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THESEUS

Hub4Circularity

A First of a kind Hub for circularity demonstrator for Attica and peripheral regions

Grant Agreement No 101178059

D7.8 Fertigation of reclaimed water v1

Work Package: 07 Water Symbiotic Flows

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Contributor(s)	Konstantinos Lekkas (EYDAP), Nikiforos Klosteridis (EYDAP), Stelios Samios (EYDAP), Konstantinos Zozolos (EYDAP), Kolikoniaris Petros (EYDAP)

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Publishable summary

The objective of deliverable D7.8, within the THESEUS project, is to assess the benefits and potential risks of large-scale fertigation using reclaimed water. The deliverable is developed in the context of Task 7.4, which supports the implementation of centralized water reuse schemes in Eastern Attica. The work is carried out by National Technical University of Athens and EYDAP, in alignment with the EU Regulation 2020/741 and the updated framework introduced by the Directive (EU) 2024/3019.

The deliverable follows a risk-based approach, combining the development of a Risk Management Plan (RMP) with field-scale experimentation. The RMP is structured around system analysis, identification of hazards, assessment of exposure pathways, and definition of appropriate mitigation measures to ensure the safe use of reclaimed water.

A demonstration site is being developed within the premises of the WWTP of Paiania–Koropi in Eastern Attica, consisting of an experimental agricultural field planned to be irrigated with Class A reclaimed water suitable for unrestricted irrigation, corresponding to the treated effluent of the plant. The study will investigate the fate of emerging contaminants (e.g. pharmaceuticals and personal care products), as well as antibiotic resistance genes and antibiotic-resistant bacteria, across the water–soil–crop system. In parallel, the impacts on crop performance and soil health will be evaluated.

This first version of D7.8 focuses on the initial phase of implementation. It includes the preparation of the demonstration field, soil characterization prior to irrigation, the design of the planting scheme, and the initiation of planting activities. In addition, it provides key information on the WWTP and reclaimed water quality, establishing the baseline for subsequent monitoring and assessment.

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Abbreviations

Abbreviations	Full name
API	Application Programming Interface
ARB	Antibiotic-Resistant Bacteria
ARGs	Antibiotic Resistance Genes
BOD_5	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
EIA	Environmental Impact Assessment
ESIF	European Structural and Investment Funds
EU	European Union
EYDAP	Athens Water Supply and Sewerage Company
HEDNO	Hellenic Electricity Distribution Network Operator
IP67	Ingress Protection rating 67
KYA	Joint Ministerial Decision
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
p.e.	Population Equivalent
PM	Particulate Matter
PPCPs	Pharmaceuticals and Personal Care Products
RMP	Risk Management Plan
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UV	Ultraviolet
VOCs	Volatile Organic Compounds

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WHO	World Health Organization
WWTP	Wastewater Treatment Plant
YPEKA	Ministry of Environment, Energy and Climate Change
YPEN	Ministry of Environment and Energy

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1 Introduction

1.1 Setting the scene

The Region of Attica, hosting a large share of Greece's population and economic activity, faces increasing pressure on its water resources due to climate change, urbanization, and growing demand across sectors. As a Mediterranean region, Attica is particularly vulnerable to prolonged droughts, rising temperatures, and strong seasonal variability, which intensify water scarcity and challenge the reliability of conventional water supply systems.

In this context, the transition towards alternative and more sustainable water sources is becoming essential. Water reuse, and particularly the use of reclaimed wastewater for agricultural irrigation, represents a key solution to reduce pressure on freshwater resources while supporting circular economy principles. Fertigation with reclaimed water offers additional benefits, such as nutrient recovery and improved water-use efficiency, while also raising important considerations related to environmental safety, public health, and long-term impacts on soil and crops.

At the same time, the European regulatory framework is evolving towards stricter requirements for both water reuse and wastewater treatment. The EU Regulation 2020/741 establishes minimum quality standards for reclaimed water used in agriculture, while the Directive (EU) 2024/3019 introduces enhanced obligations for pollutant removal, monitoring, and control of emerging contaminants. These developments highlight the need for integrated, risk-based approaches to ensure the safe and sustainable implementation of water reuse practices.

Within this framework, Eastern Attica represents a key area for the development of centralized water reuse schemes, supported by wastewater treatment infrastructure and increasing interest in reclaimed water use for irrigation. The Mesogeia plain of Eastern Attica constitutes one of the main agricultural zones of the region, characterized by extensive vineyards and olive groves that sustain a significant share of local agricultural activity. This creates a consistent demand for irrigation water and highlights the potential of reclaimed water as a reliable alternative resource. However, the large-scale application of reclaimed water requires a thorough understanding of both its benefits and potential risks, particularly in relation to contaminant behaviour, soil health, and crop performance.

1.2 Purpose of the deliverable

D7.8, developed under the THESEUS project, aims to assess the benefits and potential risks associated with large-scale fertigation using reclaimed water in Eastern Attica. Developed in the context of Task 7.4, the deliverable supports the implementation of centralized water reuse schemes through a structured and evidence-based approach.

The main objective is to evaluate the implications of reclaimed water use in agriculture, considering both environmental and agronomic aspects. Emphasis is given to the fate and removal of emerging contaminants, including pharmaceuticals and personal care products (PPCPs), across water, soil, and crops, with consideration of their potential accumulation in agricultural products. In parallel, the assessment includes

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the investigation of antibiotic resistance genes (ARGs) and antibiotic-resistant bacteria (ARB) within the wastewater treatment system, together with the evaluation of potential impacts of reclaimed water on crop performance, soil properties, and overall soil health.

The work is supported through field-scale experimentation at a dedicated demonstration site located within the premises of the EYDAP WWTP of Koropi-Paiania in Eastern Attica. The site consists of an experimental agricultural field planned to be irrigated with Class A reclaimed water produced by the treatment plant, suitable for unrestricted irrigation, enabling the evaluation of reclaimed water reuse under realistic operational conditions.

The overall approach follows the principles of Regulation (EU) 2020/741 and the associated risk-based framework for water reuse applications. In this context, the deliverable contributes to the progressive development of a Risk Management Plan (RMP), which will incorporate elements such as system characterization, hazard identification, exposure assessment, monitoring procedures, and mitigation measures associated with reclaimed water irrigation practices.

As reclaimed water irrigation activities are at preliminary status during the preparation of the present deliverable, this first version primarily focuses on the initial characterization of the demonstration system and the establishment of baseline environmental conditions prior to reclaimed water application. More specifically, D7.8 Version 1 includes the preparation of the demonstration field, the physicochemical characterization of the soil prior to irrigation, the design of the planting scheme, and planting activities. In addition, it provides key information regarding WWTP and reclaimed water quality, establishing the initial framework for the subsequent monitoring and assessment activities of the project.

1.3 Relation with other Tasks/Deliverables

Deliverable 7.8 is closely linked to Task 7.4, within which the experimental activities and the development of the risk-based framework for reclaimed water reuse are carried out. The outcomes of this deliverable provide the scientific and technical basis for assessing the safe application of fertigation practices using reclaimed water under real field conditions.

In addition, D7.8 contributes directly to Task 7.6, which focuses on the development of a Strategic Master Plan on Circularity in the Attica Region. The results generated—particularly those related to risk management, water quality requirements, contaminant behaviour, and impacts on soil and crops—provide essential input for the design and optimization of water reuse schemes. These insights support the identification of appropriate treatment levels, reuse applications, and system configurations.

Furthermore, the findings contribute to the definition of investment priorities and infrastructure needs, including the integration of reclaimed water into agricultural systems and the development of centralized reuse schemes. They also support the formulation of regulatory and operational frameworks, as well as pricing and cost-recovery mechanisms, ensuring that water reuse solutions are not only technically feasible but also economically and institutionally viable.

Overall, D7.8 provides key evidence to support the development of a coherent and implementable Strategic Master Plan, enabling the transition towards circular and resilient water management systems in the Attica Region.

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2 Study Area & Conceptual Framework

2.1 Conceptual Framework for Future Risk Assessment and RMP Development

The reclaimed water reuse demonstration developed within the THESEUS project is based on a risk-oriented approach following the principles of Regulation (EU) 2020/741 regarding the safe reuse of treated wastewater for agricultural irrigation. The overall framework considers the entire reclaimed water reuse chain, including the wastewater treatment plant (WWTP), the reclaimed water production and distribution system, the agricultural application area, and the surrounding environmental receptors potentially affected by reclaimed water irrigation practices.

As illustrated in Figure 1, the conceptual framework defines the main system boundaries and the key components involved in the reclaimed water reuse chain, from urban wastewater collection and treatment to agricultural irrigation and crop production. Emphasis is given to the interactions between reclaimed water quality, soil properties, crop development, groundwater conditions, and potential human and environmental exposure pathways. The assessment will evaluate the fate and removal of emerging contaminants, including pharmaceuticals and personal care products (PPCPs), across water, soil, and crops, with consideration of their potential accumulation in agricultural products. In parallel, the assessment will investigate the fate and removal of ARGs and ARB within the wastewater treatment system, while also evaluate the impact of reclaimed water on crop performance, soil properties, and overall soil health, including biodiversity.

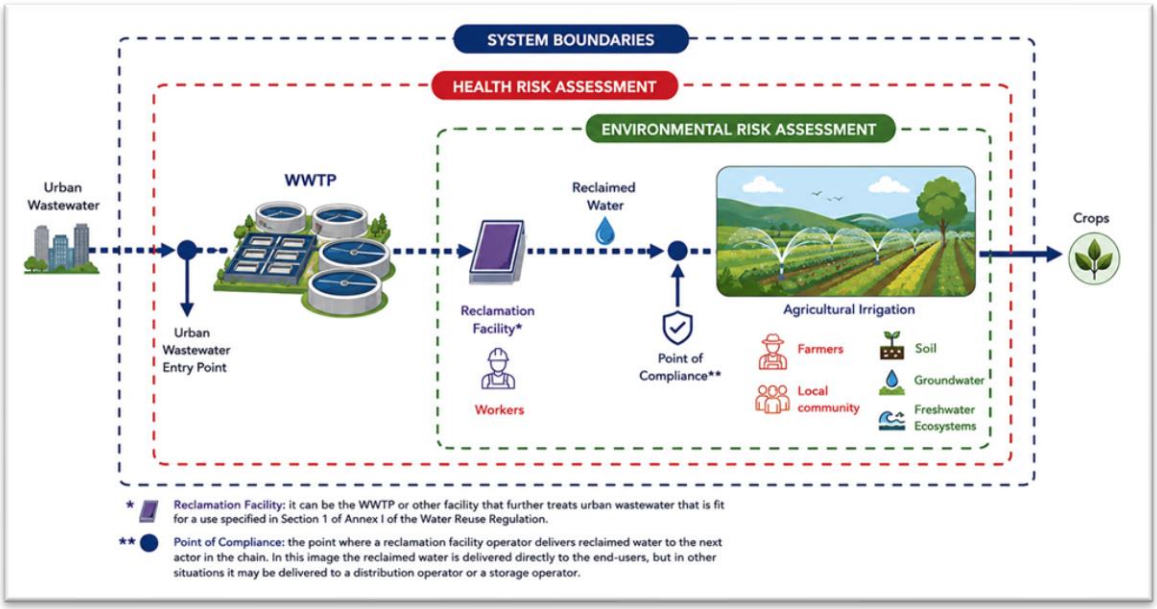


Figure 1: Conceptual representation of the reclaimed water reuse system boundaries, environmental compartments, and potential human and environmental exposure pathways considered within the future RMP framework (JRC,2022).

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The framework also identifies the main environmental and human receptors potentially affected by reclaimed water irrigation practices, including farmers, field workers, local communities, soil, groundwater, freshwater ecosystems, and agricultural crops. In parallel, the identification of environmental and health risk assessment components supports the future development of an integrated Water Reuse Risk Management Plan (RMP) in line with the requirements of Regulation (EU) 2020/741.

According to Annex II of Regulation (EU) 2020/741, the development of a Water Reuse Risk Management Plan should incorporate elements such as system characterization, hazard identification, exposure assessment, monitoring procedures, and mitigation measures. Since the irrigation of the pilot site with reclaimed water is at initiation stage during the preparation of the present deliverable, the current work mainly focuses on the characterization of the study area in terms of soil composition and the establishment of baseline environmental conditions prior to reclaimed water application.

The activities presented in the following sections therefore provide the initial environmental and technical framework supporting the future development of the Risk Management Plan and the study of reclaimed water irrigation under in real field conditions.

2.2 Eastern Attica: Regional Context

Eastern Attica constitutes a rapidly developing peri-urban region of the Athens metropolitan area, characterized by a diverse land-use pattern that includes residential areas, industrial zones, and extensive agricultural land. The Mesogeia plain (Figure 2), where the study area is located, represents one of the most important agricultural zones of Attica, hosting a variety of crops such as vineyards, olive groves, and horticultural production activities. The region is increasingly affected by water stress due to urban expansion, climate variability, and competing water demands across sectors. These pressures highlight the need for alternative water resources and more efficient water management practices. In this context, the use of reclaimed water emerges as a key strategy to enhance water resource efficiency, reduce dependence on freshwater supplies, and support sustainable agricultural production.

