SOLUTION FACTSHEETS

seacure

Co-funded by the European Union

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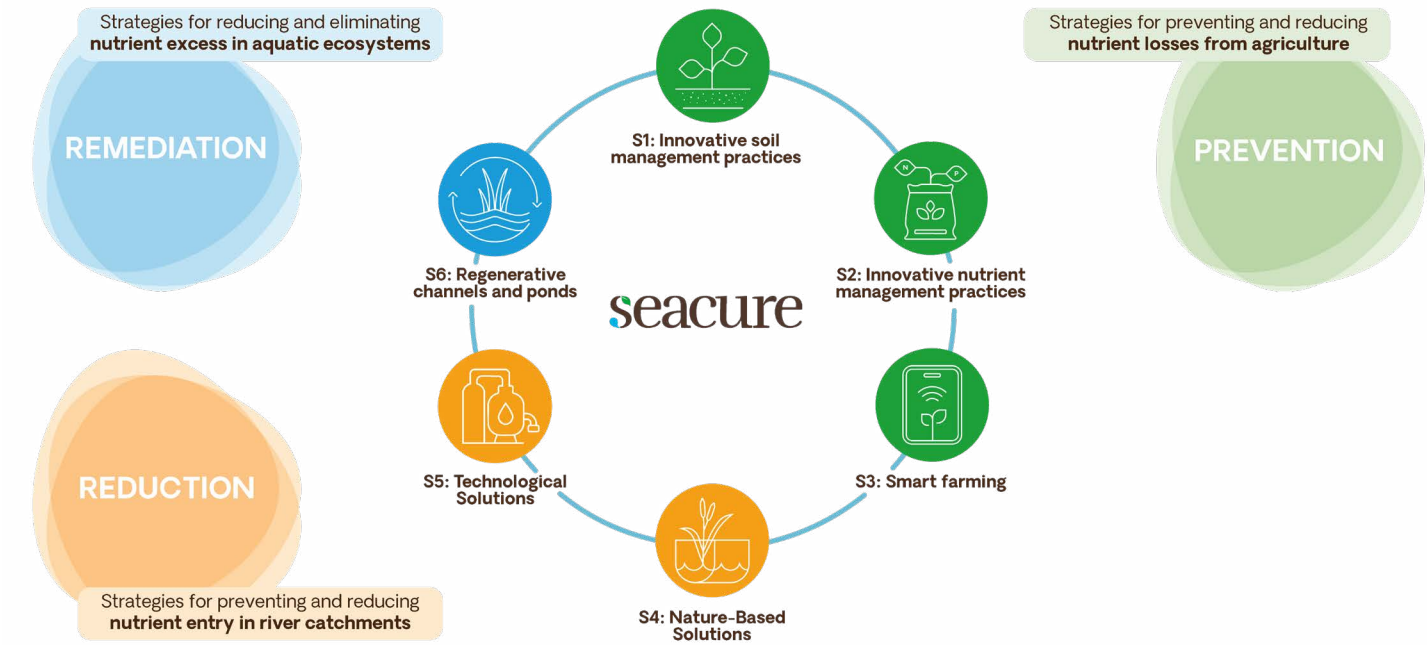
SEACURE SOLUTIONS

The SEACURE project adopts a holistic approach in addressing the issue of nutrient pollution with solutions targeting the different stages of the nutrient flow cycle across the landscape-river-sea system. In that sense, SEACURE solutions can be classified into three different overarching strategies: (1) Prevention, (2) Reduction, and (3) Remediation.



PREVENTION

Prevention solutions are strategies for preventing and reducing nutrient losses from agriculture. For this solution type, the primary goal is to establish more C-, N- and P- efficient agro-ecosystem by introducing effective combinations of existing technologies and high potential innovations in nutrient recycling technologies and soil & crop management practices, thus improving the sustainability of farm systems, reducing negative impacts on soil, water, air and climate. To achieve this, SEACURE is implementing three types of prevention solutions:

S1. Innovative management practices

S2. Innovative soil management practices

S3. Smart farming

REDUCTION

Reduction solutions are strategies for preventing and reducing nutrient entry in river catchments. These measures focus on reducing nutrient flow into rivers by curbing nutrient losses in rural areas due to intensive agricultural practices, or in urban areas through improved wastewater treatment. To achieve it, SEACURE is implementing two categories of reduction solutions:

S4. Nature-Based solutions

S5. Technological solutions

REMEDIATION

Remediation solutions are strategies for reducing and eliminating nutrient excess in ecosystems to prevent eutrophication. The main aim of this strategy is to demonstrate measures for reducing water eutrophication and remediating nutrient excess before reaching the Mediterranean Sea. In this stage, we apply remediation measures to rivers, canals and ponds:

S6. Regenerative channels and ponds

PREVENTION

Solutions for preventing and reducing nutrient losses from agriculture

S1. INNOVATIVE SOIL MANAGEMENT PRACTICES

SEACURE demonstrates solutions to improve nutrient retention in the soil through perennial crops and regenerative agricultural practices to decrease nitrate leaching and enhance Soil Organic Matter (SOM) in the soil. The implementation of these practices in areas characterized by intense agriculture is expected to have beneficial effects on soil fertility while preventing nutrient losses.
This category includes:

Living Soil Horticulture (LSH)

Perennial Crops (PC)

Cover Catch Crops (CCC)

Living Soil Horticulture (LSH)

The Living Soil Horticulture (LSH) technique enhances soil organic matter (SOM) and biological porosity by **incorporating large amounts of lignified plant materials into horticultural soils.** This promotes a rapid increase in SOM and stimulates soil organisms, such as earthworms, that create stable, biologically driven porosity within 1-3 years, replacing the temporary porosity created by tillage and mechanical soil operations.

Current studies indicate that LSH activates physical and microbial mechanisms that enhance carbon retention and stabilisation in soil aggregates. Within SEACURE, this practice is being demonstrated in Central Catalonia (DEMO 6) to evaluate long-term effectiveness in improving soil structure, fertility, and reducing nutrient leaching in horticultural systems.

Benefits

- Improves **soil structure, fertility**, and **biodiversity**
- Reduces **fertiliser needs** and **tillage requirements**
- Enhances **water retention, root growth,** and **nutrient cycling**
- Reduces **nitrate (NO3−)** and **phosphorus (PO43−) leaching** and runoff

Replicaiton potential

Transferable to **horticultural systems** across regions seeking to **improve soil health and reduce fertiliser dependency**. Particularly suitable for degraded or **low-organic-matter** soils prone to nutrient leaching.

Perennial Crops (PC)

In Central Catalonia (DEMO 6), SEACURE is validating the cultivation of intermediate wheatgrass (Thinopyrum intermedium), **a deep-rooted perennial crop (PC)** with long life cycles that promotes continuous soil carbon accumulation. Its extensive root system enhances **access to deep soil water and nutrients**, improving resilience under variable climatic conditions. This species represents an innovative **alternative for Mediterranean systems traditionally dominated by annual crops.**

Building on promising results from the NUTRIBUDGET project, SEACURE will assess the crop's optimal establishment and its long-term effects on reducing nutrient losses and improving soil condition.

