HYDROUSA

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Water in the context of circular economy

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Pilot Assessment Report

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Brief Description	This deliverable constitutes a comprehensive report detailing the two-year operational performance of all demonstration systems. The report provides insights into the operating conditions of the systems, their performance in terms of pollutant removal, and an assessment of the quantities of recovered water from various non-conventional sources. Additionally, it outlines the water quality achieved and the resulting crop yields. Moreover, the report addresses any operational challenges encountered, detailing the issues faced and the corresponding resolutions implemented. This comprehensive overview aims to offer a thorough understanding of the entire operational landscape and outcomes of the demonstration systems over the two-year period.

Keywords	Water recovery, wastewater treatment, nature-based solutions, non-conventional water sources

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EXECUTIVE SUMMARY

HYDROUSA project aims to setup, demonstrate and optimise on-site, innovative nature-based solutions (NBS) for the management of alternative non-conventional water streams, including wastewater, rainwater, groundwater, atmospheric vapour water and seawater to produce valuable resources, which can then be treated to enrich the domestic water supply and valorised to increase agricultural production and boost the economic activities of water-scarce Mediterranean areas. Towards this objective six demonstration sites (HYDROs 1-6) at full scale have been developed and optimized in three Mediterranean islands (Lesvos, Mykonos and Tinos). The present deliverable (D5.1) presents the main results of the 2-year and even more operation of all demonstration systems of HYDROUSA (HYDROs). An extended monitoring strategy has been set and implemented for each HYDRO based on the integration of modern and low-cost smart automation systems and lab scale measurements.

HYDROs 1&2 have been implemented in Antissa, at Lesvos Island. HYDRO1 is a novel wastewater treatment system appropriate for decentralized areas with high seasonal loads, consisting of anaerobic treatment in the form of upflow anaerobic sludge blanked (UASB) reactors followed by a system of vertical flow constructed wetlands (CW) in series and UV disinfection. The biogas produced in the anaerobic stage, after collection is being upgraded to pure methane ready to fuel vehicles, while the excess sludge after appropriate treatment through drying and composting is being converted to compost. Monitoring results provided adequate evidence for the production of a high-quality reclaimed water being classified as Class A with a low carbon footprint. In total more than 34,400 m^3 of raw wastewater have been treated in HYDRO1 and more than 32,600 m^3 of reclaimed water and more than a ton of compost (1,250 kg) have been produced. Accordingly, four prototype novel pilot scale CWs with a treatment capacity of up to 1 m^3/d were set up and optimized, thus highlighting the potential of future applications of low footprint constructed wetlands systems.

HYDRO2 is a 1 ha agroforestry system consisting of a wide diversity of trees, shrubs, aromatic plants and annual crops. The main field of HYDRO2 has an area of about 0.8 ha and includes more than 60 different plant species, while the second field includes a seasonal plantation of maize/barley accompanied with some aromatic plants and trees. On an annual basis, more than 6,500 m^3 of reclaimed nutrient-rich water produced in HYDRO1 were used to fertigate both fields. In total more than 14.5 tons of crops were harvested and donated to local farmers and families in Antissa village during the 2 years of operation.

HYDRO3 is located in Ano Mera, Mykonos Island and is an innovative, nature-inspired rainwater harvesting system consisting of a shallow, sub-surface rainwater collector and two cylindrical light structure storage tanks. The harvested water is utilized for irrigating 0.4 ha of oregano. HYDRO3 has consistently operated for four consecutive years, collecting annually 60 m^3 of rainwater (at an average recovery rate of more than 80%), which were used to irrigate the oregano plot and producing 825 kg of oregano/year/ha. To supplement water production, two vapour recovery system were installed, producing more than 28m^3/year of condensed water vapour. Monitoring results provide enough evidence on the high-quality characteristics of both water streams (the rainwater collected and the water produced by the two dehumidifiers) fully satisfying the needs for irrigation use and for drinking water quality respectively.