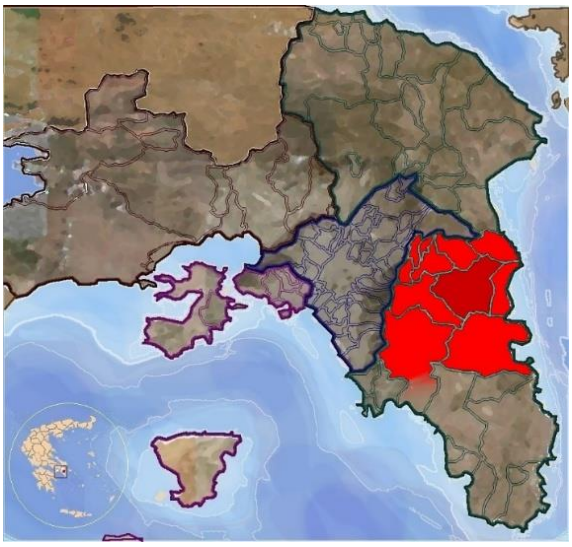


Figure 2:Mesogeia Attikis highlighted in red

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2.3 Preliminary Assessment of Environmental Pressures in the Wider Study Area

Prior to the selection of the demonstration site for reclaimed water reuse applications within the THESEUS project, a preliminary assessment of the wider Mesogeia region was carried out to identify existing environmental pressures, anthropogenic activities, and potential contamination sources that could influence agricultural soils, groundwater resources, and the overall environmental conditions of the study area.

Considering the proximity of the area to Athens International Airport (Figure 3), as well as the presence of major transportation infrastructure, agricultural activities, urban development, and industrial operations, the assessment focused on the investigation of environmental parameters related to atmospheric quality, soil conditions, and groundwater status.

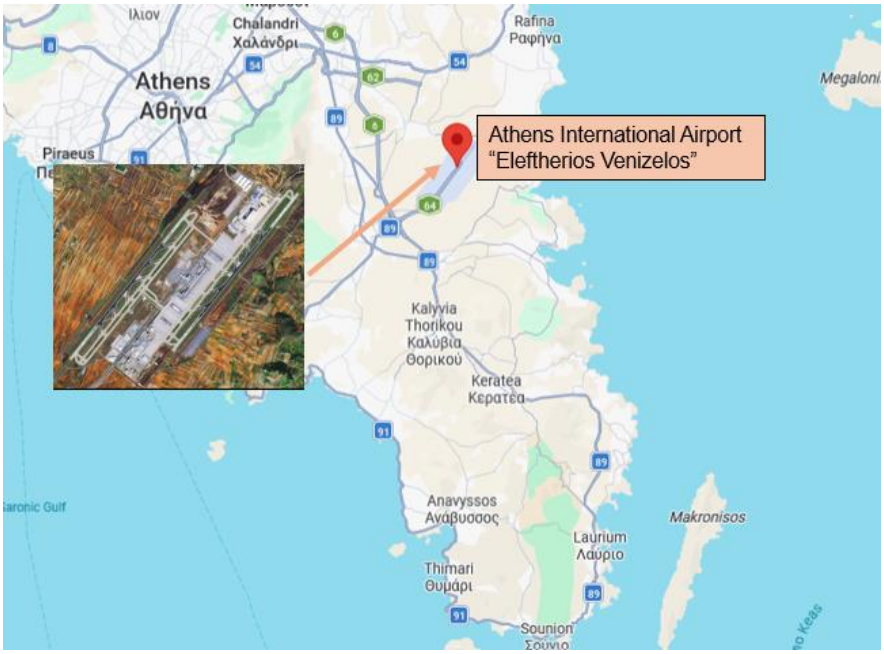


Figure 3: Location of Athens International Airport "Eleftherios Venizelos" within Eastern Attica

For this purpose, available Environmental Impact Assessments (EIAs), scientific studies, monitoring reports, and regional environmental management plans were reviewed to document the existing environmental setting of the wider area and support the selection of the demonstration site. The assessment also aimed to support the interpretation of future monitoring results by distinguishing potential impacts associated with reclaimed water reuse from existing background environmental pressures and potential elevated contaminant concentrations within the wider area.

The preliminary assessment included the examination of:

- atmospheric pollution sources and air quality parameters,
- potential atmospheric deposition of pollutants,
- soil quality characteristics and heavy metal occurrence,
- groundwater quality and hydrogeological conditions,

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- existing anthropogenic pressures related to agricultural and urban activities.

The assessment conducted presents the general environmental setting of the wider Mesogeia region, where the reclaimed water reuse activities of the THESEUS project are implemented.

2.3.1 Study Area

The study area is located within the Attica peninsula, which constitutes the southeastern extension of the eastern central mainland part of Greece in the proximity of the airport. Human activities within the area are particularly intense, while significant urban development has taken place, resulting in a densely populated region. In the northern part of the area lie the towns of Spata (9,839 inhabitants), Paiania (12,137 inhabitants) and Glyka Nera (6,971 inhabitants), together with several smaller settlements. In the central part, the cities of Koropi (19,475 inhabitants) and Markopoulo (13,134 inhabitants) are located, while in the southern part lie the towns of Keratea (10,642 inhabitants) and Kalivia Thorikou (9,477 inhabitants). The area additionally includes numerous settlements consisting mainly of holiday residences, many of which were developed without formal planning authorization. Urban expansion has largely occurred in an unplanned manner, resulting in significant environmental and spatial planning issues. The wider region has experienced intense residential development during the last 30 years due to suburbanization processes taking place within the Athens metropolitan area, particularly following the operation of Athens International Airport “Eleftherios Venizelos”. This urban expansion further intensified after the infrastructure projects implemented in the wider area in preparation for the Athens Olympic Games in 2004 (ELSTAT,2011).

The wider project area includes the following major infrastructure (Municipality of Koropi, 2023):

- Rafina Port
- Athens International Airport “Eleftherios Venizelos”
- Attiki Odos motorway
- Spaton Avenue
- Marathonos Avenue
- Kalyvion Avenue
- Athens–Sounio Avenue
- Urban and peri-urban road networks of Koropi, Paiania, Pallini, Agia Marina, Agios Dimitrios, Paralia Kalyvion, Saronida, Anavyssos and Palaia Fokaia
- Airport fuel pipeline
- Regional natural gas network
- Water supply network

Water supply within the wider area follows a hybrid pattern; either there are areas supplied by EYDAP SA through the Municipality without responsibility and participation in the operation of the local internal network, or areas with a mixed water supply system, i.e. areas where some sections are covered by EYDAP SA and other sections are covered either by a private network or under the responsibility of the Municipal Authority (EYDAP, n.d.). Electricity demand is supplied through the HEDNO (DEDDIE) electricity distribution network.

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Within the wider study area, there are no permanent rivers or other permanent surface water bodies (lakes, ponds, etc.). This is attributed both to the natural geomorphology of the region and the relatively low annual precipitation, as well as to extensive anthropogenic interventions such as stream infilling, conversion of natural streams into agricultural land, urban development and road construction activities. As a result, quantitative hydrological data and flow measurements for streams and the Erasinos River remain limited. The available data mainly concern estimated maximum fifty-year flood discharges for streams and the Erasinos River. Part of the precipitation falling within the hydrological basins is discharged through surface runoff, while another part infiltrates into the subsurface (Municipality of Koropi, 2023).

The main land uses identified within the wider study area include the following:

Agricultural Land

These areas correspond to land cultivated during the last five years for agricultural production and are estimated to cover approximately 2,000 hectares.

Forest Areas

These include areas partially or fully covered by trees or shrub vegetation and are estimated to cover approximately 12,700 hectares.

Agricultural Structure of the Area

The largest percentage of agricultural land corresponds to non-irrigated cultivations, while a considerably smaller proportion corresponds to irrigated agriculture. This is mainly attributed to the relatively low precipitation, the absence of extensive water management infrastructure and the depletion of the groundwater aquifer due to continuous groundwater abstraction. Viticulture constitutes the dominant agricultural activity of the region, occupying the largest proportion of the cultivated land, including both dry and irrigated vineyards. Vineyards are mainly used for wine grape production, while table grape production is considerably more limited. Olive cultivation also occupies a significant proportion of tree cultivations. Olive groves are generally located in elevated and sloping areas and are typically non-irrigated. The total olive production is mainly used for olive oil production, while edible olive production is practically absent. Additional tree cultivations mainly include almond trees, fig trees and pistachio trees. Vegetable cultivations cover a relatively limited area compared to the total agricultural land. The main products include vegetables, while potato and melon cultivations are less extensive. Irrigation within these areas is mainly supplied through pumping systems connected to private groundwater boreholes. Arable cultivations include soft and hard wheat, barley, oats, hay crops and grasses used for livestock production. Floriculture activities within the region remain relatively limited and mainly include open-field cultivations and greenhouse facilities (Municipality of Koropi, 2023).

The characterization of local agricultural practices and dominant cultivations was considered particularly important for the design of the demonstration activities, as crop selection within the THESEUS project aimed to reflect representative agricultural conditions and cultivation patterns of the wider Mesogeia region.

2.3.2 Anthropogenic pressures on the natural environment

Although the demonstration activities of the THESEUS project are implemented within the premises of EYDAP WWTP of Koropi-Paiania using reclaimed water complying with Class A reuse requirements, the wider study area is characterized by the coexistence of multiple anthropogenic activities that may influence the

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environmental conditions of the surrounding environment independently of reclaimed water reuse applications.

Attention was given to the presence of Athens International Airport "Eleftherios Venizelos", which constitutes one of the dominant anthropogenic activities within the wider Mesogeia region. Airport-related operations, including aircraft movements, fuel handling and storage activities, ground support operations, road traffic, and atmospheric emissions, may potentially contribute to the release and dispersion of pollutants within the surrounding environment, along with the major transportation infrastructure, urban expansion, agricultural activities and other human pressures in the region.

Considering the above, the environmental compartments associated with the demonstration activities were investigated in terms of contaminants, in particular

- atmospheric environment and potential atmospheric pollution sources,
- soil quality conditions and potential pollutant accumulation,
- groundwater quality and hydrogeological conditions.

As mentioned above, the assessment aimed to identify possible pollutant pathways, background contamination sources and environmental pressures associated with existing human activities in the wider area prior to the implementation of reclaimed water reuse applications.

2.3.3 Existing Atmospheric Pollution Conditions within the Study Area

The proximity of the demonstration site to Athens International Airport "Eleftherios Venizelos" and other major emission sources within the wider Mesogeia region accounts for the atmospheric environment to be considered one of the main environmental compartments requiring preliminary assessment. . Although reclaimed water reuse is the primary focus of the THESEUS demonstration activities, airborne pollutants originating from surrounding anthropogenic activities may contribute to the existing environmental background and could potentially affect soil quality through atmospheric deposition processes, as well as influence the growth and development of cultivated plants within the wider agricultural area, including the crops cultivated within the framework of the demonstration activities.

Airport-related emissions are mainly associated with aircraft movements, ground support operations, fuel handling activities, road traffic within and around the airport, and auxiliary infrastructure. Aircraft emissions are considered particularly relevant during the Landing and Take-Off (LTO) cycle (Figure 4), which includes taxiing, take-off, climb-out, approach and landing operations below approximately 3,000 ft. These operational phases are of particular importance for local air quality, since emissions occur close to ground level and may therefore influence surrounding areas more directly than emissions released at cruising altitude (Christodoulakis et al., 2022).

The main pollutants associated with airport and aircraft operations include nitrogen oxides (NOx), carbon monoxide (CO), sulphur oxides (SOx), volatile organic compounds (VOCs), hydrocarbons and particulate matter (PM). Particulate emissions may additionally originate from tyre and brake wear during landing and take-off operations, while incomplete fuel combustion may contribute to the release of unburned

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hydrocarbons and polycyclic aromatic hydrocarbons (PAHs). Depending on particle size and prevailing meteorological conditions, these pollutants may either deposit close to the emission source or be transported over greater distances before deposition on surrounding soils and surfaces (Atasoy et al., 2021).

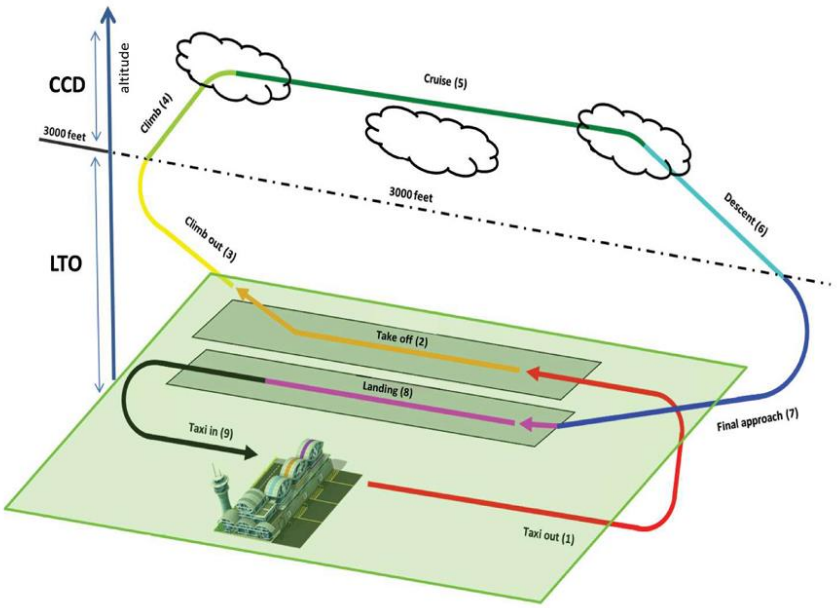


Figure 4: Illustration of the different flight phases and the parts that separate each phase (Christodoulakis et al., 2022)

Available environmental assessments and monitoring data for the wider Mesogeia region indicate that airport-related emissions may contribute to local air quality conditions, mainly through short-term concentration peaks, but do not appear to determine the general atmospheric pollution profile of the wider study area. Additional CO concentrations attributed to airport operation have been reported to remain below 0.18 mg/m³, which is considered negligible compared to the regional background concentration of approximately 18 mg/m³. Similarly, the maximum additional smoke concentration has been estimated at 13 mg/m³, resulting in total concentrations of approximately 28 mg/m³ when combined with background levels, remaining below the relevant WHO annual average guideline value (Municipality of Koropi, 2023).