Benefits

- Improves **water retention** and builds **labile carbon stocks**
- Reduces **nitrate (NO_2^-)** leaching and protects **groundwater quality**
- Enhances **soil ecosystem services** and **resilience to climate variability**
- Offers **added economic potential** as a dual-use crop (grain and forage)

Replicaiton potential

Suitable for **farming systems** aiming to reduce nutrient losses and improve soil water balance, particularly in regions **affected by nitrate pollution, groundwater contamination, or soil degradation** linked to intensive agriculture.

Cover Catch Crops (CCC)

In SEACURE, the introduction of **different cover catch crop (CCC) species** is being implemented in rice paddies of local farmers within the Axios River Delta (DEMO 3) to manage soil nutrient dynamics and assess their effectiveness under diverse environmental and agronomic conditions. The demonstration in a real operational environment managed by Kostantinos Farm (KKFARM), offers a unique opportunity to study its responses to diverse environmental conditions, interactions with other crops, the influence of species selection on nutrient retention, and its **ability to overcome nutrient-pollution challenges over time**.

By determining its long-term performance, this approach provides critical basis for evaluating reductions in NO3-leaching, increases in soil organic matter (SOM), and improvements in water-retention capacity, demonstrating the effectiveness of s**ustainable practices in preventing and reducing nutrients losses from agriculture**. Overall, these demonstrations are expected to generate evidence that will boost the adoption of similar systems in other regions with similar needs and characteristics.

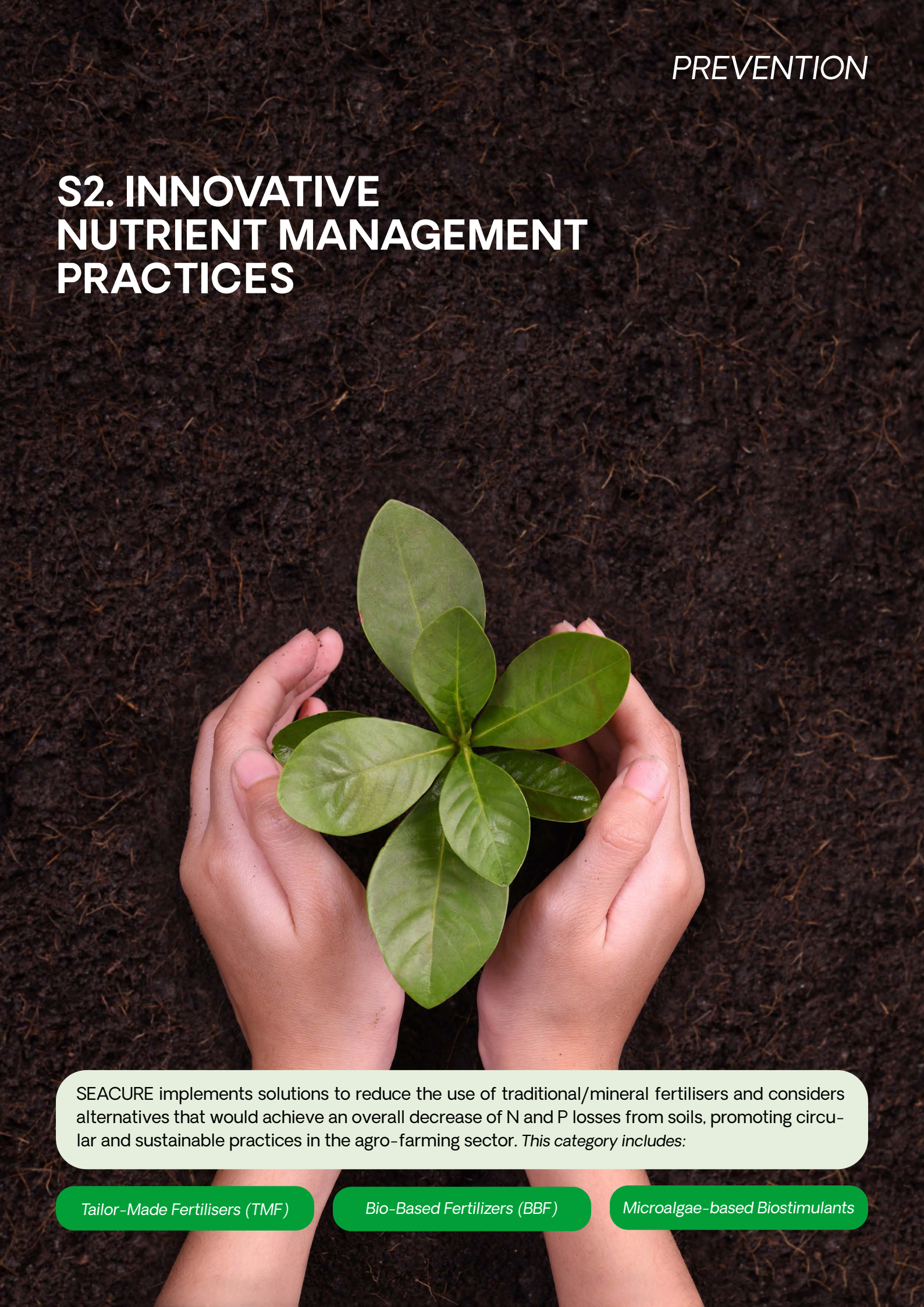
Benefits

- Increased **Soil Organic Matter (SOM)** by around 1.6%
- Improved **water infiltration** and **reduced surface runoff**
- Reduction of **nutrient leaching** by 40–50%
- Improved **soil structure** and **water retention capacity**
- Contribution to the reduction of nitrate (NO_2^-) losses

Replicaiton potential

Suitable for farming systems aiming to reduce nutrient losses and enhance soil resilience, particularly in Mediterranean and semi-arid regions **affected by soil degradation and nutrient leaching linked to intensive agriculture.**

S2. INNOVATIVE NUTRIENT MANAGEMENT PRACTICES



SEACURE implements solutions to reduce the use of traditional/mineral fertilisers and considers alternatives that would achieve an overall decrease of N and P losses from soils, promoting circular and sustainable practices in the agro-farming sector. *This category includes:*

Tailor-Made Fertilisers (TMF)

Bio-Based Fertilizers (BBF)

Microalgae-based Biostimulants

Tailor-Made Fertilisers (TMF)

In Central Catalunya (DEMO 6), SEACURE implements **tailor-made fertilisers (TMFs) derived from livestock manure** to optimise nutrient management while maintaining crop yields. By recovering nutrients from manure, TMFs help close nutrient cycles between crop and livestock systems, preventing nutrient losses in the environment. TMFs are customised fertilisers designed to match crop nutrient requirements based on soil type, fertility status, and local conditions. Combining **recovered bio-based and mineral components**, they achieve balanced nutrient ratios, enhance fertiliser precision, and reduce nutrient losses.

Building on experience from the H2020 FERTIMANURE and NOVAFERT projects, SEACURE demonstrates that partially **substituting conventional manure fertilisation with TMFs reduces nutrient losses while maintaining yields**. The demonstration also assesses long-term effects on groundwater and soil fertility, and the economic viability for farms of different scales.