In HYDRO4 an existing rainwater harvesting system of domestic residences located in a village of Mykonos Island has been upgraded for several purposes: i) to store water to be reused for domestic non-potable purposes in the local residences (e.g., washing, flushing toilets, etc.), ii) to reclaim potable water after slow sand filtration and iii) to recharge water into the aquifer, mitigating the long-encountered problem of saline water intrusion. In HYDRO4, more than 270 m^3 of rainwater and surface runoff have been recovered for domestic use and aquifer recharge on an annual basis, while more than 500 m^3 of water has been stored into the aquifer. The water stored into the aquifer has been used to irrigate the nearby land of 0.2 ha of lavender.

Based on the continuous monitoring plan, the collected water presents very satisfactory quality characteristics fully complying with the needs for the irrigation of the lavender plot.

In HYDRO5 seawater and brine from the desalination plant in Tinos Island are treated through a low-cost seawater desalination system (Mangrove Still System) and channelled into a greenhouse to produce clean water via evaporation and condensation, edible salt and tropical fruits. After more than two years of operation, it is well evidenced that the produced water (more than 200 L/d) is appropriate for the delivery of high value tropical fruits and *Aloe* (more than 500 kg have been produced) by precision agriculture techniques utilizing effectively smart low-cost online probes and tools.

In HYDRO6 water loops are integrated within a remote eco-tourist facility in Tinos Island. This includes the treatment of wastewater using reed beds and rainwater harvesting and the production of drinking water quality from vapour water using condensation systems. The facility is remotely located off the grid and thus all activities are powered using renewable energy. After more than three years of continuous operation, around 180m^3 of rainwater has been harvested and 73 m^3 of reclaimed water has been produced on an annual basis. Reclaimed water was used to irrigate several local crops with a total production to the order of 1100 kg.

ABBREVIATIONS

AEW	Aerated Wetland
AnR	Anaerobic Reactor
AR	Artificial Recharge
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CW	Constructed Wetland
DO	Dissolved Oxygen
EC	Escherichia Coli
E.C.	Electrical Conductivity
ELT	Tinos Ecolodge
FW	Fresh Water
GHG	Greenhouse gases
GLS	Gas-Liquid-Solid
HRT	Hydraulic Retention Time
IR	Irrigation water
KPI	Key Performance Indicators
MuFu	MultiFunctional Roof
MSS	Mangrove Still System
NBS	Nature Based solutions
NLR	Nitrogen Loading Rate
OLR	Organic Loading Rate
ORP	Oxidation reduction potentia
PGH	Productive GreenHouse
PLC	Programmable logic controller
SCADA	Supervisory control and data acquisition
SDB	Sludge dry bed
SDRB	Sludge drying reed bed
SOC	State of Charge
SLR	Sludge Retention Time
SSF	Slow Sand Filter
SW	Sea Water
TC	Total Coliforms
TECU	Thermoelectric cooling unit
TN	Total Nitrogen
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Blanket
UV	Ultraviolet
VF SAT	Vertical Flow Saturated constructed wetland
VF UNSAT	Vertical Flow Unsaturated constructed wetland
VSSF CW	Vertical Subsurface Flow Constructed Wetland
VSS	Volatile Suspended Solids
WEFE	Water Energy Food Ecosystems 2
WF	Water Flower

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1. INTRODUCTION

Deliverable 5.1 (D5.1) was implemented within the activities of WP5 and more specifically of Task 5.1. D5.1 is a report presenting the main results of the 2-year and even more operation of all demonstration systems of HYDROUSA.

HYDROUSA project aims to setup, demonstrate and optimise on-site, innovative nature-based solutions (NBS) for the management of different water streams, including wastewater, rainwater, groundwater, atmospheric vapour water and seawater to produce valuable resources, which can then be treated to enrich the domestic water supply and valorised to increase agricultural production and boost the economic activities of water-scarce Mediterranean areas.

The HYDROUSA concept has been materialised by implementing six demonstration sites (HYDROs 1-6) at full scale in three Greek islands (Lesvos, Mykonos and Tinos). This concept is summarised in Figure 1.1.