For SO_2, the maximum additional concentration attributed to airport operation reaches 36 mg/m³, leading to total concentration levels approaching the relevant guideline target. In the case of VOCs, the maximum additional concentration reaches 76 mg/m³, although no specific regulatory threshold has been established for atmospheric hydrocarbon concentrations. NO_2 represents the most relevant parameter from an air quality perspective, with a maximum additional concentration of 65 mg/m³. When combined with the background concentration of approximately 26 mg/m³, total concentrations may exceed the WHO annual average guideline value under specific conditions (Atasoy et al., 2021).

Monitoring campaigns performed by the Institute of Environmental Research and Sustainable Development (IERSD) using a mobile atmospheric pollution monitoring station in Markopoulo further support this interpretation. Measurements were conducted at two locations within the settlement of Markopoulo for a total period of 140 calendar days, including 107 monitoring days at the Markopoulo High School location.

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Except for particulate matter, concentrations of the major atmospheric pollutants generally remained below the applicable air quality standards. Elevated particulate matter concentrations were mainly observed at the Cemetery monitoring location, where values exceeded those typically recorded in ordinary urban areas and other monitoring stations within the Athens metropolitan basin (Municipality of Koropi, 2023).

The observed pollution patterns were found to be strongly influenced by meteorological conditions. Northern winds were dominant and generally associated with relatively high wind speeds, while southern winds occurred during approximately 30% of the monitoring period. Calm atmospheric conditions with variable wind directions were recorded during approximately 25–30% of the monitoring period. Higher pollution levels were generally observed during calm conditions or periods dominated by southern winds. Under such conditions, short-term peaks of primary pollutants, including NO, CO, hydrocarbons and particulate matter, were recorded, particularly at the Markopoulo High School background monitoring station.

These peaks could potentially be linked to airport-related activities, especially aircraft exhaust emissions during landing and take-off operations, although the contribution of other local pollution sources cannot be excluded. Importantly, however, these events were characterized as short-term and relatively low-frequency episodes. Over approximately 135 days of observations, such peaks occurred on less than 10% of the monitored days, affected local atmospheric quality for approximately 1–2 hours, and remained below applicable regulatory limits where such limits exist.

Additional long-term monitoring data from the air quality monitoring network operated by Athens International Airport since 1998 further indicate that concentrations of CO, NO_2, O_3 and SO_2 within the wider Mesogeia region generally remain below the applicable legislative limits. Minor exceedances were reported for PM10 and PM2.5 during specific periods and locations, particularly in Markopoulo and Koropi. However, seasonal variations of atmospheric pollutants suggest that several additional regional sources contribute significantly to local air quality conditions, including domestic heating, biomass combustion, road traffic, quarry activities and Saharan dust transport episodes (Municipality of Koropi, 2023).

Overall, the available evidence suggests that the operation of Athens International Airport may influence local air quality episodically, particularly under specific atmospheric dispersion and wind conditions, but does not appear to cause a persistent deterioration of the atmospheric environment within the wider study area. The atmospheric quality of the region is instead shaped by a combination of transported pollution from the Athens metropolitan basin and multiple local anthropogenic activities.

2.3.4 Soil Environment and Background Environmental Pressures

Following the assessment of atmospheric conditions within the wider Mesogeia region, particular attention was also given to the soil environment, since soils may function as both receptors and long-term accumulators of pollutants originating from surrounding anthropogenic activities. Considering the coexistence of agricultural activities, urban development, transportation infrastructure, industrial and small-scale industrial activities, as well as the operation of Athens International Airport “Eleftherios Venizelos”, the investigation of existing soil conditions was considered necessary in order to identify potential background environmental pressures that could influence the interpretation of future monitoring results associated with the THESEUS demonstration activities.

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Starting with the existing environmental pressures affecting the soil environment, one of the main potential sources of contamination within the wider study area is associated with the historical absence of fully centralized sewerage infrastructure in several settlements of the Mesogeia region (Municipality of Koropi, 2023). As a result, subsurface disposal of domestic wastewater through absorption pits and leaking septic tanks has constituted an important potential source of environmental pressure for both soils and groundwater resources. Additional pressures may arise from industrial and small-scale industrial activities, uncontrolled waste disposal practices, fertilizer and pesticide application in agricultural areas, and possible leakages associated with airport-related infrastructure and operations.

Airport activities were also considered as a potential contributor to soil contamination through atmospheric deposition processes. As mentioned before, aircraft exhaust emissions generated during landing and take-off operations may contain particulate matter, hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), sulphur compounds and trace metals originating from fuel combustion, lubricants, brake wear and tyre abrasion (IPCC, 2000). Following their release into the atmosphere, these pollutants may eventually deposit on surrounding soils. Nevertheless, it should be noted that heavier particles generally settle close to the emission source, typically within distances of approximately 100 m from the source area, while finer particles may be transported over longer distances depending on meteorological and dispersion conditions (Hitchins et al., 2000).

Considering the coexistence of the above anthropogenic pressures within an area dominated mainly by agricultural land uses, the investigation of existing soil conditions was considered necessary in order to establish a baseline environmental profile for the wider study area. The surrounding area of the demonstration site is characterized primarily by non-irrigated cultivations and areas covered by low natural vegetation (EYDAP, 2023), making it important to distinguish potential background contamination associated with long-term regional activities from possible impacts related to reclaimed water reuse applications implemented within the THESEUS project.

To evaluate existing soil conditions within the wider area of Athens International Airport, particular consideration was given to the study of Massa (2017), which investigated the distribution of heavy metal concentrations in soils surrounding the airport, including agricultural areas adjacent to the current demonstration site (Figure 5). The study included the collection and analysis of 86 surface soil samples (0–10 cm depth) distributed throughout the airport perimeter and surrounding agricultural areas. Prior to the assessment of heavy metal concentrations, the physicochemical characteristics of the collected soils were also investigated to better interpret metal distribution and mobility within the soil matrix. The results indicated that the soils of the wider Mesogeia region are generally characterized by moderate texture, with sand contents ranging from 28.0% to 85.4% and clay contents ranging from 8.0% to 42.6%. Soil pH values were slightly alkaline, indicating sub-alkaline conditions and relatively low metal mobility within the soil matrix. Organic matter content ranged from trace levels up to 21.06%, while calcium carbonate content ranged between 2.7% and 54.4%. These findings indicate soils with relatively good drainage and aeration characteristics. (Massas et al., 2017). These physicochemical characteristics are generally consistent with the soil analyses conducted within the framework of the THESEUS demonstration activities in the Koropi WWTP area.

In addition, the concentrations and spatial distribution of selected heavy metals within the investigated soils were evaluated. Total concentrations of Cu, Zn, Fe, Mn, Ni, Cr and Ba were determined following aqua regia

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extraction. The reported median concentrations of Cu, Zn, Fe, Mn, Ni, Cr and Ba were 23, 81, 22×10³, 497, 87, 74 and 423 mg kg^{-1}, respectively. Although the median concentrations were not considered particularly high, elevated concentrations observed at the 90th percentile for several metals suggested localized enrichment processes within specific parts of the study area. The spatial distribution analysis indicated increased concentrations of Pb and Cu mainly within the northern part of the study area, while Zn concentrations appeared to increase progressively from the southern towards the northern sector. Higher concentrations of Ba, Cr and Mn were mainly observed in the western part of the investigated area (Massas et al., 2017).

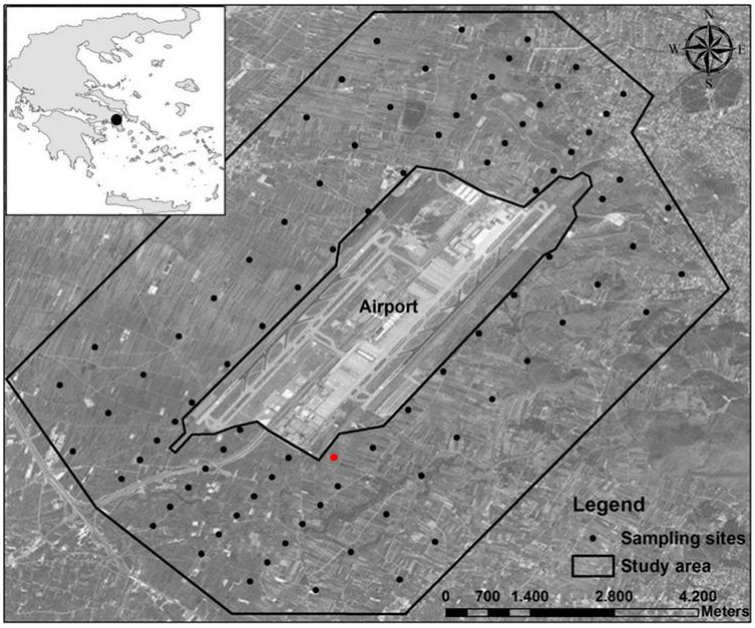


Figure 5: Studied area and sampling sites. (Massas et al., 2018)

A particularly important aspect of the study was the investigation of whether the detected metals were associated with the natural geochemical background of the soils or originated from anthropogenic activities within the wider area. For this purpose, the enrichment factor (EF) approach was applied in order to distinguish between geogenic and anthropogenic contributions to the observed metal concentrations. The results suggested that Cr, Ni, Mn and Fe are primarily associated with geogenic sources related to the parent material of the soils. In contrast, Pb, Cu and Zn showed limited correlation with the physicochemical properties of the soils, indicating that their presence may be associated with secondary anthropogenic enrichment processes, mainly through atmospheric deposition (Massas et al., 2017).

The study further indicated that aircraft landing and take-off operations, aircraft maintenance activities and traffic intensity within and around the airport may contribute to the observed enrichment of soils with Pb, Cu and Zn. However, despite the indication of anthropogenic influence, the calculated EF values generally suggested absent to mild or moderate contamination levels within the investigated soils.

An extension of the previous investigation additionally indicated that the elevated availability of Cu detected in several locations of the study area may not be exclusively related to airport activities. Atmospheric deposition of Cu may also originate from agricultural practices, particularly from the long-term application of Cu-based fungicides in vineyards and olive cultivations surrounding Athens International Airport. This

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observation is particularly important for the interpretation of environmental monitoring results within the THESEUS project, since agricultural activities themselves may contribute to the background concentrations of specific trace elements within the study area (Massas et al., 2018).

Additional assessment of metal mobility through the Mobility Factor (MF) approach indicated relatively high mobility for Pb and Mn and moderate-to-high mobility for Cu and Ni. Although sequential extraction analyses were performed only for a subset of the collected samples, the obtained MF values suggest that part of these metals may occur in relatively mobile or bioavailable forms within the soils of the wider airport area (Massas et al., 2018).

To better evaluate the environmental significance of the observed metal concentrations within the wider airport area, comparative investigations were additionally performed between soils located within the airport perimeter, surrounding agricultural areas and other urban and industrial regions of Attica. The results indicated that, although signs of metal enrichment associated with anthropogenic activities were identified in soils surrounding Athens International Airport, the concentrations detected in the agricultural soils of the Mesogeia region remain considerably lower than those typically reported in heavily urbanized and industrialized areas, such as central Athens and the Thriassio Plain. These findings suggest that airport-related activities may contribute to a certain degree of metal accumulation in surrounding soils; however, the overall magnitude of this contribution appears relatively limited compared to the long-term atmospheric deposition pressures observed in major urban and industrial environments (Massas et al., 2018).

Overall, the available evidence suggests that the soils surrounding the demonstration site may be influenced by a combination of geogenic characteristics and long-term anthropogenic pressures associated with agriculture, transportation infrastructure, urban development and airport-related activities. However, the currently available data do not indicate severe or widespread soil contamination conditions within the wider study area.

From the perspective of the THESEUS demonstration activities, these findings support the need for baseline environmental characterization and continuous monitoring to distinguish possible impacts associated with reclaimed water reuse from pre-existing background environmental pressures already affecting the area.

2.3.5 Groundwater Quality and Hydrogeological Conditions

Following the assessment of atmospheric and soil conditions within the wider study area, the investigation of groundwater quality and hydrogeological conditions was also considered necessary due to the complex environmental setting of the Mesogeia region and the coexistence of multiple anthropogenic pressures that may affect the groundwater environment, besides the reclaimed water reuse activities implemented within the THESEUS project. Understanding existing groundwater conditions was considered particularly important to establish the environmental baseline of the area and distinguish potential pre-existing impacts from possible effects associated with reclaimed water reuse applications.

Groundwater resources constitute one of the main water supply sources within the wider Mesogeia region and are extensively used for irrigation of agricultural land, water supply of seasonal urban demands, supplementary domestic use, hotel facilities, livestock units, poultry farms and industrial or small-scale industrial activities (Municipality of Koropi, 2023). In recent years, continuously increasing water demand has

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been observed within the region mainly due to the expansion of irrigated agricultural areas and the ongoing residential development outside formally planned urban zones. This has resulted in the extensive exploitation of groundwater resources through numerous abstraction wells and boreholes, many of which operate without formal authorization (Municipality of Koropi, 2023).

