Food Agency for irrigation water for leafy greens are high (SFA, 2023). *Commercial aspects for energy crops* - Compared to edible crops, the legal framework surrounding the production and sales of energy crops is fairly simple.

On the other hand, the profitability is not as stable as the grower might wish for. This is mainly due to fluctuating prices on the market for the fuels produced. This, in turn, depends on market prices for other energy commodities. The market in Sweden for Salix fuel is highly localised, with effects on both fuel price and transport costs.

The above analysis concludes that a) Edible crops are not a viable option for developing a productive wetland at Gårdstånga Nygård; b) Growing willow for energy is an attractive alternative for making the wetland system productive.

3.2 Reports from Austria and Italian case sites

UNIBO and CER analysed the recovery of nutrients from agricultural drainage water. A pilot plant based on wetland mesocosms was set up to test different substrates and different plant species to enhance nutrient removal from agricultural drainage water and allow for their later use as fertiliser/soil amendment.

Based on the results of task 4.4, activated biochar will also give added value to the constructed wetland (studied by ALCN, UNIBO and CER), which provides ways to improve the moisture retention capacity of soils. The residual biomass can then be harvested, shredded and supplied as feedstock to other local biomass conversion processes like biogas plants. Alternatively, they can also be used for mulching or composting material on site, thus, fully closing nutrient loops. Details of this work have been summarised in two factsheets “Factsheet: A Filter System for Subsurface Drainage Water Treatment (C2)” and “A Bio-Inspired Multi-Layer Filter System” (see WATERAGRI D6.2).

4 Conclusions

For the Swedish case site at Gårdstånga Nygård (GN):

- Most indicators based on analysis results show no significant water quality problems with low concentration and small variation intervals.
- The pH and turbidity show a clear variation pattern. pH has a max-min-mean value of 9.78 – 6.7 –7.79, showing a slight tendency of basicity.

- For nutrients and other indicators, the variation range of each parameter for the water samples is smaller than that for minerals. All the values are within the safety intervals for these indicators (EU, 1998; WHO, 2017).
- Wetland sediment applications on agricultural land are a complex issue, with increased challenges when additional aspects such as nutrient recovery must be incorporated. Furthermore, legislative barriers are not clearly addressed in many cases, especially in Sweden.
- The identified 8 keyword phrases provide a holistic view when interacting with the FCW system. We conclude that these 8 keyword phrases are equally important and must be treated carefully when implementing the FCW system for nutrient recycling and recovery.

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