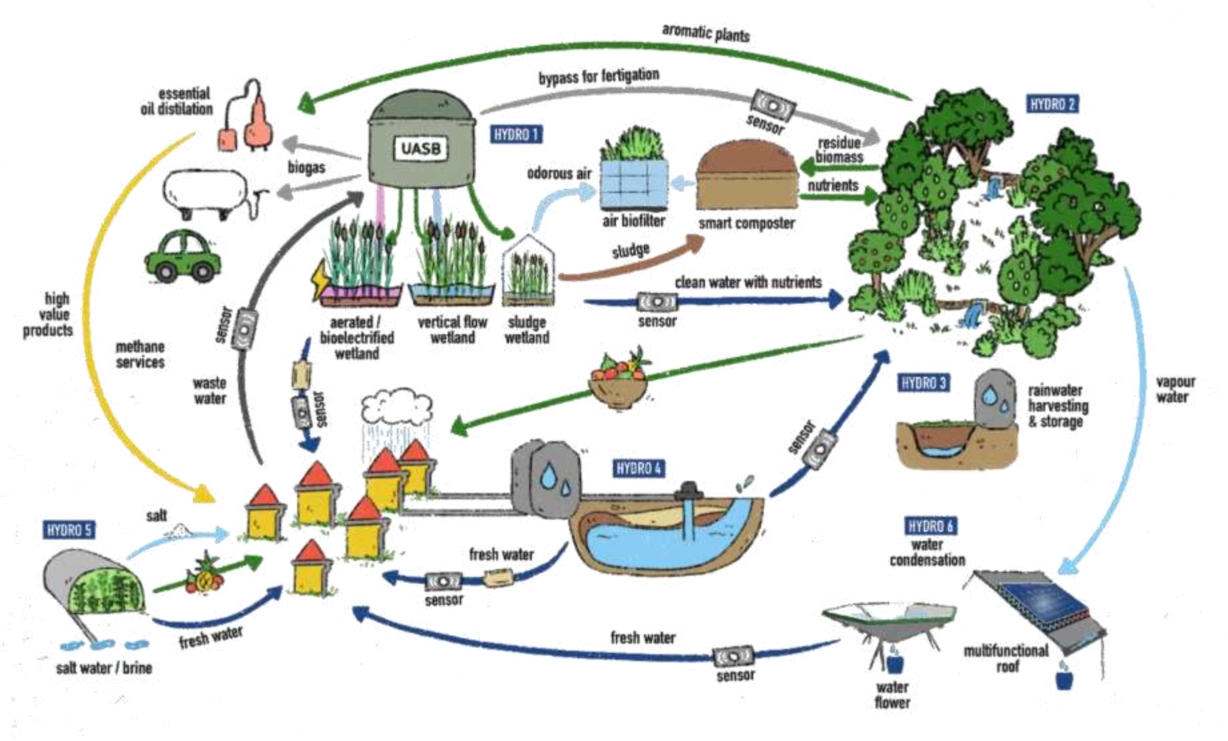

Figure 1.1. Overview of the water cycles developed at the six demo cases in HYDROUSA

HYDRO1 is a novel wastewater treatment system appropriate for decentralized areas with high seasonal loads, consisting of anaerobic treatment in the form of upflow anaerobic sludge blanked (UASB) reactors followed by a system of vertical flow constructed wetlands (CW) in series (saturated and unsaturated). The UASB-CW effluent undergoes UV disinfection in order to achieve Class A reclaimed water. The biogas produced in the anaerobic reactors is collected and treated to produce pure methane which is used as a fuel for vehicles of the municipality. The excess sludge of the UASB reactors is treated in an integrated process consisting of sludge treatment wetland and a composting system in series to produce compost. Part of the treated water, depending on the irrigation needs, is used to fertigate a 1 ha agroforestry system (HYDRO2) consisting of a wide diversity of trees, shrubs, aromatic plants, and seasonal crops. The main field of HYDRO2 has an area of about 0.8 ha and includes more than 60 different plant species while the second field includes a seasonal plantation of maize/barley accompanied with some aromatic plants and trees. Both HYDRO1 and 2 are located in Lesvos Island.