The long-term intensive exploitation of groundwater resources has significantly affected both groundwater quantity and quality within the study area. Local depletion of shallow aquifers has progressively led to deeper groundwater abstraction and intensified exploitation of deeper hydrogeological formations. At the same time, groundwater quality degradation has been associated with the combined influence of agricultural, urban and industrial pressures, including intensive fertilizer application, leakage from septic tanks and absorption pits, disposal of domestic wastewater, livestock and poultry farming activities, and uncontrolled urban development. As a result, the shallow groundwater system is generally characterized by hard to very hard water conditions, alkaline pH values, elevated total dissolved solids (TDS) and increased concentrations of NO_3^-, Cl^-, Na^+ and K^+ ions (Ministry of Environment and Energy, 2017).

An additional major environmental pressure affecting the groundwater system of the wider Mesogeia region is seawater intrusion, particularly within the karstic aquifers of the area. In combination with excessive groundwater abstraction, seawater intrusion processes have progressively intensified, leading to increased chloride concentrations and salinization of groundwater resources (Municipality of Koropi, 2023).

According to the 1st Revision of the River Basin Management Plan (RBMP) of Attica approved in December 2017, the wider study area belongs to the groundwater body EL0600152 “Mesogeia”. The groundwater body is classified as having Good Quantitative Status but Poor Chemical Status, reflecting the extensive and long-term groundwater quality pressures affecting the area. Reported groundwater conductivity values range between 1000 and 5400 μS/cm, while chloride concentrations locally approach 1300 mg/L and nitrate concentrations may locally reach values as high as 650 mg/L. Elevated concentrations of Fe, Zn, Cr and As have also been reported in parts of the groundwater system, mainly associated with agricultural and industrial activities within the region. The highest chloride concentrations are mainly observed in the eastern part of the groundwater body, indicating the influence of seawater intrusion processes (Ministry of Environment and Energy, 2017).

In order to better evaluate groundwater conditions in the vicinity of Athens International Airport and the demonstration site, particular consideration was additionally given to the groundwater monitoring network established within the airport area (Chilakos and Kavouras, 2004). Eight groundwater monitoring boreholes were installed for groundwater quality monitoring purposes. Five of these boreholes (WO-1 to WO-5) were installed within the overburden layer, while three additional boreholes (WU-1, WU-2 and OFCG) were installed within the bedrock formations. Two boreholes located along the western airport perimeter (WO-1 and WO-2) are considered upgradient monitoring points, whereas the remaining boreholes located along the eastern airport perimeter are considered downgradient monitoring points (Figure 6).

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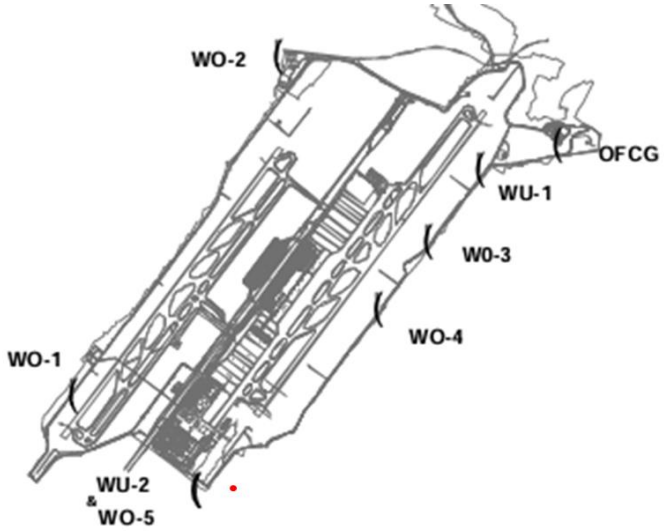


Figure 6: Ground water monitoring locations at AIA (Chilakos and Kavouras, 2004)

The demonstration site is near the WU-2 and WO-5 monitoring boreholes, allowing the available monitoring data to provide a representative indication of groundwater conditions within the immediate surrounding area of the THESEUS activities. Monitoring results indicated elevated concentrations of nitrates, sodium, calcium and magnesium in several monitoring boreholes, with exceedances of European groundwater quality criteria being recorded. However, these elevated concentrations had already been detected since 1998, prior to the construction and operation of the airport, suggesting that the observed groundwater degradation is not solely associated with airport activities.

The available hydrogeological investigations indicate that the observed groundwater quality degradation is associated both with the natural geological conditions of the area and with long-term anthropogenic pressures, mainly agricultural activities and leakage from septic systems. Importantly, no systematic exceedances associated specifically with airport-related contaminants were identified within the monitoring programme. Monitoring data from boreholes WU-2 and WO-5, located closest to the demonstration site, indicate elevated nitrate concentrations together with increased TDS, chloride and sodium concentrations, supporting the interpretation that diffuse agricultural pressures, historical wastewater disposal practices and regional hydrogeological conditions constitute the dominant groundwater quality pressures within the area (Chilakos and Kavouras, 2004).

Taken together, the available evidence suggests that groundwater quality within the wider Mesogeia region has already been significantly influenced by long-term anthropogenic pressures predating the implementation of the THESEUS demonstration activities. Consequently, the investigation of groundwater quality and hydrogeological conditions was considered necessary to establish the existing environmental baseline of the study area and support the interpretation of future monitoring results associated with reclaimed water reuse applications.

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3 Koropi–Paiania WWTP

3.1 Site Overview and Selection Rationale

The WWTP selected within the THESEUS project for effluent reuse applications is the EYDAP WWTP of Koropi-Paiania , located in Eastern Attica. The facility serves approximately 15.600 population equivalent and operates within the Attica river basin, contributing to the overall wastewater management strategy of the region. However, the capacity of the WWTP is significantly higher and it is expected to receive increased volumes of wastewater in the near future.

The strategic location of the WWTP of Koropi–Paiania, near one of the main agricultural zones of the Athens metropolitan area, constitutes a key selection criterion. This geographical advantage enhances the feasibility and relevance of reclaimed water use, particularly for irrigation purposes, and directly supports the objectives of the THESEUS project related to circular water management and resource efficiency.

Figure 7(Left) presents the distribution of WWTPs across the Athens metropolitan area, highlighting the selected Koropi–Paiania facility. Figure 7(right) illustrates the spatial relationship between the WWTP and the surrounding agricultural land, further demonstrating the suitability of the site for large-scale reclaimed water applications.

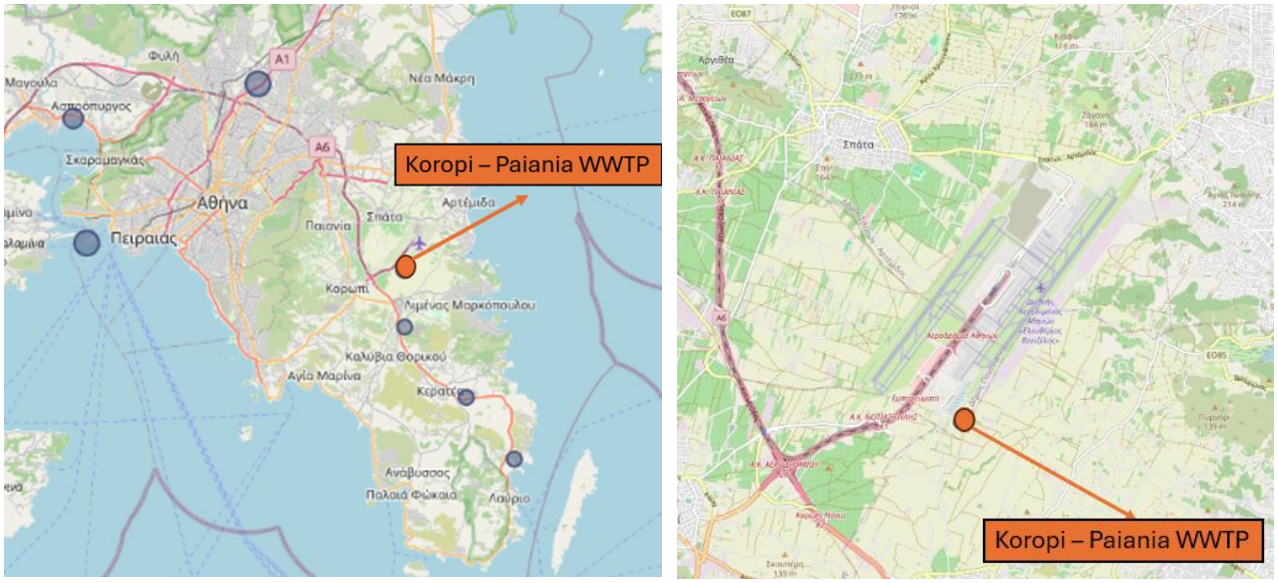


Figure 7: WWTPs in Athens highlighting the Koropi–Paiania WWTP (left), and its proximity to surrounding agricultural land in Mesogeia (right).

3.2 Technical Description of the WWTP of Koropi–Paiania

The WWTP of Koropi-Paiania–is a recently constructed facility serving a wide area of Eastern Attica, located within the Mesogeia plain. The plant operates under the responsibility of EYDAP, and forms part of the regional wastewater management strategy implemented under the ESIF 2014–2020 programme. The facility was completed in September 2023 and commenced operation in December 2023.

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The WWTP has been designed for a treatment capacity of approximately 99,500population equivalent(p.e.). The current operational flows correspond to the present state of sewer network connections within the service area, with an average inflow of around 2,800 m^3/d and peak flows reaching up to 6,400 m^3/d. The corresponding organic load is approximately 1,400 kg BOD_5/d on average, with higher values observed during peak operating conditions. The plant provides secondary treatment with nutrient removal (nitrogen and phosphorus), followed by tertiary treatment and final disinfection, ensuring compliance with the requirements of Directive 91/271/EEC for urban wastewater treatment.

The treatment process is structured in successive stages, including preliminary, primary, secondary, and tertiary treatment, followed by disinfection and sludge management processes, as illustrated in the overall plant layout (Figure 9). The layout highlights the spatial arrangement and interconnection of the main treatment units, supporting efficient process integration and operational flexibility.

The overall configuration of the facility is designed to ensure stable operation under varying hydraulic and organic loading conditions, while consistently meeting environmental discharge requirements. These technical characteristics support the reliable production of treated effluent suitable for reuse applications, in line with the objectives of the THESEUS project (Figure 8).

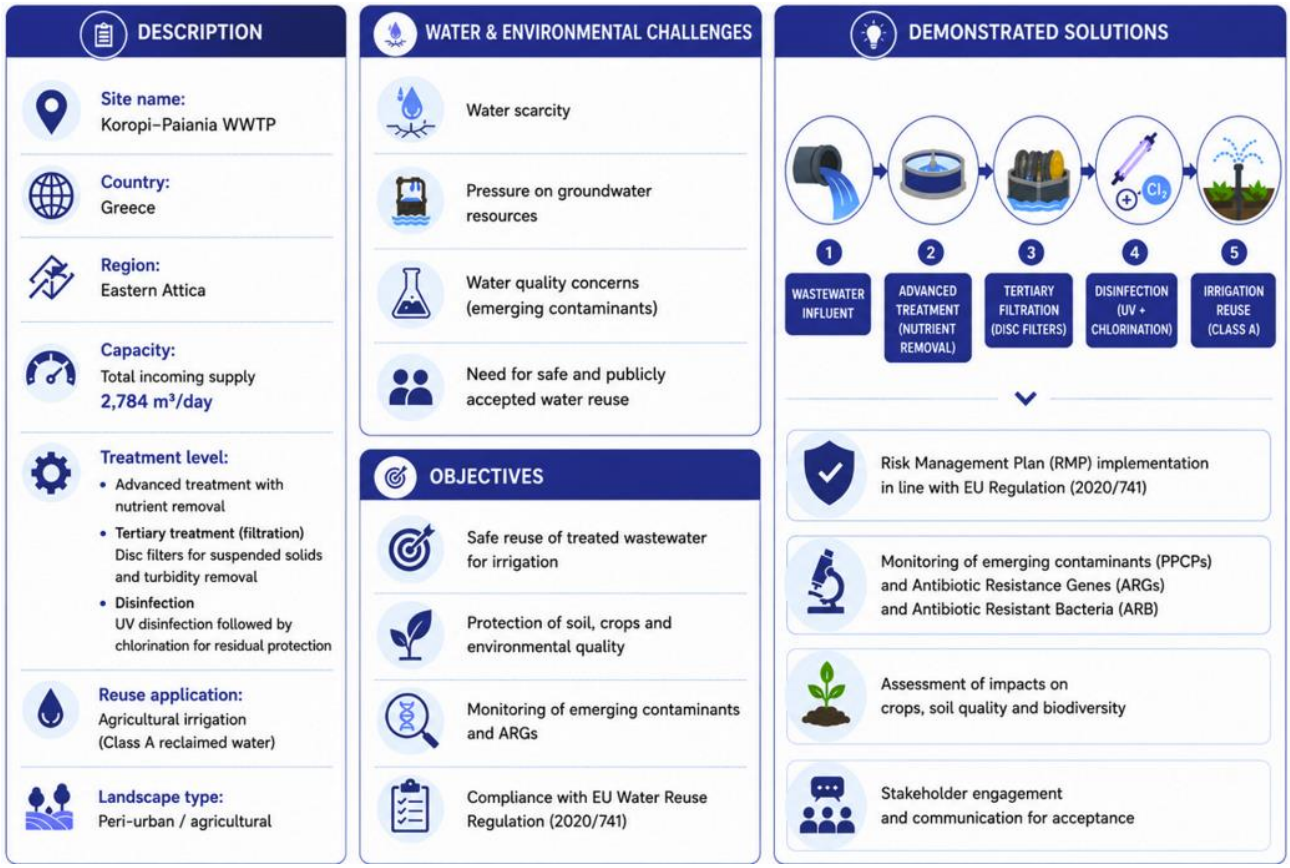


Figure 8: Overview of the EYDAP WWTP of Koropi–Paiania demonstration site within the THESEUS project, presenting the main site characteristics, water-related challenges, project objectives, and the demonstrated reclaimed water reuse solutions for agricultural irrigation.