Benefits

- Improves **nutrient-use efficiency and soil fertility**
- Enables **cost-efficient fertilisation** (potential savings of 24-37%) **without yield reduction**
- Reduces **nitrate leaching and surface nutrient runoff**
- **Reconnects nutrient flows** between crop and livestock systems

Replicaiton potential

Particularly relevant for **livestock-intensive regions facing nutrient surpluses and fertiliser-dependent areas aiming to reduce mineral inputs**. This solution offers a replicable model for nutrient recovery and recycling, contributing to circular, bio-based fertilizer value chains across diverse agricultural systems.

Bio-Based Fertilisers (BBFs)

SEACURE is validating the production of **bio-based fertilisers (BBFs) derived from biosolid wastes in wastewater treatment plants** (WWTPs), transforming them into comprehensive resource recovery facilities. Building on knowledge from the H2020 SEA2LAND and PROMISCES projects, thermochemical processes are applied under oxygen-limited conditions to recover nutrients from sewage sludge and organic wastes, concentrating nutrients in biochar while removing organic contaminants and toxins.

In the Esino River Basin (DEMO 5), SEACURE mixes nutrient-rich biomasses from a combined EBPR/microalgae reactor (see S5) and constructed wetlands installed in a WWTP (see S4) with co-digested sludge, agro-wastes, and wood residues to produce nutrient-rich biochar through **non-oxidative thermochemical conversion** (i.e., pyrolysis or gasification). The resulting BBFs are tested for their phosphorus and nitrogen content and for their potential to improve nutrient recovery efficiency through wet chemical extraction.

Benefits

- Improved **resource recovery**
- Decreased **dependency on mineral fertilisers** through **local nutrient recycling**
- Reduction of **nutrient discharges from wastewater**
- **Valorisation** of nutrient-rich **biosolid wastes** into **high-quality fertilisers**

Replicaiton potential

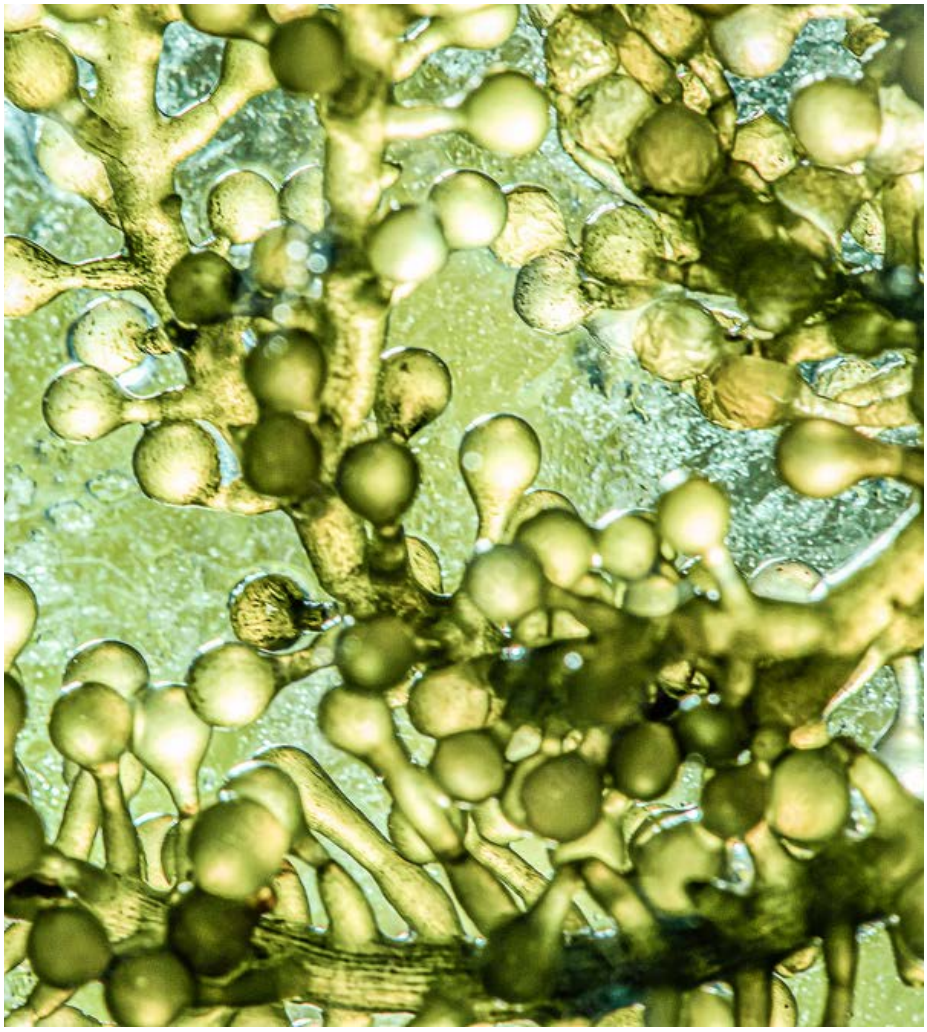
Suitable for **medium-to-large-scale WWTPs with sludge treatment systems** interested in adopting thermochemical or resource recovery technologies. Particularly relevant for regions seeking to **reduce nutrient discharges** to receiving waters and **promote circular bioeconomy** initiatives in their territory.

Advanced Bio-stimulants (ABs)

SEACURE is implementing **advanced bio-stimulants (ABs) derived from microalgae** to enhance crop productivity and soil health while reducing nutrient losses from agriculture. Previous experiments under the BlueBioChain project demonstrated the potential of microalgae-derived amino acids to improve soil organic matter and water-retention capacity in crops such as maize and wheat.

Microalgae can thrive in a wide range of habitats, including non-arable land, requiring only light and a carbon source to sustain growth throughout the year. Microalgal biostimulants (MBS) have emerged as promising tools for **enhancing the sustainability of crop production**. Biostimulants, which are derived from organic materials, can stimulate crop growth and development even when applied in small amounts, **functioning effectively under both optimal and stressful conditions**.

In Axios River Delta (DEMO 3), SEACURE will validate and demonstrate the application of microalgae-based bio-stimulants in real farming conditions to assess formulation performance on crop yield, soil quality, and nutrient-use efficiency.



Benefits

- Enhanced **crop productivity** and **resilience**
- Improved **soil organic matter** and **water-retention capacity**
- **Reduced reliance** on mineral fertilisers and synthetic inputs
- Lower **nutrient losses** and improved **soil health**

Replicaiton potential

Applicable in agricultural regions aiming to **enhance soil fertility** and **crop performance** through sustainable fertilisation strategies. Particularly suitable for areas with **access to microalgae cultivation facilities or wastewater treatment plants** capable of producing algal biomass for biostimulant development.

S3 SMART FARMING

S3. Smart Farming

SEACURE is advancing the development and implementation of smart farming tools designed to improve agricultural management and prevent nutrient losses, while maintaining or increasing crop yields *This category includes:*

Precision Agriculture (PA)

Online Fertigation (OF)

Precision Agriculture (PA)

In the Axios River Delta (DEMO 3), the project is implementing a combination of two **precision agriculture modules (PreFer & ProFit)**, previously developed and continuously tested in the field during the last eight years (2018-2025), to **optimise fertilisation plans** by accounting for both soil conditions and crop needs, maintaining optimal yields while reducing overall fertiliser inputs.

