DEMONSTRATING INNOVATIVE PATHWAYS
ADDRESSING WATER POLLUTION IN THE
MEDITERRANEAN AGRO•HYDRO•SYSTEM

Open Call for Financial Support to Third Parties as a mechanism to showcase the feasibility, replicability and scalability of innovation solutions through Public Authorities in the Mediterranean

ANNEX 10

Solution Descriptions

Co-funded by
the European Union

1. Novel monitoring Strategies

1.1. Description

Novel monitoring strategies for tracking soil and water pollution, with an emphasis on nutrients, integrate various technologies to provide a comprehensive and dynamic picture. Beneficiaries may implement strategies including IoT and smart sensors, including low-cost hardware nodes and water quality probes, that are deployed in key hydrographic network sites to provide real-time data on physicochemical parameters and pollutant levels.

DNA- and RNA-based indicators complement these by offering highly sensitive biological insights into ecosystem health and responses to pollution, assessing microbial community structure and functional shifts directly linked to nutrient loading. Beneficiaries may implement DNA metabarcoding targeting phytoplankton communities and/or benthic macroinvertebrates. Fastq generated sequencing files may be shared with NKUA together with nutrient data from the same aquatic samples, to test our developed DNA-based indicators. Alternatively, after consultations and relevant meetings we can provide DNA-based indicators according to the water type that the beneficiary targets and test their effectiveness in their systems. Then a refinement of the indicators to fit the case study will be done. If metabarcoding sequencing is not feasible by the beneficiary, some budget allocation towards outsourced sequencing is recommended.

These diverse data streams are then aggregated and interpreted, often using AI and digital twin concepts, to pinpoint pollution sources and track their movement through the agro-hydro-system.

1.2. Examples of the category

1.2.1) Integrated Monitoring for Nutrient Leaching in Agricultural Fields. IoT sensors and smart probes are installed directly in the soil to continuously measure soil moisture, temperature, and electrical conductivity, providing real-time data on water movement and potential nutrient transport. Alongside this, in-situ measurements or samples are taken for nutrient levels. Water samples are regularly collected from drainage tiles or shallow groundwater wells. Spatial analysis techniques are applied to the combined data to pinpoint the precise location and timing of nutrient leaching and agrochemical runoff from agricultural sources.

1.2.2) Tracking Pollution with Real-time IoT and DNA/RNA Analysis: In a river basin affected by agricultural runoff, a network of IoT sensors is deployed, providing continuous, real-time measurements of water quality parameters. Water samples are collected and subjected to rapid DNA/RNA extraction protocols, and subsequent analysis for DNA-based indicators can identify shifts in phytoplankton or other microbial communities characteristic of eutrophication, or detect specific genes related to pesticide degradation.

1.2.3) To evaluate the effectiveness of a newly installed riparian buffer strip (a nature-based solution), IoT sensors are placed along the buffer to monitor soil moisture and groundwater levels, and nutrient concentrations are measured with samples through the strip. Downstream, water samples are regularly collected for traditional nutrient analysis. DNA extraction protocols are applied to both soil samples from

the buffer and water samples from the adjacent stream, to identify DNA-based indicators that reveal the activity of microbial communities involved in nutrient retention (e.g., denitrification) or agrochemical breakdown within the buffer.

1.2.4) Cost-effective water quality monitoring network that utilizes cheap IoT nodes and sensors, like those using Arduino or raspberry pi, for real-time measurement of parameters such as water level, temperature, EC, Ph, nitrate, phosphate, and turbidity in agricultural river basins. These low-cost nodes transmit data via LPWAN technologies (LoRaWAN, NB-IoT) to a cloud-based platform for storage and analysis, enabling continuous tracking of nutrient pollution.