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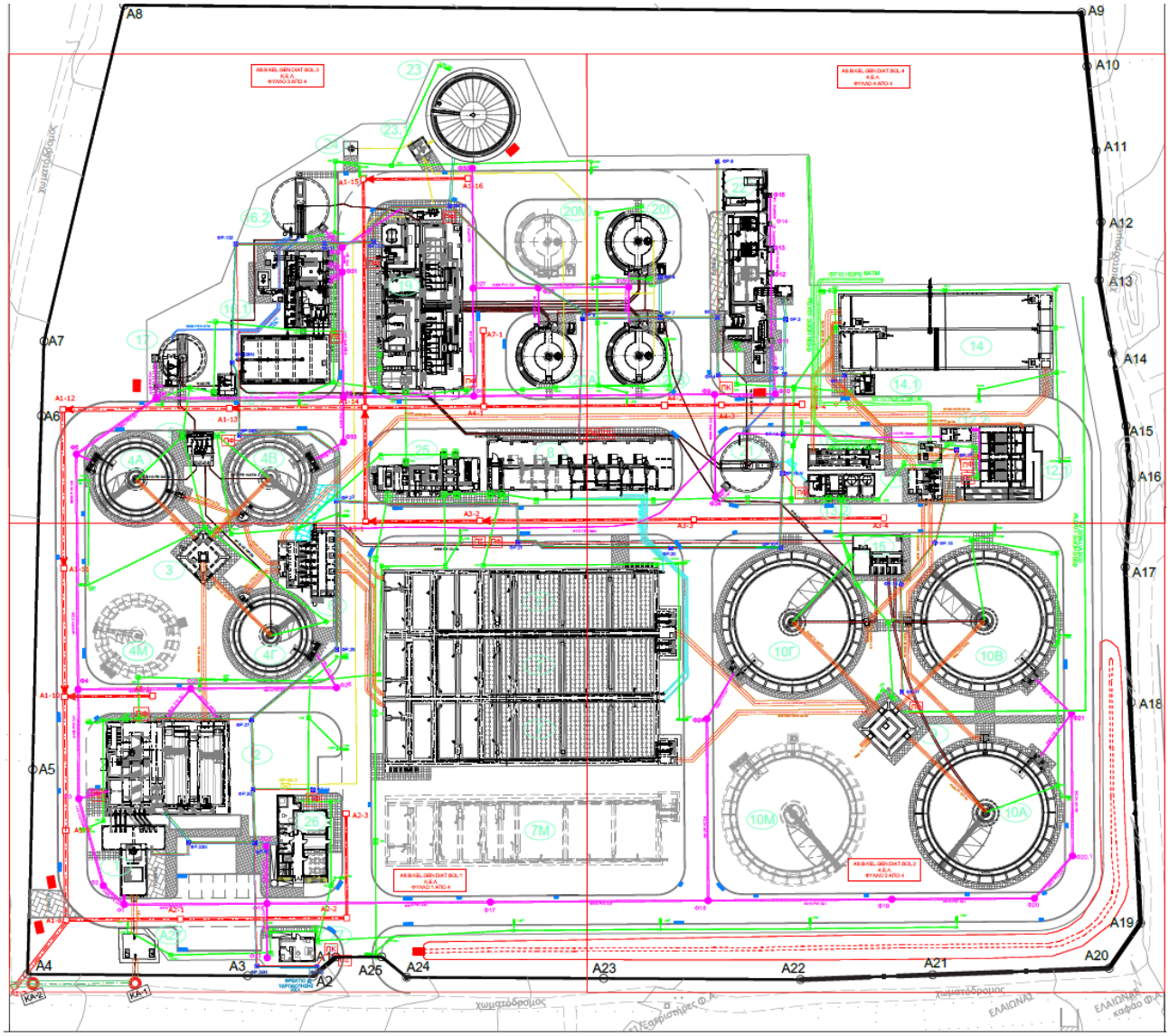


Figure 9: General layout of the WWTP of Koropi–Paiania, illustrating the arrangement of treatment units, pipelines, and supporting infrastructure.

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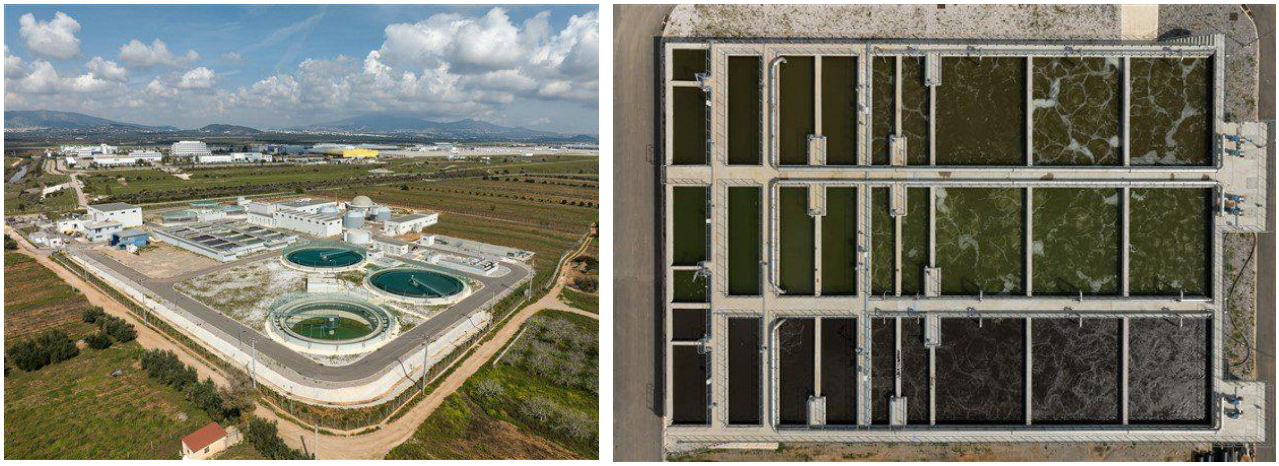


Figure 10: The WWTP of Koropi–Paiania in Eastern Attica: (left) panoramic view of the treatment facility; (right) top view of the biological treatment units, highlighting the aeration tanks and clarifiers

3.2.1 Preliminary Treatment and Influent Handling

Wastewater entering the facility is conveyed to the inlet chamber, where it is hydraulically regulated before being directed to the preliminary treatment units. At the initial stage, coarse screening is applied through parallel channels equipped with automated screens, designed to retain large solids and debris. The system allows for operational flexibility through parallel units that can be isolated during maintenance. Following screening, wastewater is conveyed to the initial pumping station, where it is lifted to the required elevation to enable gravity flow through the rest of the treatment plant. The pumping system consists of multiple units with redundancy, ensuring reliable operation under peak flow conditions.

3.2.2 Pre-treatment: Screening, Flow Measurement and Grit Removal

Downstream of the pumping station, the wastewater undergoes further pre-treatment, including fine screening, flow measurement, grit and grease removal. Flow measurement is performed using Venturi channels, enabling accurate monitoring of influent flow rates and supporting process control.

Grit and grease removal is achieved through aerated grit chambers, where controlled air injection creates appropriate hydraulic conditions for the separation of inorganic particles and floating materials. The system is designed to remove a high percentage of particles larger than 0.2 mm, ensuring protection of downstream equipment and processes. Collected grit is separated, washed, and removed, while fats, oils, and grease are collected in dedicated compartments and managed externally. All pre-treatment units are installed within enclosed structures equipped with odor control systems to minimize environmental impacts.

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3.2.3 Primary Clarification

3.2.3.1 Flow Distribution Chamber I

After preliminary treatment, the wastewater is conveyed to Flow Distribution Chamber I, which distributes the flow equally to the primary clarification tanks. In the current phase, the flow is distributed to three primary clarifiers, while provision has been made for a fourth tank in the future phase. The chamber ensures balanced hydraulic loading of the primary treatment line and allows the wastewater to be directed uniformly to each clarifier. This is important for maintaining stable settling conditions and avoiding uneven loading between the tanks.

3.2.3.2 Primary Clarification Tanks

The primary clarification stage consists of three circular settling tanks, with provision for a fourth identical tank in the future phase. The purpose of this stage is to remove settleable solids and floating materials from the wastewater before it enters the biological treatment stage.

Inside the tanks, the flow velocity is reduced, allowing heavier suspended solids to settle at the bottom as primary sludge. At the same time, floating materials such as grease and scum are retained and collected from the surface. The clarified wastewater is collected through peripheral overflow channels and then conveyed to the next treatment stage. The settled sludge is scraped towards the central collection zone and transferred to the primary sludge pumping station for further handling. According to the design assumptions, primary clarification contributes to the reduction of the incoming pollutant load, with estimated removals of approximately 25% for BOD_5, 55% for suspended solids, 10% for nitrogen, and 5% for phosphorus.

3.2.3.3 Primary Sludge Pumping Station

The sludge collected at the bottom of the primary clarifiers is transferred to the primary sludge pumping station. From there, it is conveyed to the primary sludge thickening unit.

This stage is important for separating and managing the solids removed during primary clarification. By removing primary sludge at this point, the organic and solids load entering the biological treatment stage is reduced, improving the overall efficiency and stability of the wastewater treatment process.

3.2.4 Intermediate Lifting Pumping Station and Flow Distribution Chamber II

3.2.4.1 Intermediate Lifting Pumping Station and Bypass Chamber

The effluent from the primary clarification tanks is collected and conveyed to the intermediate lifting pumping station. This unit raises the wastewater to the required hydraulic level, allowing the flow to continue by gravity through the following treatment stages. The system also includes a bypass arrangement, which

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allows the downstream units to be bypassed, when necessary, for example during operational interruptions or emergency conditions. This provides operational safety and protects the downstream treatment line.

3.2.4.2 Flow Distribution Chamber II

After intermediate lifting, the wastewater is directed to Flow Distribution Chamber II, located upstream of the biological treatment stage. Its main function is to distribute the flow equally to the biological treatment lines. At this point, the incoming wastewater is combined with return activated sludge and other internal flows, such as filter backwash water. The chamber promotes hydraulic balancing and proper mixing before the flow enters the biological treatment tanks. This ensures uniform loading of the biological treatment lines and supports stable operation of the activated sludge process.

3.2.5 Biological Treatment Tanks

3.2.5.1 General Description

The biological treatment stage is based on the activated sludge process with conventional aeration, combined with biological nitrogen and phosphorus removal. The system consists of three parallel treatment lines in the current phase, with provision for a fourth line in the future. Each line includes anaerobic, anoxic, facultative anoxic/aerobic, and aerobic compartments. This configuration allows the sequential removal of phosphorus, nitrogen, and organic matter. The process follows a plug-flow arrangement, which improves treatment efficiency and helps reduce problems such as sludge bulking and foaming. The biological treatment system is designed to respond to seasonal variations. Part of the treatment volume can operate either as anoxic or aerobic, depending on temperature and process requirements. This provides flexibility and helps reduce energy consumption.

3.2.5.2 Anaerobic Phosphorus Removal Tanks

The first stage of each biological treatment line is the anaerobic zone, where biological phosphorus removal takes place. In this section, the incoming wastewater is mixed with return activated sludge under anaerobic conditions. These conditions favor the activity of phosphorus-accumulating microorganisms, which support the subsequent uptake and removal of phosphorus from wastewater. The anaerobic zone also includes a selector compartment, which helps promote the growth of floc-forming microorganisms and limits the development of filamentous bacteria. This contributes to improved sludge settleability and reduces the risk of sludge bulking and foaming.

3.2.5.3 Anoxic Denitrification Tanks

After the anaerobic stage, the mixed liquor is transferred to the anoxic denitrification tanks. These compartments are designed for nitrogen removal under oxygen-limited conditions. In the anoxic zones, nitrates are converted into nitrogen gas through denitrification. This process is supported by the recirculation of mixed liquor from the aeration tanks back to the anoxic compartments, ensuring that nitrates are available

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for removal. The anoxic tanks are designed to maintain good mixing and plug-flow conditions, improving contact between biomass, organic matter, and nitrate.

3.2.5.4 Facultative Anoxic/Aerobic Tanks

The facultative tanks provide operational flexibility to the biological treatment process. These compartments can operate either as anoxic zones or as aerated zones, depending on the seasonal and operational needs of the plant. During colder periods, when denitrification may require longer reaction times, these tanks can be used as additional anoxic volume. During warmer periods, they can operate as additional aeration volume to support organic matter oxidation and nitrification. This flexible design allows the plant to adapt to changes in wastewater characteristics, temperature, and treatment requirements, while also improving energy efficiency.

3.2.5.5 Aeration Tanks

The aeration tanks are the main stage for organic matter removal and nitrification. In these compartments, oxygen is supplied to support the activity of aerobic microorganisms. The main biological processes taking place in the aeration tanks are the oxidation of organic matter, the conversion of ammonia to nitrate through nitrification, partial stabilization of biological sludge, and phosphorus uptake by the biomass. Fine-bubble aeration is used to ensure efficient oxygen transfer. Dissolved oxygen monitoring allows the aeration supply to be adjusted according to the actual oxygen demand of the process, helping to improve both treatment performance and energy efficiency.