PreFer integrates geographic information systems (GIS) with data from soil sampling, meteorological records, and yield monitors. Using **advanced machine learning algorithms**, it generates **precise, site-specific fertilisation prescriptions**. The **ProFit** module assesses the economic **profitability of precision farming practices** on a 5-meter scale. Both modules function within ifarma, a pre-existing farm management information system (FMIS), previously tested on a variety of farms in the Axios River plain and elsewhere.

SEACURE combines the PreFer and ProFit modules within the ifarma system to deliver a holistic **precision agriculture approach that links agronomic and economic performance**. This integrated tool enables farmers and practitioners to evaluate the economic impact of precision agriculture techniques and make informed decisions that optimise fertiliser use, prevent nutrient losses, and maximise profitability.

Benefits

- **Optimised fertilisation** based on **real-time** soil and crop **data**
- Up to 20 % **reduction in fertiliser use**, according to farmers' evidence
- Up to 15 % **increase in crop yield**, according to yield maps derived from harvesters in the last 5 years (2020-2024)
- On average 8.4% **higher yields than conventional farming**, according to yield maps derived from harvesters in the last 5 years (2020-2024)
- **Reduced nutrient losses** from agricultural soils and runoff
- Potential improvement in **farm profitability**

Replicaiton potential

Applicable in **farming systems aiming to optimise fertiliser use** and improve nutrient management through **data-driven decision tools**. It is particularly relevant for regions with **access to digital infrastructure** and **soil and crop monitoring data**, where smart technologies can enhance nutrient efficiency, reduce losses, and improve farm profitability.

Online Fertigation (OF)

In the Axios River Delta (DEMO 3), SEACURE is implementing an **online fertigation (OF) system** in a real operational setting within a collective irrigation network to **optimise the reuse of drainage water for irrigation** and improve resource-use efficiency. The **IT Module** design automatically regulates the **blending of drainage and freshwater** based on real-time data on soil moisture, crop water needs, and water quality.

Developed from methodologies of the H2020 ATLAS project and drawing on international experience such as WaterTap (USA), the demonstration is testing the online-controlled fertigation system's effectiveness in improving irrigation management, reducing nutrient losses from agriculture, and preventing freshwater salinisation.

Benefits

- **Optimised irrigation** and **fertilisation** (conditional on drainage-water nutrient content)
- **Decreased fertiliser inputs** and **nutrient loads**
- Reduction in **freshwater use** and **groundwater abstraction**
- Prevention of **freshwater salinisation**

Replicaiton potential

The online fertigation system is relevant for **irrigated regions facing water scarcity, salinisation, or nutrient losses** from intensive irrigation, particularly for Mediterranean and semi-arid climates with variable rainfall and high irrigation demand. The solution is applicable to **irrigation and drainage networks** interested in adopting **data-driven monitoring and control tools** to optimise water and fertiliser use.

REDUCTION

Solutions for preventing and reducing nutrients' entry into river catchments

S4. NATURE-BASED SOLUTIONS

SEACURE is implementing nature-based solutions (NBS) to reduce nutrient inputs into rivers from both point and diffuse sources, targeting emissions from urban wastewater and stormwater runoff. Through optimisation, testing, and validation under real-life demonstrative conditions, SEACURE enhances the performance of these systems for nutrient removal, water quality improvement, and ecosystem restoration. *This category includes:*

Combined system of Constructed Wetlands and High-Rate Algal Pond (CW&HRAP)

Bioswale (BS)

Constructed Wetlands & Biochar (CW&BC)

Combined system of Constructed Wetlands & High-Rate Algal Pond (CW&HRAP)

In Thessaly Plain, Greece (DEMO 4), the project is implementing a **combined nature-based system** integrating an **unsaturated constructed wetland (UNSAT-CW),** a **high-rate algal pond (HRAP),** and a **saturated constructed wetland (SAT-CW**). This hybrid system aims to produce class A reclaimed water suitable for reuse and fertigation.

In the first stage **pre-treated wastewater** from a septic tank is directed into the **UNSAT-CW**, where aerobic microorganisms oxidise organic matter to CO_2 and nitrify ammonia to nitrate. **Recycled glass** will be **tested as an innovative substrate** alongside conventional media to enhance treatment performance.

In the second stage, **the effluent from the UNSAT-CW is further treated in an HRAP**, where photosynthetic microalgae assimilate inorganic nitrogen and convert it into protein-rich biomass. **Recirculation** of the oxygen-rich **HRAP effluent back to the UNSAT-CW** will be examined to demonstrate if it can pose a **cost-effective** photosynthesis-driven aeration method aiming to **reduce energy demand.**

In the final stage, the **SAT-CW** supports anoxic microbial denitrification, **converting remaining nitrate into nitrogen gas. Biochar**, combined with conventional filter media, is used to **enhance the removal of residual micropollutants**. After treatment, the final effluent will undergo UV disinfection and will be stored for **reuse in irrigation**.

Through long-term, full-scale evaluation, SEACURE will validate the system's performance and functionality via **continuous monitoring and analysis**, addressing gaps in existing research, which is largely limited to laboratory or short-duration studies. The demonstration will generate the evidence needed to refine design and operational parameters for integrated CW–HRAP systems and to support their broader replication and **integration with other wastewater treatment technologies**.

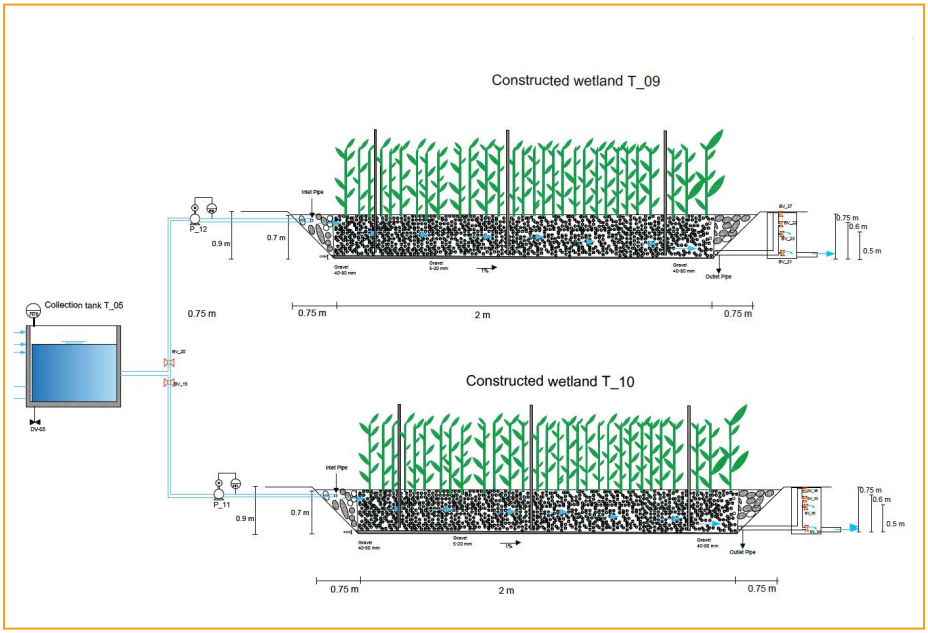
Benefits

- High **efficiency in nitrogen removal** from wastewater
- **Lower energy demand** enabled by photosynthetic aeration
- **Cost-effective** and **low-maintenance** treatment compared to conventional systems
- **Reduced land area** requirements relative to horizontal flow constructed wetlands

Replicaiton potential

This combined system is suitable for **rural and peri-urban areas with municipal or decentralised wastewater treatment needs**, especially where low-energy, nature-based and nutrient-focused solutions are required. It is particularly relevant in regions with elevated agricultural nutrient pressures or **designated Nitrate Vulnerable Zones.**

The nitrogen-rich algal biomass produced also offers opportunities for regions pursuing circular reuse. The system provides **opportunities for biomass valorisation** (e.g., protein recovery), to be used for high-value **commercial** & **industrial applications**.