2. Integrated indicators for water management and water quality/quantity monitoring.

2.1. Description

Integrated indicators for water management and water quality/quantity monitoring, as envisioned by Path4Med, are designed to serve multiple critical functions in addressing soil and water pollution from agricultural sources such as tracking pollution sources, trajectories, and trends, assisting the evaluation of agricultural policies towards addressing soil and water pollution and facilitating the net impact assessment of incentives, interventions and measures. These indicators go beyond simple measurements integrating existing indicators with new DNA- and RNA-based indicators. This biological component is particularly useful for detecting early signs of pollution and understanding ecosystem health changes due to specific agricultural activities.

Beneficiaries may apply a combination of DNA- and RNA-based indicators; existing biological indices such as phytoplankton as a key indicator (according to WFD 2000/60/EC), and other biological communities like macrophytes, invertebrates, and fish; soil health indicators; water quality parameters and indicators such as nitrate and phosphate concentrations in rivers and lakes and the number of sampling positions with inadequate quality; and socioeconomic indicators like Knowledge, Awareness, and Practices (KAP) of farmers and number of farmers involved in interventions (male, female, youth) to assess the current status of soil and water pollution and the impact of policies applied in the study region.

2.2. Examples of the category

2.2.1) Net impact assessment of implemented precision irrigation and nature-based solutions on reducing water pollution and improving surface and ground water status through.

2.2.2) Evaluation of policies designed to mitigate pollution from extreme weather events, based on runoff and specific nutrient losses (nitrogen, phosphorus) monitoring with frequent sampling during high-flow events to capture episodic pollution; assessment of land management practices that influence sediment and nutrient runoff through earth observation (e.g. tillage regimes, cover crops); DNA-based indicators in river samples assessing the overall ecosystem health in response

to these episodic pollution events and the effectiveness of conservation measures like reduced tillage or buffer strips.

2.2.3) Application of Integrated Indicators in nitrate vulnerable zones to evaluate the effectiveness and net impact of agri-environmental measures on groundwater status. Monitoring of water fluxes and nutrient dynamics in the unsaturated zone with soil moisture and electrical conductivity probes, combined with simulation of water, and solute movement in variably saturated media for various soil – plant – atmosphere – management combinations integrated with Earth Observation providing an overview of cropping patterns and irrigation practices and DNA-based indicator analysis to identify specific microbial markers related to nitrate degradation.

3. Earth Observation data sources and analysis techniques representing states and fluxes of the Agro-Hydro System

3.1. Description

Earth Observation (EO), utilizing satellite data (e.g., Copernicus) and Unmanned Aerial Systems (UAS), offers spatially explicit information on crop conditions, land use, and indicators of water quality such as chlorophyll-a for eutrophication. By utilizing platforms like Copernicus and NASA Landsat, spatially explicit and continuously updated information on the agro-hydro-system is available. This includes data on hydrological states and fluxes, and crop conditions. EO techniques can help monitor nutrients (eutrophication) and nutrient loads in irrigation return flows, as well as soil moisture, crop stress, soil properties and fertility. Various algorithms, including AI, are employed to estimate these parameters. This also extends to irrigation and nutrients management, where high spatial resolution satellite images coming from satellites or UAS can monitor crop development stages, derive crop coefficients, monitor crop stress, delineate uniform management zones and estimate soil moisture and evapotranspiration. Beneficiaries may apply proximal and or distal Earth Observation data sources and analysis techniques for managing nutrients and irrigation, and for monitoring soil and water pollution from nutrients.

3.2. Examples of the category

3.2.1) Optimizing Nitrogen Fertilizer Application using Satellite-derived Crop Stress Maps: By analysing multispectral imagery from satellites like Sentinel-2, EO techniques can delineate uniform management zones within a field and monitor crop stress and development stages. Algorithms, potentially involving AI, process these images to generate maps indicating areas with nutrient deficiencies or excess nitrogen. Farmers can then use this information to precisely apply nitrogen fertilizers only where needed, optimizing nutrient use efficiency, reducing overall fertilizer consumption, and minimizing nitrate leaching into groundwater.