3.2.5.6 Mixed Liquor Recirculation

Mixed liquor recirculation is an essential part of the biological nitrogen removal process. Mixed liquor from the outlet of the aeration tanks is returned to the anoxic zones, where the nitrate produced during nitrification can be removed through denitrification. This internal recirculation supports the overall nitrogen removal efficiency of the system and ensures the connection between the aerobic and anoxic stages of treatment.

3.2.5.7 Blower Building and Aeration Control

The blower system supplies the air required for the aeration tanks and the facultative compartments when they operate under aerobic conditions. The air is distributed through fine-bubble diffusers installed in the treatment tanks. Aeration is controlled according to dissolved oxygen measurements, allowing oxygen supply to match the actual needs of the biological process. This helps avoid both under-aeration and excessive aeration, contributing to stable treatment performance and reduced energy consumption.

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3.2.5.8 Secondary Clarification

Following biological treatment, the mixed liquor is conveyed to secondary clarifiers, where biomass is separated from the treated water. Part of the sludge is recirculated to the biological process, while excess sludge is removed for further treatment.

3.2.6 Tertiary Treatment

The tertiary treatment stage is applied after secondary clarification to further improve the effluent quality and enable the safe reuse of treated wastewater. The system has been designed to support both internal reuse applications within WWTP (e.g., tank washing and irrigation) and future controlled agricultural reuse schemes. Following secondary treatment, the effluent is conveyed to a diversion chamber, where continuous flow monitoring is performed using Venturi channels and ultrasonic flow measurement systems. Part of the flow is directed to the tertiary treatment unit, while excess flows bypass the system and are conveyed to the equalization tank.

The core tertiary treatment process consists of four parallel mechanical filtration units equipped with rotating drum filters. Wastewater passes through a fine filtration medium where suspended solids are retained. The filtration system operates automatically and includes an automatic backwashing system for cleaning the filter medium and maintaining stable operation. The filtration unit achieves significant suspended solids removal, producing an effluent with suspended solids concentrations below 10 mg/L. The filter medium has a pore size of 40 µm, ensuring efficient solids separation prior to disinfection.

After filtration, the treated effluent is directed to the UV disinfection unit for additional sanitary protection and improved reclaimed water quality. Backwash water from the filters is collected in a dedicated tank and recirculated to the biological treatment line, ensuring proper management of wash water and improving the overall operational efficiency of the plant.

3.2.7 Disinfection and Effluent Equalization

3.2.7.1 Ultraviolet (UV) Disinfection Unit

Following tertiary filtration, the treated effluent is directed to the UV disinfection unit. Disinfection is achieved through ultraviolet radiation generated by low-pressure, high-intensity mercury lamps installed in open channels parallel to the flow.

The UV system is designed to provide effective pathogen inactivation and ensure high microbiological effluent quality suitable for reuse applications. The installation includes two parallel channels equipped with multiple UV lamp banks operating under gravity flow conditions.

The system is designed to achieve microbial concentrations below the required reuse limits, while maintaining stable operation under varying hydraulic conditions. UV intensity and lamp operation are automatically adjusted according to the incoming flow, optimizing both performance and energy consumption.

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An automatic cleaning system is included in maintaining the efficiency of the quartz sleeves and ensure stable UV transmittance during operation.

3.2.7.2 Effluent Equalization and Post-Aeration

Both the secondary-treated effluent and the tertiary-treated effluent from the UV unit are conveyed to the equalization tank. The tank serves both as an effluent balancing facility and as the discharge chamber of the treatment plant. The equalization system consists of two separate compartments, allowing independent management of secondary and tertiary-treated effluents. Chlorination is applied within the inlet mixing chambers of the tanks to provide supplementary disinfection and residual protection. Post-aeration is also applied in the equalization tanks to maintain adequate dissolved oxygen concentrations in the final effluent. This improves the quality of the discharged water and prevents anaerobic conditions during conveyance and disposal. Aeration is automatically controlled through dissolved oxygen monitoring, allowing the system to operate according to the actual oxygen demand while minimizing energy consumption. In addition, part of the tertiary-treated effluent is retained for reuse as industrial water within the WWTP.

3.2.7.3 Effluent Chlorination

In addition to UV disinfection, the plant includes a chlorination system that provides supplementary or alternative disinfection when required.

Chlorination is applied to:

- provide residual disinfection in the final effluent,
- disinfect secondary effluent when UV treatment is bypassed or unavailable.

Sodium hypochlorite solution is used as the disinfecting agent. The chlorination system operates automatically, with dosing adjusted according to flow rate and residual chlorine measurements. The system ensures stable disinfection performance while maintaining the required residual chlorine concentration at the outlet of the equalization tanks.

3.2.8 Sludge Treatment and Management

Sludge generated during primary and secondary treatment undergoes thickening, mechanical processing, and dewatering. The plant includes gravity thickening and mechanical thickening units, followed by sludge dewatering systems. The produced sludge amounts to approximately 175 tons of dry solids per year, with a solids content of around 15–16%. The sludge is currently managed primarily through energy recovery processes.

3.2.9 Process Control and Environmental Protection

The WWTP of Koropi-Paiania is equipped with automated monitoring and control systems that ensure stable operation and continuous supervision of key parameters such as flow, levels, and process performance. Odor

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control is implemented through enclosed treatment units and dedicated deodorization systems based on air extraction and treatment using activated carbon filtration, achieving high removal efficiency of odorous compounds. The overall design of the plant ensures compliance with environmental regulations, operational safety, and adaptability to future extensions and reuse applications.

3.2.10 Monitoring Results and Evaluation of WWTP Performance

As part of the routine operation and control procedures of the WWTP, regular monitoring and analytical testing are carried out to evaluate both the influent wastewater characteristics and the quality of the treated effluent produced by the facility. The continuous monitoring of the plant constitutes an essential operational requirement, allowing the assessment of treatment efficiency, process stability, and compliance with the applicable environmental and water reuse regulations.

Within this framework, the present section presents and evaluates the monitoring results obtained from the WWTP during the examined operational period. The analysis includes the main physicochemical parameters monitored at both the influent and effluent of the biological treatment system. More specifically, the monitored parameters include Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Total Suspended Solids (TSS), Total Nitrogen (TN), Total Phosphorus (TP) associated with water quality assessment and reuse suitability.

The monitoring of influent wastewater characteristics is particularly important, as the composition and pollutant load of the incoming wastewater directly affect the operation and performance of the biological treatment process. Wastewater entering the treatment plant may present significant temporal fluctuations due to variations in water consumption patterns, seasonal effects, industrial activities, stormwater intrusion, or other operational conditions within the sewer network. Consequently, the systematic monitoring of the influent provides valuable information regarding the hydraulic and pollutant loads received by the facility and supports the efficient operation of the treatment system.

At the same time, the evaluation of the treated effluent quality is of major importance, especially in cases where the reclaimed water is intended for reuse applications. In the present study, particular emphasis is given to the assessment of the treated wastewater quality in relation to the requirements for unrestricted irrigation. The compliance of the reclaimed effluent with the applicable quality criteria and regulatory thresholds is considered essential to ensure the safe reuse of treated wastewater for agricultural purposes while protecting public health and the environment.

In addition, the monitoring and evaluation procedures are carried out in accordance with the requirements of Directive 91/271/EEC and the Greek Ministerial Decision KYA 5673/400/1997, which define the required effluent quality limits, the minimum annual number of samples depending on the treatment plant capacity expressed in population equivalent (p.e.), as well as the maximum allowable number of samples that may deviate from the established effluent quality requirements.

For this reason, the monitored parameters are evaluated not only in terms of treatment performance but also with respect to the suitability of the produced reclaimed water for reuse applications. Parameters such as BOD_5, COD, TSS, nutrient concentrations constitute key criteria for determining whether the treated effluent fulfills the required standards for unrestricted irrigation. The ability of the treatment plant to

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consistently achieve satisfactory effluent quality under varying influent loading conditions represents a critical aspect of the overall treatment process.

Figure 11 presents the temporal variation of the main physicochemical parameters monitored at the outlet of the biological WWTP.

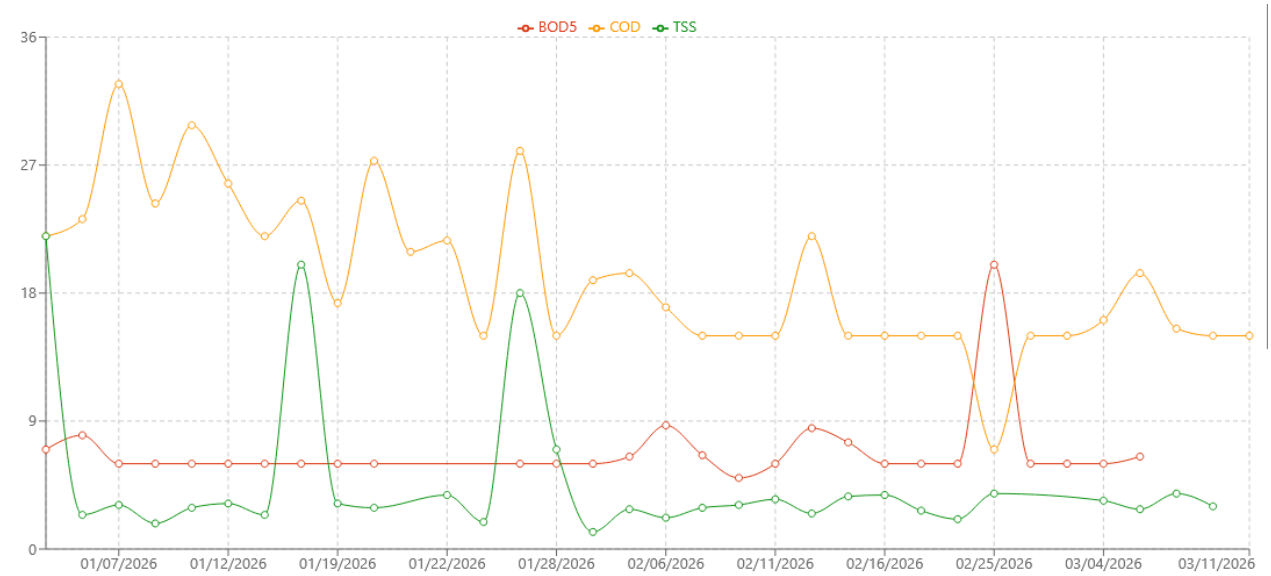


Figure 11: Variation of the main wastewater quality parameters in mg/L monitored at the effluent of the biological WWTP during the operational period (ΥΠΕΝ,2026)

As shown in the figure, the treated effluent generally exhibited relatively stable concentrations throughout the monitoring period, indicating satisfactory operation of the biological treatment system. In particular, TSS concentrations remained consistently low in most sampling events, demonstrating effective removal of suspended solids during treatment. Similarly, BOD_5 concentrations were maintained at comparatively low levels, reflecting satisfactory removal of biodegradable organic matter.

COD concentrations showed moderate fluctuations during the examined period but remained within a relatively stable range overall. Occasional increases observed in specific sampling events may be associated with temporary variations in influent loading or operational conditions within the treatment process. Nevertheless, the overall results indicate stable treatment performance and satisfactory pollutant removal efficiency.

The treated effluent exhibited consistently low concentrations of BOD_5 and suspended solids throughout the examined operational period, indicating satisfactory physicochemical quality and stable operation of the biological treatment system. The calculated mean BOD_5 concentration was approximately 8.1 mg/L, while the corresponding mean TSS concentration was approximately 3.1 mg/L, with both parameters remaining within the limits established for unrestricted irrigation reuse applications according to both the Greek reuse legislation (KYA 145116/2011) and the applicable European regulatory framework. In particular, these values are compatible with the physicochemical requirements associated with **Class A reclaimed water** under Regulation (EU) 2020/741, which corresponds to the highest reclaimed water quality category intended for unrestricted irrigation applications.

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In addition, COD concentrations remained relatively low and stable throughout the monitoring period, further confirming the satisfactory performance and efficiency of the treatment process. Although turbidity and microbiological parameters are not included within the currently available dataset, continuous monitoring and future analytical campaigns are expected to further support the comprehensive assessment of reclaimed water quality and verification of compliance with all applicable reuse requirements.

Overall, the monitored effluent quality demonstrates the ability of the WWTP to consistently produce treated wastewater of appropriate quality, supporting compliance with the applicable discharge and water reuse requirements for unrestricted irrigation applications.

4 Agricultural Field Selection and Preparation

The agricultural field selected for the reclaimed water irrigation demonstration is located within the boundaries of the EYDAP WWTP of Koropi–Paiania premises. The selected area covers approximately 2,000 m² and was chosen due to its proximity to the reclaimed water distribution infrastructure, controlled accessibility, and suitability for irrigation monitoring activities (Figure 12).



Figure 12: Location of the selected 2,000 m² agricultural field within the WWTP of Koropi–Paiania premises (left) and on-site view of the field prior to preparation and planting activities (right).

Before planting, several field preparation works were required to improve soil conditions and make the area suitable for cultivation. Initially, mechanical tillage and soil milling were performed to loosen and homogenize the upper soil layer (Figure 13). Large stones and coarse materials were subsequently removed to facilitate cultivation practices, irrigation installation, and plant growth.