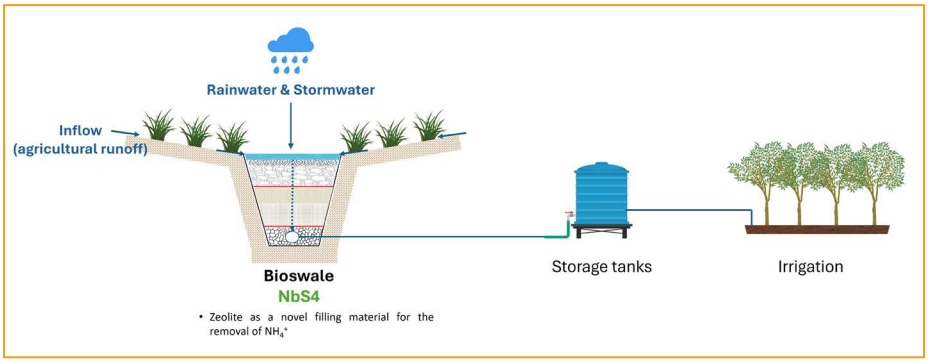


Bioswale (BS)

A **bioswale system (BS)** is being implemented in the agricultural area of the Thessaly Plain, Greece (DEMO 4) to manage stormwater runoff, reduce nutrient loads, and mitigate flood risk. Bioswales are gently sloped, vegetated channels that collect, filter, and convey stormwater, allowing water to **infiltrate into the soil** or be **directed to storage tanks for future use**, such as irrigation.

At DEMO 4, the bioswale is constructed within an existing roadside ditch, reaching a depth of approximately 1.5 metres after minor in situ modifications to optimise hydraulic performance. The design integrates **two stratified filter zones**, one with sand, and one with a sand + zeolite mixture, each underlain by gravel layers. This configuration allows **direct comparison of zeolite's capacity** for ammonium, nutrient, and metal removal under real field conditions.

The system applies passive hydrological principles, relying on natural slope, infiltration, and vegetative uptake to retain and treat stormwater **without external energy or mechanical pumping**, while vegetation enhances pollutant filtration, stabilises the soil, and supports biological uptake. The demonstration will provide field-scale evidence to support wider adoption of bioswales as effective, resilient, and **nature-based systems for managing stormwater** and **reducing diffuse agricultural pollution,** strengthening water resilience in landscapes with intensive farming activity.



Benefits

- **Reduction of nutrient loads,** particularly ammonium
- **Flood risk reduction** via enhanced retention, conveyance, and infiltration
- Improved **stormwater quality** suitable **for reuse** (e.g., irrigation).
- Removal of **suspended solids, nutrients**, and potentially **heavy metals**
- **Low-maintenance, cost-effective nature-based solution** requiring no mechanical equipment or energy input.
- Downstream **flow attenuation, reducing peak discharge**, and contributing to flood mitigation.
- Enhanced **landscape integration** through vegetated cover and soil–water interaction.

Replicaiton potential

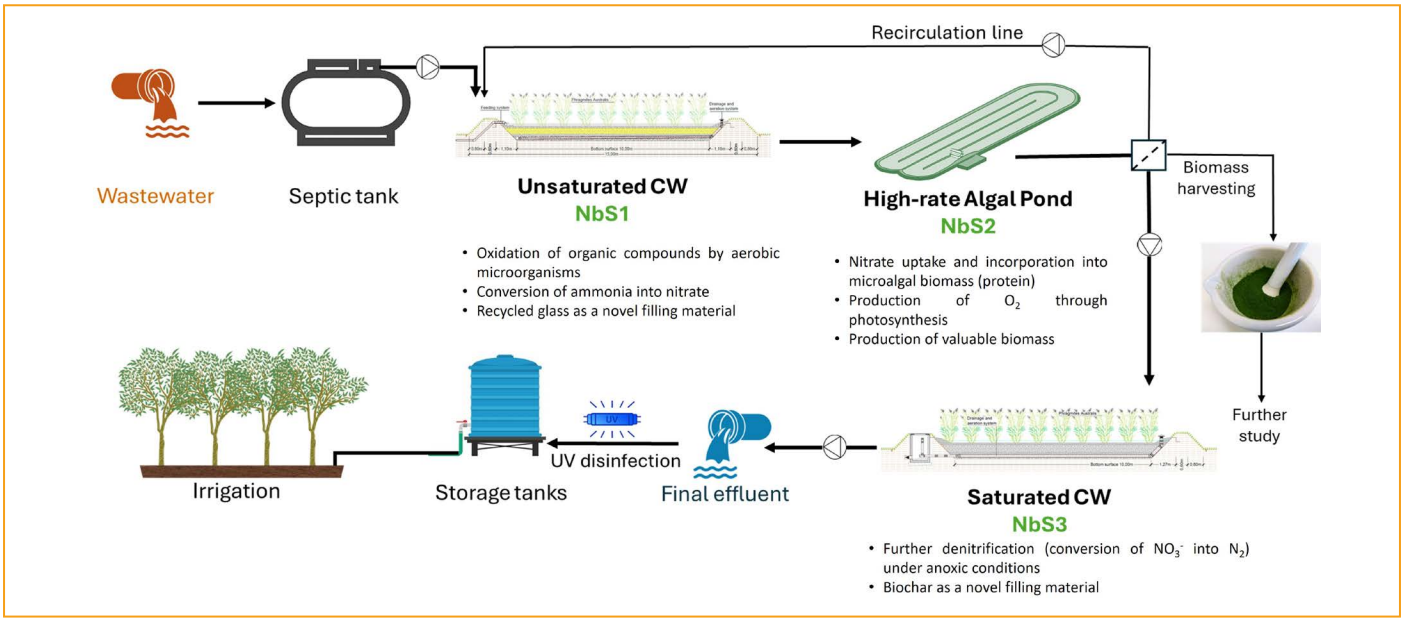
This bioswale system is suited to **rural or peri-urban areas** with **intensive farming activity facing diffuse nutrient pollution from agriculture**, seasonal heavy rainfall, **storm water management challenges** and heightened flood risk, or insufficient conventional drainage infrastructure. Particularly, the zeolite's high cation-exchange capacity makes this system especially valuable in **areas with elevated ammonium or metal concentrations**.