HYDRO3 is located in Ano Mera, Mykonos Island. It is an innovative, nature-inspired rainwater harvesting system consisting of a shallow, sub-surface rainwater collector with a surface area of 280 m^2. The rainwater is collected through drainage and transported by gravity pipes into two cylindrical light structure storage tanks. The harvested water is utilized for irrigating 0.4 ha of oregano. In HYDRO4 an existing rainwater harvesting system of domestic residences located in a village of Mykonos Island has been upgraded for several purposes: i) to store water to be reused for domestic non-potable purposes in the local residences (e.g., washing, flushing toilets, etc.), ii) to reclaim potable water after slow sand filtration and iii) to recharge water into the aquifer, mitigating the long-encountered problem of saline water intrusion.

In HYDRO5 seawater and brine from the existing desalination plant in Tinos Island are treated through a low-cost seawater desalination system (Mangrove Still Systems) and channelled into a greenhouse to produce clean water via evaporation and condensation, edible salt and tropical fruits. In HYDRO6 water loops are integrated within a remote eco-tourist facility in Tinos Island. This includes the production of drinking water from vapour water using condensation systems, the treatment of wastewater using reed beds and rainwater harvesting. Reclaimed water is used to irrigate several local crops. The facility is remotely located off the grid and thus all activities are powered using renewable energy.

The present report presents the overall results from the operation of all demo systems. The report consists of six chapters. Chapter 1 presents the objective of the report, while Chapter 2 provides a description of the operation of each demo system, the operating conditions, and the monitoring activities. Accordingly, Chapter 3 outlines the performance of each demo system with respect to water quantities recovered from the different non-conventional water sources, the water quality obtained, the crop yields delivered, as well as the KPIs achieved. The major problems encountered in each demo site and how these were resolved along with the main maintenance activities performed are discussed in Chapter 4. Finally, Chapter 5 presents the main conclusions and some recommendations for upscaling.

2. DESCRIPTION OF THE OPERATION OF HYDROS

2.1 Overall description of the operation of HYDRO1&2

HYDRO1 - Demo line

HYDRO-1 technology (Figure 2.1) is based on two processes: an anaerobic treatment followed by nature-based solutions (NBS) with constructed wetland (CW), which allows obtaining a treated effluent that is suitable to be reused for irrigation purposes.

Figure 2.1 HYDRO 1 layout

The first anaerobic reactor (AnR) is an upflow anaerobic sludge blanket reactor (UASB) which treats domestic wastewater (pretreatment level: screening and sand & grease removal) for organic carbon and suspended solids removal. The AnR is composed of two reactors with square-shaped body where anaerobic wastewater treatment takes place, i.e. biological wastewater treatment carried out without using air or oxygen, leading to low amount of sludge produced, and offering the possibility to recover the biogas produced by the anaerobic metabolism. In this case two identical rectangular reactors have been installed (2.4 x 2.4 m) with a total height of 4 m (Figure 1.1Figure 2.2). The total volume of the reactors (up to overflow) is 41 m^3. The produced biogas is collected and stored before being valorised in the biogas upgrade unit, that removes carbon dioxide (CO_2) through chemical (MEA) stripping. Sludge ports are connected to the sludge dry bed – sludge drying reed bed (SDB – SDRB) system where excess sludge is dehydrated before composting process begins.

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Figure 2.2 HYDRO 1 UASB reactor, automation control, biogas flowmeter

The AnR effluent is directed to the CW stage, which consists of a hybrid combination of Vertical Subsurface Flow (VF) CWs (Figure 2.3). The CW is designed with two stages: 1st stage, saturated downflow (VF SAT – 250 m^2); 2nd stage unsaturated intermittent load (VF UNSAT – 600 m^2). VF SAT is filled with gravel, while VF UNSAT is filled with gravel and an intermediate sand layer.