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Figure 13: Field preparation works at the selected agricultural demonstration site, including stone removal, excavation and soil tilling operations

Fertilization was then applied to improve soil fertility, followed by additional soil cultivation works to incorporate the added materials into the soil profile and create a more uniform planting surface.

Further preparation activities included field leveling, removal of residual vegetation, delineation of planting zones, and preparation for the installation of the irrigation system and soil moisture monitoring equipment. These interventions were considered necessary for the proper establishment of the demonstration site and the long-term evaluation of reclaimed water irrigation practices.

4.1 Soil sampling and soil quality assessment

Soil sampling activities were carried out within the agricultural demonstration field to evaluate the suitability of the site for reclaimed water irrigation applications and to establish the baseline soil conditions prior to the implementation of the cultivation activities. As illustrated in Figure 14, the soil sampling points were distributed across the agricultural demonstration field to achieve representative spatial coverage of the study area. The selected locations covered different parts of the cultivation field and were used to evaluate the variability of soil characteristics within the demonstration site.

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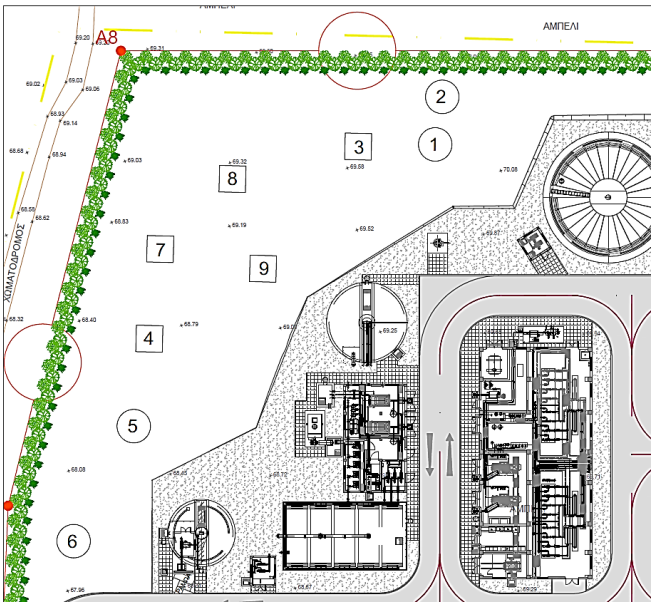


Figure 14: Spatial distribution of the soil sampling points within the agricultural demonstration field at the WWTP of Koropi–Paiania premises.

The soil monitoring campaign included multiple sampling periods between April 2025 and March 2026 and involved analyses of soil texture, physicochemical properties, nutrient availability and salinity-related parameters at different soil depths.

4.1.1 Initial soil assessment (April 2025)

The first soil sampling campaign was conducted in April 2025 at the upper soil layer (0–30 cm), representing the initial condition of the field before the implementation of the main cultivation and soil preparation activities.

The analysis classified the soil as clay loam, with approximately 38% sand, 29% silt and 33% clay, indicating a moderately heavy soil texture with relatively high-water retention capacity but potentially limited drainage and aeration conditions. The soil presented alkaline conditions (pH 7.84) and elevated calcium carbonate concentrations, while the organic matter content was relatively low (0.72%), indicating poor biological activity and limited natural fertility.

The nutrient analysis demonstrated low phosphorus availability together with reduced concentrations of several micronutrients, particularly iron and manganese, conditions commonly associated with alkaline soils rich in calcium carbonate. These characteristics were considered important constraints for crop establishment and nutrient uptake and therefore highlighted the need for fertilization and soil conditioning measures before planting activities.

In addition, the initial analysis indicated relatively low electrical conductivity values, suggesting the absence of significant salinity problems at the beginning of the demonstration activities. Overall, the first assessment confirmed that although the field was suitable for agricultural reuse applications, improvement measures would be required to enhance soil fertility and optimize cultivation conditions.

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The preliminary soil analyses also included the determination of selected heavy metals to establish the baseline environmental conditions of the demonstration field prior to the application of reclaimed water irrigation. Specifically, the concentrations of nickel (Ni), chromium (Cr), and lead (Pb) were measured and recorded as part of the initial soil characterization.

The measured concentrations were 16.1 mg/kg for nickel (Ni), 21.4 mg/kg for chromium (Cr), and 17.7 mg/kg for lead (Pb). According to the laboratory assessment, these values do not indicate excessive accumulation or contamination issues at the current stage and can therefore be considered representative baseline concentrations for the agricultural field before the initiation of reclaimed water irrigation practices.

The determination of these parameters is considered particularly important within the framework of the project, as it provides a reference point for future monitoring campaigns aiming to evaluate potential long-term accumulation trends associated with reclaimed water reuse applications. The baseline characterization of heavy metals will support the comparative assessment of soil quality throughout the operational period of the demonstration site and contribute to the overall environmental risk evaluation of reclaimed water irrigation practices.

4.1.2 Detailed soil profile assessment (August 2025)

A second and more detailed soil investigation campaign was performed in August 2025. Soil samples were collected from three different depths (0–30 cm, 30–60 cm and 60–90 cm) to evaluate the vertical variability of soil characteristics across the profile and to identify possible limitations affecting root development and irrigation management (Figure 16). Soil sampling activities were performed with the assistance of a mechanical excavator, allowing the excavation of soil pits and the collection of representative samples from different soil depths (Figure 15).



Figure 15: Soil excavation and sampling activities performed using mechanical excavation equipment within the selected agricultural field.

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Figure 16: Soil samples collected from different sampling points within the demonstration field.

The analysis confirmed that the soil across all depths is predominantly classified as clay loam to clayey loam, with relatively high clay content and moderate water retention capacity. The laboratory assessment characterized the soil as moderately heavy, indicating that although the soil can retain moisture efficiently, attention should be given to drainage conditions and irrigation management practices.

The pH values remained slightly alkaline throughout the entire soil profile (approximately 7.4–7.5), while high concentrations of calcium carbonate ($CaCO_3$) were identified in all sampling depths, confirming the highly calcareous nature of the field. According to the laboratory evaluation, these conditions may reduce the availability of phosphorus and micronutrients, particularly iron and zinc, potentially leading to nutrient deficiencies in sensitive crops.

Electrical conductivity values remained relatively low to moderate throughout the profile, indicating the absence of severe salinity issues at the current stage of the project. However, sodium concentrations and exchangeable sodium percentage (ESP) values were monitored carefully due to their importance in reclaimed water irrigation applications and their potential influence on soil permeability and structure over time.

The nutrient analyses revealed generally low organic matter concentrations and limited nitrogen and phosphorus availability across the examined depths, indicating relatively poor natural fertility and reduced microbial activity. Several micronutrients, including iron, zinc, manganese, boron, and copper, were also evaluated as low or marginal in specific soil layers. For this reason, the laboratory which conducted the soil analyses proposed corrective fertilization measures, including phosphorus supplementation, magnesium amendments, micronutrient additions, and the incorporation of organic matter prior to cultivation activities.

The evaluation of nutrient ratios and cation exchange characteristics further highlighted imbalances associated mainly with magnesium, potassium, phosphorus, and boron availability. In deeper soil layers, elevated Ca/Mg and K/Mg ratios were identified, suggesting potential limitations in magnesium availability and possible impacts on nutrient uptake efficiency.

Particular emphasis was also given to the determination of selected heavy metals, including nickel (Ni), chromium (Cr), and lead (Pb), in all examined soil depths in order to establish a detailed baseline environmental profile before the application of reclaimed water irrigation. In the upper soil layer (0–30 cm), concentrations of 10.2 mg/kg for Ni, 17.3 mg/kg for Cr, and 14.1 mg/kg for Pb were recorded. At the intermediate depth (30–60 cm), concentrations reached 15.4 mg/kg for Ni, 18.2 mg/kg for Cr, and 17.2 mg/kg

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for Pb, while at the deeper layer (60–90 cm), concentrations of 15.7 mg/kg for Ni, 19.6 mg/kg for Cr, and 17.2 mg/kg for Pb were measured.

The measured heavy metal concentrations did not indicate evidence of significant contamination at the time of sampling and therefore provided an important baseline dataset for future monitoring activities.

4.1.3 Follow-up assessment after field preparation and fertilization (March 2026)

A follow-up soil analysis campaign was conducted in March 2026 after the implementation of the main field preparation activities, including repeated tillage operations, fertilization and soil incorporation works. The analysis focused again on the upper soil layer (0–30 cm), which represents the most active cultivation zone and the layer directly affected by irrigation and agricultural management practices.



Figure 17: soil samples from the agricultural field during March 2026 sampling campaign

The analysis confirmed that the soil maintained a clay loam texture, with approximately 38.9% sand, 28.9% silt, and 32.2% clay, indicating relatively stable structural characteristics compared to the previous sampling campaigns. The soil was again classified as moderately heavy, with relatively high-water retention capacity and potential drainage limitations under intensive irrigation conditions.

The physicochemical characterization showed that the soil remained alkaline (pH 8.04) and highly calcareous, with elevated calcium carbonate concentrations. According to the laboratory assessment, these conditions may continue to reduce the availability of phosphorus and several micronutrients, particularly iron and zinc, potentially affecting nutrient uptake efficiency during crop development.

Electrical conductivity values remained low, indicating that no salinity-related impacts were observed at this stage. Since reclaimed water irrigation had not yet started, the results mainly reflect the natural soil characteristics together with the influence of the field preparation and fertilization practices applied before plantation activities.

Compared to previous analyses, increased potassium concentrations were observed, most likely associated with the fertilization and soil amendment activities performed during field preparation. At the same time, nitrogen and phosphorus availability remained relatively low, while micronutrients such as zinc, iron, boron, and copper continued to present low or marginal concentrations according to the laboratory evaluation.

The laboratory recommendations emphasized the need for continued nutrient management and organic matter incorporation to improve soil fertility and microbial activity. Additional recommendations included

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phosphorus supplementation, micronutrient additions, and the application of acidic nitrogen fertilizers to partially mitigate the effects of the alkaline soil conditions.

The analysis also included the determination of selected heavy metals, specifically nickel (Ni), chromium (Cr), and lead (Pb), in order to further enrich the baseline environmental characterization of the site prior to reclaimed water application. The measured concentrations were 9.7 mg/kg for Ni, 16.4 mg/kg for Cr, and 13.8 mg/kg for Pb. Since irrigation with reclaimed water is at preliminary stage, these values represent pre-operational background concentrations following field preparation activities and can therefore be used as reference values for future monitoring campaigns during the operational phase of the demonstration.

4.1.4 Comparative assessment of soil quality evolution

To evaluate the evolution of soil properties throughout the monitoring period, the main physicochemical parameters obtained during the different sampling campaigns were comparatively assessed. Table 1, presents the evolution of the main physicochemical and agronomic soil parameters during the different monitoring campaigns carried out before the initiation of reclaimed water irrigation. The results indicate that the field preparation activities, including tillage operations and fertilisation practices, influenced several soil quality indicators, particularly within the upper cultivation layer (0–30 cm).

The most notable variation was observed in potassium concentrations, which increased substantially during the March 2026 campaign, most likely due to the fertilisation and soil amendment activities applied prior to plantation. In parallel, sodium concentrations and electrical conductivity values decreased compared to the August 2025 monitoring campaign, indicating improved soil conditioning and reduced soluble salt concentrations following the field preparation works.

Throughout all monitoring campaigns, the soil maintained a clay loam texture and generally alkaline conditions, while elevated calcium carbonate concentrations confirmed the calcareous nature of the field. Organic matter content remained consistently low across all sampling periods, indicating limited natural fertility and reduced microbial activity. In addition, phosphorus concentrations and the availability of several micronutrients, particularly iron and zinc, remained relatively low according to the laboratory evaluations, mainly due to the alkaline soil conditions.

Heavy metal analyses, including nickel (Ni), chromium (Cr), and lead (Pb), were also performed during all monitoring campaigns to establish baseline environmental conditions prior to reclaimed water application. The measured concentrations remained within similar ranges throughout the monitoring period and did not indicate evidence of heavy metal accumulation or contamination at this pre-operational stage.

Overall, the monitoring results provide an important baseline characterization of the demonstration field before the initiation of reclaimed water irrigation and establish a reference dataset for the future evaluation of long-term soil evolution, nutrient dynamics, and potential environmental impacts during the operational phase of the project.

Table 1: Summary of key soil quality parameters during the monitoring campaigns

Parameter	April 2025 (0–30 cm)	August 2025 (0–30 cm)	August 2025 (30–60 cm)	August 2025 (60–90 cm)	March 2026 (0–30 cm)

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Soil texture	Clay loam	Clay loam	Clay loam	Clay loam	Clay loam
pH	7.84	7.44	7.45	7.48	8.04
Electrical conductivity (µS/cm)	493	493	853	924	249
Organic matter (%)	0.72	0.46	0.76	0.83	0.49
Phosphorus (mg/kg)	3.10	1.96	4.21	3.69	2.66
Potassium (mg/kg)	215.12	113.82	151.26	198.58	682.11
Sodium (mg/kg)	266.73	377.95	356.37	350.85	110.65
Calcium carbonate (%)	33.26	25.92	31.87	33.76	29.97
CEC (cmolc/kg)	24.17	26.99	21.73	22.63	24.37
Ni (mg/kg)	16.1	10.2	15.4	15.7	9.7
Cr (mg/kg)	21.4	17.3	18.2	19.6	16.4
Pb (mg/kg)	17.7	14.1	17.2	17.2	13.8
Organic matter evaluation	Low	Low	Low	Low	Low

4.1.5 Field layout and irrigation design

Regarding the planting design, the field was divided into two separate sections, separated by a trench as shown in Figure 18 to prevent cross-interference between the irrigation applications. One section is irrigated using reclaimed water, while the second section is irrigated with potable water from the water supply network and serves as a control area. This experimental layout was selected in order to evaluate both crop

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growth performance and the potential accumulation and behaviour of micropollutants under the two irrigation conditions.