3.2.2) Monitoring Eutrophication and Nutrient Loads in Rivers and Coastal Waters: Satellite data from Copernicus can be used to monitor chlorophyll-a concentrations in rivers and coastal areas, serving as a direct indicator of eutrophication caused by excess nutrients. This information, combined with hydrological models and data on irrigation return flows derived from EO, allows for tracking nutrient loads from agricultural sources to water bodies. This helps authorities to identify pollution hotspots and evaluate the effectiveness of policies aimed at reducing nutrient runoff.

3.2.3) Precision Irrigation Scheduling with EO-derived Evapotranspiration and Soil Moisture: High spatial resolution satellite images or UAS data can be processed to estimate actual evapotranspiration (ET) and soil moisture levels across agricultural fields. This information, combined with crop coefficients derived from EO, allows for precise calculation of crop water needs. Irrigation systems can then be scheduled to deliver the exact amount of water required, minimizing over-irrigation, reducing water waste, and preventing the leaching of soluble nutrients from the root zone.

3.2.4) Assessing Soil Degradation and Fertility Changes Over Time: EO techniques, utilizing both satellite and UAS imagery, can be used to monitor soil properties and fertility by analysing spectral responses related to soil organic matter content, soil texture, and erosion indicators. By comparing images over several seasons, changes in soil health can be identified, such as the progression of soil degradation or improvements in fertility due to sustainable agricultural practices. This aggregated data provides valuable insights for policy evaluation and the design of interventions aimed at improving soil health and reducing associated nutrient losses.

4. Innovative data aggregations and interpretation methodologies (incl. digital twins, modelling, AI) improving capacity on risk assessment and response.

4.1. Description

Data aggregation and interpretation methodologies, especially when integrated with advanced tools like Digital Twins, modelling, and AI, are crucial for effective monitoring and assessment of water and soil pollution and soil health. In the case of monitoring and assessment of water and soil pollution status and sources involves combining data from various monitoring technologies, such as in-situ IoT and Smart Sensors providing real-time data on water quantity (level, discharge) and quality (physicochemicals) from strategically placed sensors in rivers, aquifers, vadose zones, coastal zones, and soil; Earth Observation (EO) Data including satellite and drone imagery providing spatially explicit information on crop conditions, land use, soil moisture, evapotranspiration, and indicators of water quality (e.g., chlorophyll-a concentrations for eutrophication); Biological data reflecting shifts in microbial communities and functional roles due to pollution, offering sensitive insights into ecosystem health; data from traditional water and soil sampling for chemical and biological parameters, providing ground-truth for sensor and

EO data; historical data from existing monitoring networks and historical datasets to establish baselines and long-term trends. They may include Spatial Aggregation combining high-resolution local sensor data with broader-scale EO data to create comprehensive maps of pollution status across various scales (farm, catchment, regional, continental) and Temporal Aggregation consolidating continuous sensor data and periodic sampling results to analyse short-term fluctuations and long-term changes in pollution levels.

4.2. Examples of the category

4.2.1) Pinpointing Eutrophication Sources and Trends by aggregating satellite imagery (Earth Observation) showing chlorophyll-a concentrations in inland and coastal waters with in-situ sensor data on nutrient levels in rivers, crop patterns, vegetation indices and soil properties and using spatial analysis techniques.

4.2.2) Water/nutrient load calculation from sparse sampling for a certain period (monthly, seasonal, annual) based on R-Beale (automated stratified Beale's ratio estimator) and integrated monitoring involving data assimilation and AI.

4.2.3) Spatio-temporal Analysis to enable the identification of spatio-temporal trends in pollution and soil degradation, revealing areas that are improving or deteriorating and at what rate.

4.2.4) Identification of Pollution Sources by integrating diverse data sources and applying analytical tools. Correlating specific agricultural practices or land uses (identified via EO or farm surveys) with observed pollution levels. Using models to track the movement and fate of pollutants from their origin (e.g., fertilizer application on a field) through the hydrological system to water bodies.