Figure 2.3 HYDRO 1 VSSF Constructed Wetlands (Saturated on top, 3 Unsaturated beds on bottom)

The aim of the applied technology is to guarantee “class A” requirements for treated wastewater reuse in irrigation in terms of TSS, BOD_5, and turbidity, according to the EU Regulation 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse. Moreover, the integrated system also claims effective removal of COD and nitrification. The performance claims are intended to be robust against change of conditions that could be encountered in touristic areas of the Mediterranean region between winter (cold humid climate and lower number of residents) and summer (hot arid climate and higher number of residents, increased by the anticipated tourism). Finally, biogas from anaerobic process can be also collected and reused.

The process that takes place in the anaerobic reactor consists of the following phases. Wastewater flows upwards through a sludge bed composed by anaerobic biological sludge which occupies about half the volume of the reactor. There, the anaerobic microorganisms decompose the organic matter of sewage, generating biogas. The CW stage utilizes the complex physical – chemical – biological processes, required for the pollutants’ removal. Saturated VF CW is continuously fed (with the effluent stream of the AnR), over the top of the bed and for the whole surface, maintaining saturated conditions and developing anaerobic/anoxic conditions. Wastewater is intended to stay beneath the surface of the gravel bed and flow through the roots and rhizomes of the plants and the gravel pores. The inert material is maintained under water saturated conditions. This solution is suitable to remove organic and solid loads, as well as to provide partial denitrification, if nitrate nitrogen is available. In the unsaturated vertical subsurface flow (VF) wetland, wastewater is intermittently pumped on the top of the beds and infiltrates vertically within the inert material. The unsaturated VF wetland is divided in two feeding lines and offers the possibility of an alternate feeding system, to enhance the prevalence of unsaturated conditions, which occur through the transfer of large quantities of oxygen inside the main bed filled with coarse sand. The high oxygen transfer is suitable to remove the organic matter and perform nitrification satisfactorily.

After disinfection, reclaimed water is stored in a tank that is used as the fertigation tank of HYDRO2 (Figure 2.4). The system enables to reclaim a large amount of water and nutrients (TN and TP) that coupled with a disinfection unit (e.g. UV irradiation), can be reused in agriculture under class A reclaimed water quality of EU Regulation 2020/741, i.e. permitting to reuse and recover water and nutrients with minimum operational and maintenance cost in comparison to conventional technologies (lower sludge production, and human resources) for the cultivation of all the crop categories defined by the European regulation, i.e. crops for food, feed, industrial, energy or seed production.

Figure 2.4 Water flow from influent draw tank [a], UASB overflow [b],effluent from the CWs [c], UV disinfection [d] and final storage for irrigation [e].

Monitoring the operation of HYDRO1 was conducted by both on site measurements and lab analyses as shown in Figure 2.9. In addition, all electro-mechanical equipment was controlled by dedicated HMIs and connected to a central PLC controlled via a central SCADA system. In this way, every possible information from water and biogas flowmeters, temperature and water quality sensors as long as the state of each equipment was directly accessible by the operator to ensure smooth operation and proper monitoring of the parameters that affect wastewater treatment. On-site lab analyses, alongside with online data from various sensors enabled thorough performance assessment of the operation of the demo site.

HYDRO1 - Pilot line

The pilot system consisted of 4 parallel CWs (Figure 2.5) (three electroactive and one intensified) operating as vertical sub-surface flow CW (VSSF CW) with a total surface of 1 m^2 and height of 1 m. Three of them were filled with carbon electroconductive biocompatible material, initially colonized by electroactive *Geobacter* bacteria and the fourth one was filled with river gravel (inert material), while an air pump was installed to provide aeration bottom-up. Regarding the electroconductive CWs, three different schemes were tested in terms of saturation; the first one was fully saturated, the second was fully unsaturated and the third one was practically a two-stage system, unsaturated on top half – saturated on bottom half. It is noted that aerated CW was also saturated and the aeration was intermittent so that anoxic conditions could occur. A finer granulometry was used for the unsaturated bed parts (3-10 mm), while coarse was used for the flooded parts (10-30 mm). Each constructed wetland was planted with aquatic plants *Scirpus lacustris*.