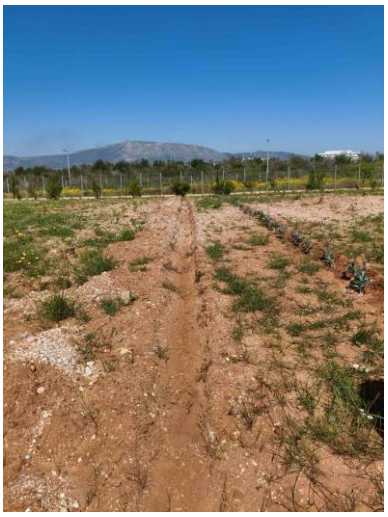


Figure 18: Trench constructed within the field to separate the two irrigation applications.

The planting strategy was designed to include both perennial and annual crops to evaluate the effects of irrigation with reclaimed wastewater under different cultivation conditions. This approach allows the assessment of both long-term exposure scenarios, associated with perennial crops that remain in continuous contact with the irrigated soil for several years, and shorter-term but more direct exposure scenarios related to annual crops. At the same time, the selected setup enables the investigation of potential accumulation effects in the soil over time.

The selection of the perennial crops was based on the agricultural characteristics of the surrounding area, aiming to include representative cultivations commonly found in the Mesogeia region of Eastern Attica. For this reason, olive trees and grapevines were selected, as they constitute dominant and economically important crops in the area. Cabbages were selected as annual crops based on the preliminary soil analyses, which indicated that the specific soil conditions of the demonstration field were suitable for their cultivation and expected growth performance. In addition, Sambucus plants (elderberries) were included due to their relatively high-water demand, allowing a more targeted evaluation of the potential accumulation of contaminants and the overall impact of reclaimed water irrigation under increased water uptake conditions.

Following the crop selection process, the overall planting layout was designed using AutoCAD to accurately calculate the required number of plants and materials to be procured, as well as to optimize the spatial arrangement of the different cultivation zones within the field. The design also supported the proper allocation of the irrigation sections and planting areas according to the objectives of the demonstration. The final layout of the field is presented in Figure 19.

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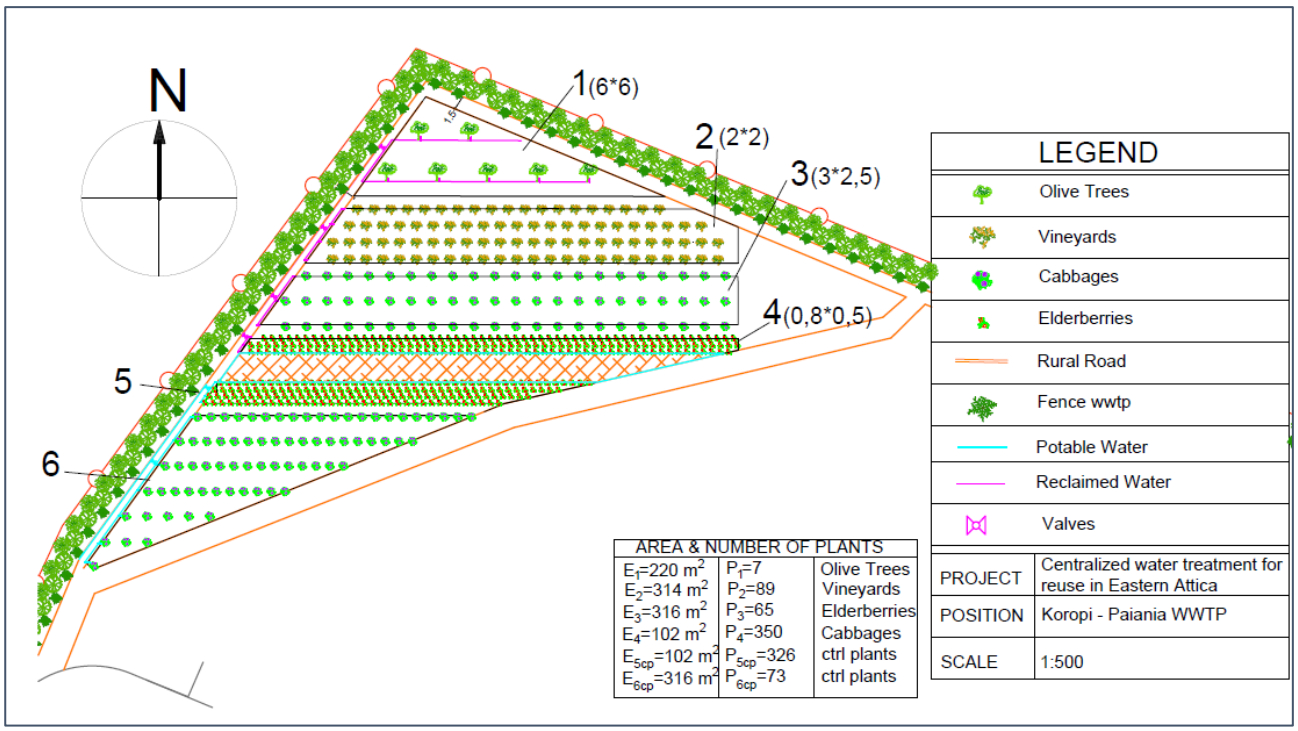


Figure 19: Layout and planting design of the demonstration field at the WWTP of Koropi–Paiania including the distribution of permanent and annual crops, irrigation networks designed for reclaimed and potable water supply, reference plots, and the overall spatial organization of the experimental area.

Automated irrigation system

Based on the technical specifications and procurement documents, five smart irrigation automation systems were procured for the needs of the demonstration field and were installed as part of the irrigation infrastructure supporting the reclaimed water irrigation activities. The selected system integrates soil monitoring sensors, electrovalves, and remote-control capabilities through the ardeusi.gr digital platform, aiming to support precision irrigation management and continuous monitoring of soil conditions during the implementation of the field-scale experiments (Figure 20).

Each irrigation unit is based on an autonomous field node capable of collecting, transmitting, and processing real-time environmental and operational data. The nodes are compact in size (11.5 × 9 × 5.5 cm), allowing flexible installation under field conditions, while their IP67-certified enclosure ensures protection against water and dust ingress, making them suitable for outdoor agricultural applications. In addition, the systems are designed to operate in an autonomous energy manner through the integration of photovoltaic panels and rechargeable batteries, eliminating the need for permanent external power supply infrastructure. The equipment also supports charging through USB or power bank systems when required.

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Figure 20: Field Node (left) and the ardeusi.gr digital platform (right) used for real-time monitoring, automated irrigation control, and visualization of soil and environmental parameters.

The planned irrigation infrastructure will support remote irrigation management through integrated electro valves and automated control functions. More specifically, irrigation will be able to be activated or interrupted remotely through the digital platform, while the system additionally supports predefined scheduling, time-based irrigation programs, and rule-based automation scenarios. This functionality is expected to allow irrigation practices to be dynamically adjusted according to field conditions and crop requirements, improving operational flexibility and irrigation efficiency during experimental activities.

Communication between the field units and the digital platform is achieved through integrated SIM-card connectivity supporting multiple communication protocols (2G/4G/GPRS/EDGE/NB-IoT), allowing continuous operation and data transmission under field conditions. The systems additionally incorporate GPS functionality for automatic positioning and equipment traceability, while anti-theft functions support remote deactivation and location tracking in case of unauthorized movement.

The soil monitoring sensors integrated into the irrigation systems are designed to continuously monitor key soil parameters including soil moisture, soil temperature, and electrical conductivity (EC). Soil moisture measurements are particularly important for determining irrigation demand and optimizing irrigation timing and duration, while soil temperature monitoring supports the assessment of crop and soil conditions throughout the experimental period. Electrical conductivity measurements will additionally provide useful information regarding soil salinity trends and possible accumulation effects associated with reclaimed water irrigation practices.

The selected 1” electro valves operate under pressures up to 15 bar and support flow rates up to 9 m^3/h, enabling stable operation of the irrigation network under the anticipated field conditions. The integration of electro valves with the digital control platform will allow both automated and user-controlled irrigation management depending on the operational requirements of the demonstration activities.

The ardeusi.gr management platform will constitute the central operational interface of the irrigation infrastructure. Through the platform, users will be able to remotely monitor all connected systems, visualize real-time and historical measurements, manage irrigation schedules, define operational rules and moisture thresholds, and generate automated alerts and notifications. The platform additionally supports five-day

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weather forecasting, estimation of irrigation duration and irrigation dose, export of monitoring data in Excel and CSV formats, and management of multiple systems and users simultaneously. Historical data storage and visualization functionalities are also expected to support the long-term assessment of irrigation performance and soil response during the experimental activities.

An important advantage of the selected infrastructure is its interoperability and scalability. The platform supports communication with external systems and digital infrastructures through API connectivity based on OpenAPI specifications as well as MQTT communication protocols. This allows future integration with additional environmental monitoring systems, digital platforms, or decision-support tools, supporting the broader objectives of smart and data-driven water management within the demonstration activities.

Overall, the planned implementation of the smart irrigation system is expected to significantly support the operation and monitoring of the reclaimed water irrigation demonstration field. The combination of real-time monitoring, automated irrigation control, remote accessibility, and continuous data collection is expected to contribute to more efficient water management, reduce unnecessary water consumption, improved operational control, and enhanced monitoring of soil and crop response throughout the experimental period.

The irrigation system was ordered and delivered to the demonstration site and has just been installed with the aid of the supplying company. The following figure present photographs taken during the delivery and receipt of the equipment.



Figure 21: Delivered irrigation system equipment, including the solar power unit (left), Agreus Field Nodes, sensor cables, and associated accessories (right), prior to installation at the demonstration site.

4.1.6 Initiation of Planting Activities

Planting activities were initiated in February 2026 at the demonstration field. More specifically, a total of 9 olive trees, 95 grapevines, 60 sambucus plants, and 60 cabbages were planted as part of the cultivation scheme designed for the project.

Prior to planting, a mechanical auger was used to prepare the planting holes in the soil. The planting process was then carried out manually, with the addition of a small amount of fertilizer to support the initial establishment and growth of the crops. The overall planting activities were completed over a two-day period (Figure 22).

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Figure 22: Representative photographs from the planting activities carried out at the demonstration field

In addition, 60 Sambucus reference plants irrigated with potable network water were also planted in order to allow comparative evaluation between reclaimed water and conventional irrigation practices. Due to seasonal and time limitations, the remaining reference plants could not be planted during the current cultivation period. However, their installation and cultivation are planned for the following planting season, where they will also be irrigated using potable network water.

Figure 23, Figure 24 & Figure 25 present representative photographs from the planting process at the demonstration site.



Figure 23: Representative photographs from the olive tree planting activities at the demonstration field.

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Figure 24: Representative photographs from the grapevine planting activities at the demonstration field, including the placement of the grapevine cuttings and the development of new shoots approximately two months after planting (right).



Figure 25: Representative photographs of the cabbage cultivation at the demonstration field.

5 Conclusions

The present version of D7.8 established the initial technical and environmental framework for the implementation of the reclaimed water fertigation demonstration within the THESEUS project. The work focused on the preliminary stage of the study, including the characterization of the wider study area, the documentation of EYDAP WWTP of Koropi–Paiania and reclaimed water quality, the selection and preparation of the agricultural field, and the establishment of baseline environmental conditions prior to irrigation.

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The soil characterization campaigns indicated that the demonstration field is characterized by alkaline and calcareous soil conditions, relatively low organic matter content, and limited availability of specific nutrients and micronutrients. In addition, the monitoring activities established baseline concentrations for selected heavy metals and key physicochemical parameters, providing an important reference point for future evaluation of reclaimed water irrigation impacts.

Field preparation activities, including tillage operations, fertilization, irrigation layout design, and planting initiation, enabled the establishment of the experimental cultivation scheme that will support the future comparative assessment between reclaimed water and potable water irrigation under real field conditions.

Overall, D7.8 Version 1 provides the baseline information and monitoring framework required for the irrigation activities and the future assessment of crop performance, micropollutant behavior, and potential environmental impacts associated with reclaimed water fertigation practices in Eastern Attica.

6 Next Steps

The next phase of the THESEUS demonstration activities will focus on systematicirrigation using Class A reclaimed water and the full operation of the experimental cultivation scheme within the demonstration field at EYDAP WWTP of Koropi-Paiania.–Following the establishment of the baseline environmental conditions presented in the current version of D7.8, the subsequent activities will evaluate the development and performance of crops irrigated with reclaimed water in comparison with the control plots irrigated with potable water.

Emphasis will be given to the investigation of the potential accumulation and behaviour of micropollutants within the water–soil–crop system, as well as to the assessment of possible impacts on soil quality and crop growth throughout the cultivation period. The monitoring activities to be performed during the operational phase of the demonstration will additionally support the progressive development and refinement of the Risk Management Plan (RMP) under real field conditions.

Overall, the next stages of the project are expected to provide important information regarding the environmental performance, feasibility, and safe implementation of reclaimed water fertigation practices within large-scale agricultural applications in Eastern Attica.

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