5. Framework of effective cascades of solutions/toolbox of agricultural approaches, practice and technologies

5.1. Description

This framework identifies, improves, adapts, and integrates established and novel agricultural practices, alongside nature-based solutions (NBS) and new-type fertilizers and relevant techniques. Examples include diversified cropping systems, optimized nutrient management (e.g., improved recycling, organic fertilization, nitrification inhibitors), efficient irrigation systems (e.g., precision irrigation, fertigation), water conservation techniques (e.g., water harvesting, treated wastewater reuse), and soil protection methods (e.g., conservation tillage, cover crops, biochar application). NBS-like treatment wetlands and riparian buffer strips are integrated to control pollutant emissions. Beneficiaries may apply a combination of solutions and monitor and evaluate the impact on nutrients pollution reduction.

5.2. Examples of the category

5.2.1) Precision Nutrient Management to Riparian Buffers. A farmer implements information-based precision irrigation and nutrient management systems

(agricultural practice) to optimize fertilizer application, significantly reducing initial nutrient excess in the soil. Any remaining leached nutrients then encounter a riparian buffer strip (NBS) strategically placed along the adjacent waterway, where vegetation and microbial activity further capture and break down pollutants before they reach the main water body.

5.2.2) Conservation Tillage to Treatment Wetlands. Fields adopt conservation tillage (agricultural practice) to improve soil structure and organic matter, thereby enhancing nutrient retention and reducing erosion and runoff. For any remaining diffuse nutrient pollution that enters the drainage system, it is routed through a treatment wetland (NBS) downstream, where natural processes (e.g., microbial denitrification, plant uptake) effectively remove excess nitrogen and phosphorus before discharge into larger water bodies.

5.2.3) Biochar Soil Amendment to New-Type Fertilizers: Agricultural soils are amended with biochar (new technology/practice) to improve soil fertility and water retention, thereby reducing nitrate leaching and pesticide losses directly in the field. This is coupled with the use of new-type fertilizers such as controlled-release or slow-release fertilizers (new technology/practice) which are designed to improve nutrient retention in the soil and ensure a slower, more targeted release to crops, significantly reducing the amount of excess nutrients available for runoff and leaching into water bodies.

6. Location-based information services for farmers and advisors

6.1. Description

Location-based information services for farmers and advisors provide tailored insights on water quality conditions at the local level, supporting more informed and sustainable agricultural practices. These services integrate geospatial data, weather and climate information, and local monitoring to deliver actionable recommendations—such as when to avoid irrigation due to contamination risks, how to manage runoff, or where to adjust fertilizer use to prevent leaching. Developed through collaboration with farmers, advisors, and environmental authorities, these tools will aim to improve on-farm decision-making while safeguarding water resources. They typically combine digital platforms (e.g. mobile apps or dashboards) with advisory support to ensure accessibility and uptake. Beneficiaries may showcase, analyse, evaluate and optimize the use of existing information services in the study area. Participatory approaches should be utilized to assess the effectiveness and to optimize the design.

6.2. Examples of the category

6.2.1) Variable Rate Nutrient & Irrigation Prescription Platform. A digital platform, co-developed with local farmer cooperatives, integrates high-resolution satellite imagery (for crop health and biomass), soil electrical conductivity maps (for soil properties and fertility), and real-time weather data. It generates variable-rate

prescription maps for both irrigation (showing precise water amounts needed for different field zones) and nutrient application (indicating optimal fertilizer rates).

6.2.2) Nutrient Runoff Risk Alert System for Rainfed Croplands. A dashboard accessible to farmers and extension services combines local weather forecasts, soil type data, and historical nutrient leaching patterns from agro-hydrological models (like Daisy) to predict high-risk periods for nutrient runoff after heavy rainfall. Farmers are informed to take precautionary measures in high-risk areas.