The solution is well-suited to regions requiring low-energy, low-impact, and easily maintainable stormwater treatment solutions. Its modular structure allows **replication in roadside ditches, field-edge channels, drainage lines, and mixed rural catchments**. The dual-media design (sand vs. sand + zeolite) allows comparison of cost, pollutant removal performance, and suitability for different runoff compositions, supporting informed media selection for future installations.

Constructed Wetlands & Biochar (CW&BC)

SEACURE is implementing and conducting long-term tests on the performance of a **horizontal flow constructed wetland (CW) amended with biochar (BC) substrates** to enhance nutrient and micropollutant removal from wastewater. The CW treats the **secondary effluent of a WWTP** in Esino River Basin, Italy (DEMO 5), including the effluent from the EBPR/microalgae pilot (see S5). The **biochar is produced locally** through non-oxidative thermochemical conversion of an optimal mix of biomass collected at the demonstration site, including microalgae, harvested plants from CWs, agrowastes, phosphorus-rich sewage sludge, and wood residues, also using appropriate modification/activation procedures.

The project will assess the effectiveness and long-term performance of biochar substrates to define optimal operating parameters and carbonisation conditions for **improved adsorption of nutrients and micropollutants.** The demonstration will provide essential data on the scalability and durability of biochar as a filler material in constructed wetlands, addressing current knowledge gaps and supporting the design of future full-scale CWs at the WWTP.



Benefits

- Improved **removal efficiency of nutrients** and **micropollutants**
- Enhanced **adsorption capacity**, improving long-term treatment performance
- Greater **operational stability** & **reduced clogging risks** during continuous use
- **Valorisation** of locally **sources biomass and waste** following a circular approach

Replicaiton potential

Applicable to **wastewater treatment plants** aiming to **enhance nutrient and micropollutant removal through nature-based solutions**. Particularly relevant for regions seeking to adopt more sustainable wastewater treatment methodologies through circular approaches that valorise locally available biomass resources and improve effluent quality.

S5. TECHNOLOGICAL SOLUTIONS

SEACURE develops and demonstrates innovative technologies to reduce nutrient inputs into rivers from both urban and agricultural wastewaters. While advanced processes are widely applied in conventional wastewater treatment, fewer solutions target nutrient losses from agricultural runoff. Through optimisation and validation under real-life conditions, SEACURE enhances the performance of these systems to improve nutrient removal, water quality, and sustainable water management. This category includes:

Denitrification biofiltration technology (BIOBOX)

Hybrid System of Constructed Wetlands and Raceway Solar Reactor

Automated Enhanced Biological P removal and Microalgae Reactor (EBPR&MR)

Denitrification patented technology (BIOBOX)

The patented **BIOBOX biological denitrification technology** is being optimised in Mar Menor Lagoon (DEMO 1) to **remove nitrates from agricultural runoff** before they reach coastal waters. This compact and modular treatment unit mimics natural denitrification processes by using specific microorganisms and bacteria to convert nitrates (NO_3^-) into atmospheric nitrogen gas, requiring only an organic carbon source.

The technology has already demonstrated high removal performance in drinking water and osmosis rejection streams. Under SEACURE, it is being adapted and optimised to operate under real environmental conditions, treating runoff intercepted from dry riverbeds during heavy rain and flash flood events. The demonstration aims to validate previous pilot-scale results and assess the system's operational efficiency and capacity for **treating large volumes of agricultural wastewater**, generating data to guide its future application in areas severely affected by diffuse nutrient pollution.

Benefits

- *High nitrate removal efficiency*
- *Compact and modular design adaptable to variable flow and load conditions*
- *Prevention of nutrient discharge into sensitive ecosystems*

Replicaiton potential

Applicable in **regions affected by diffuse nitrate pollution from agricultural runoff or drainage waters**. Particularly suitable for Mediterranean and semi-arid areas where episodic **heavy rainfall and flash floods** increase nutrient transfer to surface and coastal waters. The **modular design allows adaptation to different scales and site conditions**, supporting replication in agricultural catchments and vulnerable water bodies across regions seeking **effective nitrate reduction** from diffuse pollution sources.

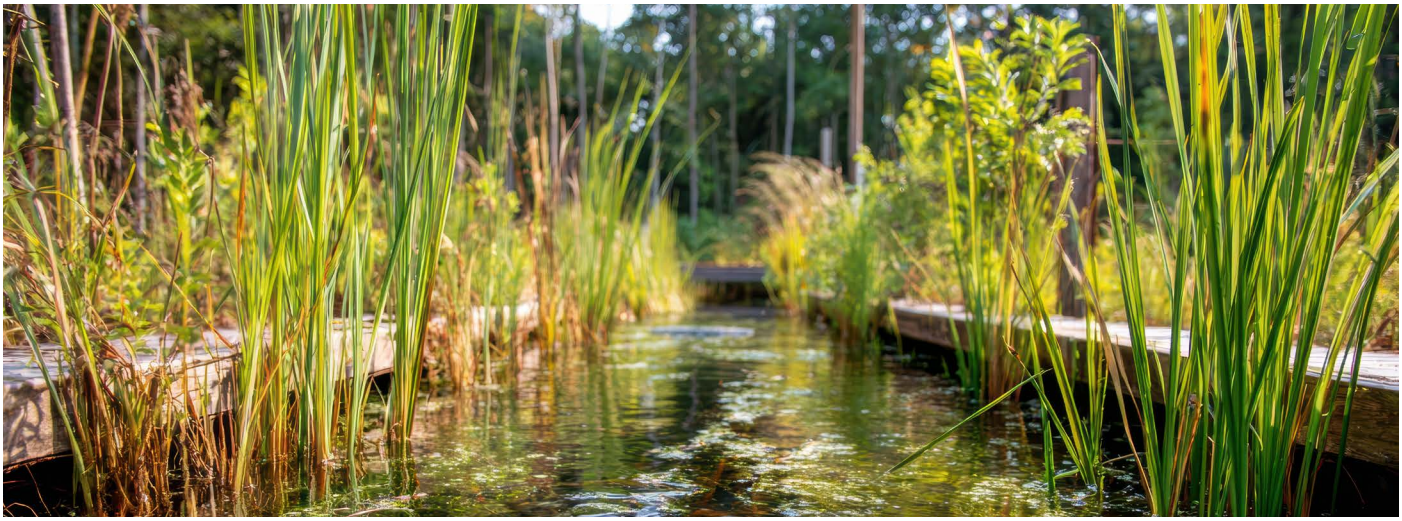
Hybrid System of Constructed Wetlands and Raceway Solar Reactor (CW&RSR)

The **Hybrid System of Constructed Wetlands and Raceway Solar Reactor (CW&RSR)** is an innovative combination of nature-based and solar-driven technologies applied as a **tertiary treatment** stage in a **municipal wastewater facility** in the Axios River Delta (DEMO 3). The constructed wetlands remove nutrients through plant uptake and microbial activity, while the raceway solar reactor improves purification through photo-oxidation and algal nutrient assimilation. The system is designed to reduce nutrient loads discharged from urban wastewater and **achieve water quality suitable for agricultural reuse**, in line with EU Regulation 2020/741.