7. Technologies to reduce presence of excess nutrients and agrochemical residues in water bodies

7.1. Description

Path4Med focuses on deploying and optimizing a range of technologies and nature-based solutions (NBS) to effectively reduce the presence of excess nutrients and agrochemical residues in water bodies. This involves streamlining existing solutions and introducing cutting-edge technologies to achieve significant pollutant reduction. Key approaches include the implementation of treatment wetlands and biofilters to manage nutrients and phosphorus in river basins, particularly effective for agricultural runoff. Riparian buffer strips, strategically placed along waterways, are emphasized for protecting surface and groundwater from diffuse agricultural pollution, with research focusing on optimal widths and vegetation for enhanced efficiency. Beneficiaries may develop new systems or renovate and monitor existing setups. The functioning and impact of the solutions should be monitored and evaluated and the upscaling potential, challenges, and limitations should be assessed.

7.2. Examples of the category

7.2.1) Optimizing a Mature Treatment Wetland. An existing full-scale treatment wetland, constructed to retain nitrogen and phosphorus from agricultural runoff, is renovated to enhance nitrogen removal and optimize its design for current pollutant loads. This renovated system is then intensely monitored using in-situ sensors and periodic water sampling to track nutrient and agrochemical removal efficiency.

7.2.2) Implementing Smart Riparian Buffer Strips. New riparian buffer strips are established along a river in an agricultural area, incorporating specific vegetation communities adapted to local climate conditions. These buffer strips are equipped with IoT sensors to monitor subsurface water flow, nutrient concentrations, and soil properties. DNA-based indicators from soil and water samples within the buffer assess the activity of microbial communities involved in nutrient breakdown.

8. Policies design and evaluation through the integrated, policy enabled modelling platform

8.1. Description

Beneficiaries will use agrohydrological modelling for the design and evaluation of agricultural policies including measures and interventions addressing soil and water pollution from agricultural sources. Various agrohydrological modelling tools can be used including the tools developed and tested in Path4Med. It may combine WOFOST (WOrld FOod STudies is a simulation model that analyses the growth and production of annual field crops), APEX (Agricultural Policy / Environmental eXtender), Daisy (A system model capable of simulating and integrating processes in soil, plants, and the lower atmosphere), AquaCrop (FAO crop growth model assessing the effect of environment and management on crop production), SWAT (Soil & Water Assessment Tool), HYDRUS (A software package designed for simulating water, heat, and solute movement in variably saturated media). The integrated agrohydrological modelling platform and MARINA models can be also used in collaboration with the responsible partners. Proposed approaches should combine these modelling capabilities with real-world data and stakeholder engagement to provide evidence-based pathways for designing and evaluating effective agricultural and environmental policies that lead to higher societal impact and broader and bolder interventions against soil and water pollution.

8.2. Examples of the category

8.2.1) Climate Change Scenarios Integration: Models can be run with future climate projections (e.g., Representative Concentration Pathways - RCPs, Shared Socio-economic Pathways - SSPs) to understand how soil and water pollution dynamics might change due to shifts in temperature, precipitation patterns, and extreme weather events. This helps in designing climate-resilient agricultural policies. E.g. MARINA model can explore future pathways for zero pollution under climate change, considering its consequences and new insights on sustainable agriculture.

8.2.2) Baseline vs. Intervention Scenarios using models like SWAT that can simulate pollutant loads (e.g., nitrogen, phosphorus, pesticides) entering water bodies under a "business-as-usual" baseline scenario (without new interventions). Then, they can simulate scenarios where specific agricultural policies (e.g., mandating buffer strips, promoting precision fertilization, implementing conservation tillage) are applied. The difference in pollutant loads between these scenarios provides a quantitative estimate of the net impact of the interventions.

8.2.3) Economic Impact Assessment: Models can be linked with economic modules (like Path4Med's DAHBSIM-household farm model) to estimate not only environmental impacts but also the economic consequences for farmers, such as changes in input costs, yields, and profitability, due to policy-driven interventions. This provides a more complete "net impact" picture, considering both environmental and socio-economic dimensions.

8.2.4) Comparing Different Scenarios and Optimization - Policy Mix Analysis: Agrohydrological models allow policymakers to test various combinations of

measures (e.g., combining improved nutrient management with riparian buffer strips and cover crops) to identify the most effective and cost-efficient "policy mixes" for achieving specific pollution reduction targets.

8.2.5) Spatial Prioritization: Models can identify critical source areas within a watershed where interventions would have the greatest impact on water quality. For example, by simulating erosion risk with PESERA or nutrient leaching with Daisy, policies can be optimized to target subsidies or regulations to specific agricultural parcels or sub-basins.

9. Information based precision irrigation and nutrient management system

9.1. Description

Path4Med's approach emphasizes the integration of various advanced technologies and methodologies to provide comprehensive and data-driven irrigation management solutions, moving beyond traditional methods towards more precise and sustainable practices. Beneficiaries will implement a system including IoT sensors networks, cloud platforms, and Earth Observation for precision irrigation and nutrient management. The efficiency of the system should be measured and compared with traditional methods in the study region. Sensors and methods should include those developed and tested in Path4Med but complementary solutions can be tested as well. The limitations and challenges should be described and approaches addressing them should be implemented. Beneficiaries should collaborate with the corresponding demo sites implementing relevant solutions.

9.2. Examples of the category

9.2.1) Monitoring Soil Moisture: involves directly measuring the water content in the soil using sensors such as Time Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR)/Capacitance probes placed at representative positions in the root zone to continuously monitor soil moisture levels. When soil moisture drops below a predetermined threshold (e.g., refill point), irrigation is triggered.

9.2.2) Monitoring Soil Matric Potential (Soil Water Potential): involves measuring the energy status of water in the soil using tensiometers or granular matrix sensors to measure the force with which water is held in the soil. When this force (tension or suction) exceeds a certain level, indicating increasing difficulty for roots to extract water, irrigation is initiated.

9.2.3) Monitoring Crop Stress: This method assesses the plant's response to water availability. Various techniques can be used such as Plant-based Sensors (dendrometers, sap flow sensors, and infrared thermometry).

9.2.4) Water Balance based on Weather Monitoring (Evapotranspiration-based methods): This method calculates crop water use (evapotranspiration, ET) based on weather data (temperature, humidity, wind speed, solar radiation) and crop characteristics.

9.2.5) Integration of short-term weather forecasts into irrigation scheduling tools: Use of short- to medium-term weather forecasts (e.g., 1 to 7-day forecasts) to anticipate rainfall and evapotranspiration, adjusting irrigation scheduling dynamically to avoid over-irrigation, reduce losses, and improve water productivity. Develop a forecast-based irrigation scheduling tool that adjusts planned irrigation volumes or postpones events based on rainfall probabilities and expected ETo. Test the tool under different crops and irrigation systems (e.g., surface, sprinkler, drip) and compare against traditional scheduling methods.

9.2.6) Integration of satellite imagery and field sensors for variable-rate application maps: Use of remote sensing data (e.g., NDVI) from satellites, drones, or proximal sensors, combined with field measurements to generate spatially explicit irrigation and fertilisation maps.

9.2.7) Use of open-access gridded weather data for site-specific irrigation and nutrient scheduling: Incorporation of high-resolution gridded weather datasets (e.g., NASA POWER, E-OBS, AgERA5) to estimate evapotranspiration and support irrigation and fertilisation decisions at field scale. Technologies involved: observed and reanalysis gridded weather datasets, spatial interpolation, crop modelling (e.g., ETo calculation, water balance, crop coefficient adjustment).

9.2.8) Platform that integrates meteorological data, satellite imagery, soil moisture sensors, and crop development and soil water balance models to recommend optimal irrigation and fertilisation schedules (e.g. AQUACROP, ISAREG).

END OF DOCUMENT