SEACURE is implementing a **sub-surface horizontal flow Constructed Wetland (CW)**, widely used as an aerobic post-treatment for domestic wastewater, as an effective ecological treatment for removing organic matter and supporting nitrate reduction. The system is complemented by a **Raceway pond reactor (RPRs)**, which consists of open-channel photoreactors in which water circulates continuously, driven by a paddle wheel. The reactor **relies on sunlight to activate oxidative processes that enable the degradation of contaminants**, and its liquid depth can be easily adjusted, making it an important operational parameter.

While less efficient than parabolic-collector photoreactors, these systems are **more cost-effective for municipal wastewater treatment, where only mild oxidative conditions are needed** to remove pathogens and micropollutants. Under these conditions, shorter treatment times (minutes) and lower energy doses are sufficient.

Building upon the results of the AQUACYCLE project, SEACURE is optimising the system's design and operational parameters under real-life conditions to evaluate treatment performance, operational efficiency, and environmental benefits, generating evidence to support replication and scaling across urban wastewater treatment facilities aiming to reduce nutrient emissions.



Benefits

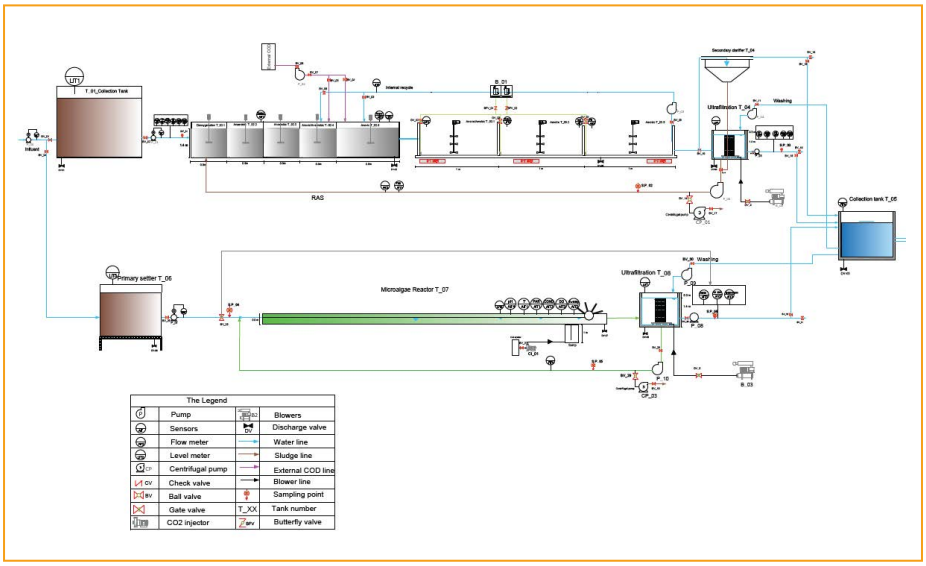
- Reduction of **nitrogen (N)** and **phosphorus (P)** loads from **urban wastewater discharges**
- Promotes **circular water reuse** suitable for agricultural irrigation
- **Cost-effective** and **sustainable** tertiary treatment alternative
- Sub-surface Horizontal CW capacity to **treat higher hydraulic loads** than Surface Flow CW

Replicaiton potential

The hybrid system is suitable for **small and medium-sized wastewater treatment plants interested in sustainable tertiary treatment options** to reduce nutrient discharges and enable safe water reuse. It is well-suited for semi-arid and warm regions, where **high solar irradiation supports the operation of solar-based treatment processes** and contributes to addressing water scarcity through safe water reuse.

Automated Enhanced Biological P removal and Micro-algae Reactor (EBPR&MR)

In the Esino River Basin (Italy, DEMO 5), SEACURE is implementing an innovative prototype at the Jesi (Ancona) wastewater treatment plant (WWTP). This intervention integrates three distinct, automated pilot lines: **Enhanced Biological Phosphorus Removal (EBPR), a Microalgae Reactor (MAR)**, and Horizontal Flow Constructed Wetlands (CW) for final polishing (see S4). The aim is to test and validate these technologies for the **advanced nutrient (N/P) removal from urban wastewater, transforming the WWTP into a smart bio-refinery** platform for environmental improvement and circular economy. This approach minimises nutrient discharge into the Esino River while maximising the recovery of valuable biomass (P-rich sludge, microalgae, and macrophyte plants). The demonstration is equipped with real-time sensors and will automatically monitor and regulate key parameters to maintain optimal operational conditions for both processes.This strategy enhances nutrient removal, while promoting nutrient-rich biomass production, which can be valorised through non-oxidative thermochemical processes (pyrolysis) for subsequent bio-based fertiliser production (see S2). The demonstration will validate the system's efficiency in reducing nutrient discharges, energy use, and GHG emissions while improving process stability, providing a model for integrated, **data-driven wastewater treatment solutions that promotes both nutrient removal and resource recovery.**



Benefits

- Efficient **removal of nutrients** from wastewater
- Improved **process performance** and **stability** through automated, real-time monitoring
- Reduced **energy consumption** and **GHG emissions** compared to conventional systems
- **Minimise nutrient discharges** and pollution in receiving water bodies
- **Valorisation of produced biomass** (P-rich sludge, microalgae, plants) by converting them into nutrient-rich biomass for biofertiliser production

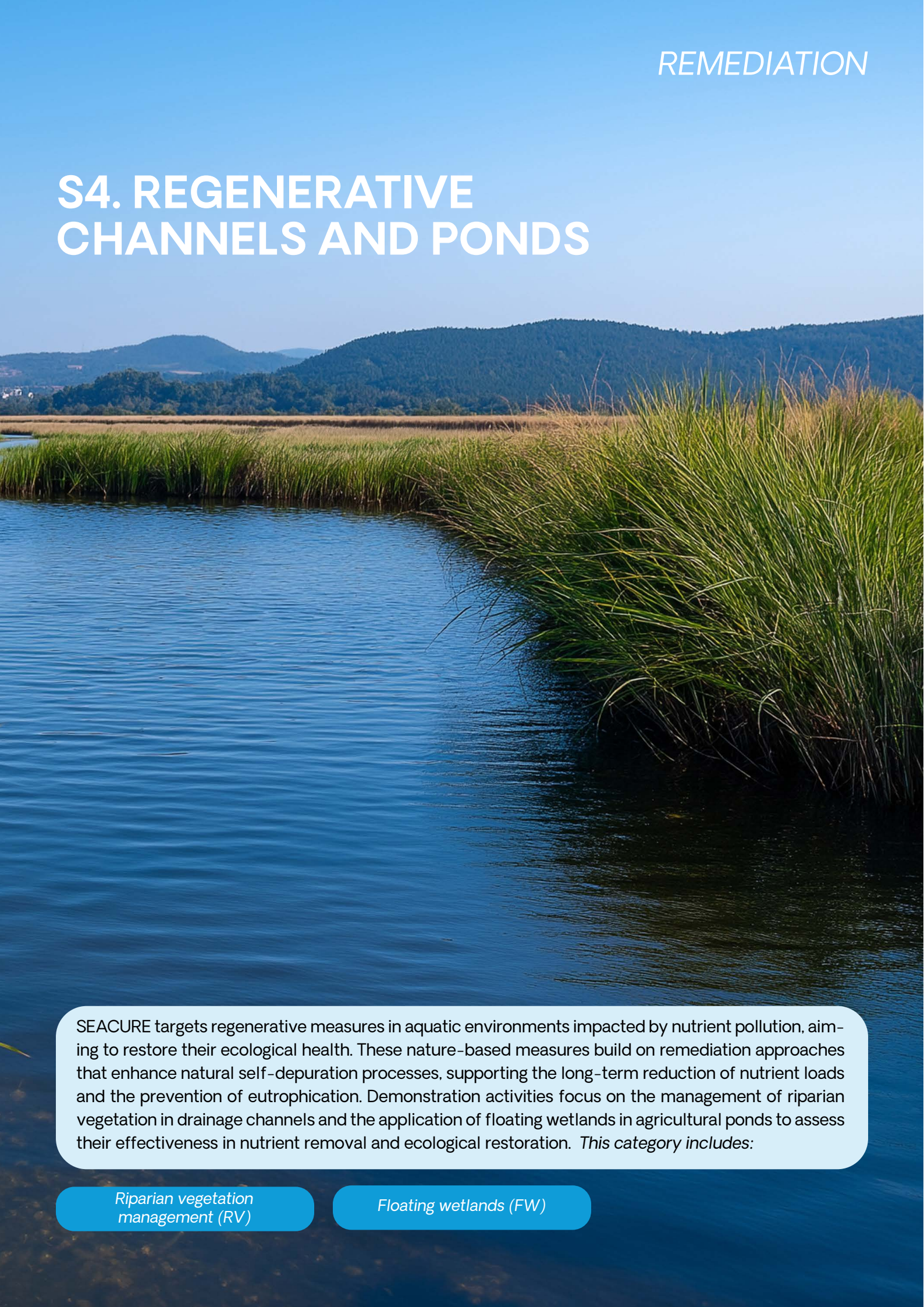
Replicaiton potential

Applicable to **urban wastewater treatment plants** aiming to improve nutrient removal and promote circular, resource-efficient operations transforming WWTP into bio-refineries. The solution is particularly relevant for **facilities looking to integrate automated, smart monitoring technologies and bio-based resource recovery into existing treatment lines**. Particularly suitable for regions with agricultural activity or agro-industrial by-products, **interested in closing nutrient loops** and advancing circular bioeconomy practices.

REMEDIATION

Solutions for eliminating nutrient excess in aquatic ecosystems

S4. REGENERATIVE CHANNELS AND PONDS



SEACURE targets regenerative measures in aquatic environments impacted by nutrient pollution, aiming to restore their ecological health. These nature-based measures build on remediation approaches that enhance natural self-depuration processes, supporting the long-term reduction of nutrient loads and the prevention of eutrophication. Demonstration activities focus on the management of riparian vegetation in drainage channels and the application of floating wetlands in agricultural ponds to assess their effectiveness in nutrient removal and ecological restoration. *This category includes:*

Riparian vegetation management (RV)

Floating wetlands (FW)

Riparian vegetation management (RV)

The project is validating the effectiveness of **riparian vegetation management (RV) practices in agricultural drainage canals** to enhance their nutrient mitigation capacity and limit the nutrient export to terminal water bodies. Implemented in a restored canal located in the Po River Delta, Italy (DEMO 2), this approach focuses on promoting the recolonisation of emergent macrophytes and adopting conservative management practices. Modifying the canal's morphology (i.e. widening the section and reducing the bank slope) favours the natural recovery of the native vegetation that was once dominant (i.e. Phragmites australis). Implementing conservative management practices of aquatic vegetation, which involves reducing the frequency of mowing operations and postponing cutting to the end of the growing season, **promotes the canal's ability to function as a natural buffer** mimicking a wetland environment, while **maintaining hydraulic efficiency.**

Extensive research has demonstrated the **high potential of canal networks to mitigate nutrient pollution when vegetation is properly managed**. The presence of aquatic macrophytes is considered a key factor in determining the potential for water depuration, particularly with regard to the removal of excess nitrogen, through their complex, synergistic interactions with bacterial communities. Shallow slow-flowing vegetated canals are hotspots of denitrification due to the development of multiple biologically active surfaces in both the water column and the rhizosphere. In SEACURE, the approach is being tested under real operational conditions to showcase **how reduced mowing operations can enhance self-depuration processes, improve nutrient control, and contribute to sustainable water management practices.**

Benefits

- **Decreased nutrient export to coastal waters**, particularly during periods of high risk of eutrophication
- **Ecosystem health** coupled with **hydraulic safety needs**
- **Enhanced ecological functioning** and biodiversity in canal networks

Replicaiton potential

The Riparian Vegetation Management approach can be **applied to agricultural drainage networks** aiming to reduce nutrient losses through nature-based maintenance practices. It is suited to **lowland, deltaic,** and **coastal agricultural regions**, where managing nutrient removal and hydraulic performance together is essential for sustainable water and land management.

Floating wetlands (FW)

Floating Wetlands (FW) are increasingly recognised as a practical and low-cost constructed wetland technology for areas with large water-level fluctuations and challenging environmental conditions. This solution involves the implementation of **vegetated floating platforms in agricultural water ponds** to enhance water quality through natural treatment processes. In the Axios River Delta, Greece (DEMO 3), SEACURE is demonstrating and optimising different vegetation management approaches for FWs under real operational conditions to **enhance the self-depuration capacity of water storage systems and increase their nitrogen (N) removal** potential, while maintaining hydraulic functionality.

Their effectiveness is largely driven by the plants and microbial biofilms that develop in the root zone, making **proper management of vegetation essential for successful pollutant removal**. Although most existing knowledge comes from controlled or small-scale applications, FWs have been used in various aquatic environments, including lakes, stormwater ponds, and rivers, and have shown promising results in reducing hydrocarbons in contaminated waters.

In coastal settings, FWs have been mainly applied for ecological enhancement (e.g., by creating habitats for birds and fish), aesthetic improvement, and sediment retention. However, their potential for treating hydrocarbons and other marine pollutants remains largely unexplored. The SEACURE demonstration will evaluate their performance and assess the feasibility of using floating wetlands as a multifunctional solution to improve water quality and enhance nutrient removal, thereby **preventing the degradation and eutrophication of surface water bodies**.

Benefits

- **Reduction of nutrient concentrations** in agricultural water ponds
- **Prevention of eutrophication** in surface water bodies
- **Improved self-depuration capacity** of water storage systems
- **Low-cost** and **low-energy solution** for pollution control
- Improved **ecological quality** and **biodiversity**

Replicaiton potential

Floating Wetlands can be **replicated in agricultural and irrigation ponds, drainage canals, and small reservoirs** requiring low-cost nutrient mitigation solutions. It is particularly relevant for **regions with large water-level fluctuations** and challenging environmental conditions, affected by nutrient pollution and water scarcity, where nature-based treatment systems can improve water quality and enhance ecological resilience within agricultural landscapes.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