The CWs operated on municipal wastewater which was pumped from the already existing Wastewater Treatment Plant of Antissa, Lesvos Island, Greece. Due to the high solids and organic load of the wastewater, especially during summer, a two-chamber septic tank was installed to reduce the load before feeding the pilot system. The septic tank was designed with two chambers for particulates' settlement and septic degradation, while the effluent was led to a third chamber (treated septic effluent), where the pilots' feeding pump was installed. Each of those chambers had a total volume of about 1 m^3. The septic tank feeding rate was a critical step for the proper operation, so that to avoid any solids overload of the pilot systems.

Figure 2.5 Pilot-scale constructed wetlands; saturated electroactive, aerated, two-stage hybrid electroactive and unsaturated electroactive (from left to the right)

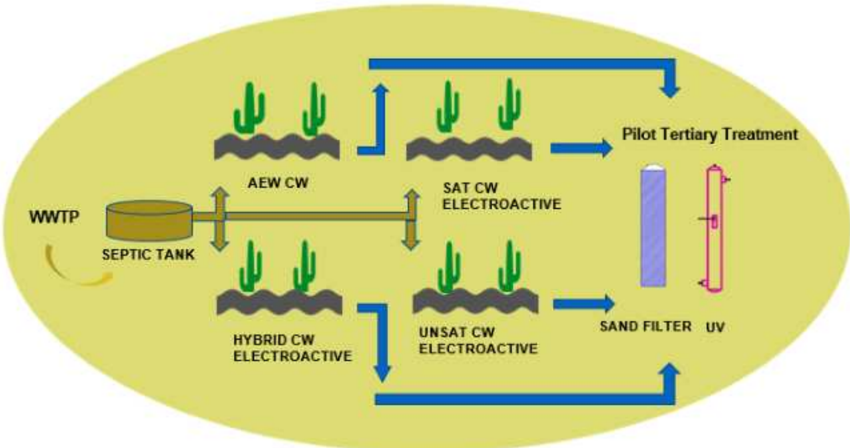


Figure 2.6 Pilot line flow diagram

HYDRO2

The reclaimed water that is produced in HYDRO1 demo site complies with the EU legislation for unrestricted agricultural use and therefore is appropriate for the irrigation of the HYDRO2 demo site. HYDRO2 is an agroforestry system with a wide diversity of trees, shrubs, aromatic plants and annual crops and is located in Lesvos Island. The demonstration site is adjacent to HYDRO1 site and uses the reclaimed water that is produced in HYDRO1 for irrigation. This nutrient-rich reclaimed water is characterized by significant nutrient content in terms of nitrogen and phosphorus and therefore could save significant amounts of commercial fertilizers that had to be used in a conventional cultivation.

The site (Figure 2.7) has an area of about 1 ha and is divided into 2 fields. The main field of the site has an area of about 0.8 ha and includes more than 60 different plant species while the second field includes a seasonal plantation of maize/barley accompanied with some aromatic plants and trees. Half area of the second field is irrigated with conventional tap water for research and comparison purposes in order to evaluate the effect of the reclaimed water on the plants' growth, health, yield etc.

Figure 2.7. HYDRO2 main field (left photo) and second field (right photo) during September 2022

The irrigation of the agroforestry system is mainly applied through a drip irrigation system that has been finalized before the start-up of the system, while at the same time traditional stone channels coupled with furrow irrigation has been constructed and tested during the 2 years of operation. The irrigation of the main field is regulated by an irrigation panel while the second field is irrigated by an autonomous irrigation system, provided by AGENSO, that includes an automatic start/stop of the irrigation process in accordance with the soil moisture sensor's measurements.

2.1.1. Operation calendar since the start-up (technological systems and cultivations)

<u>Technological systems - Demo line</u>

The start-up of UASB reactor took place in March 2021 and CW start-up along with the tertiary treatment unit followed one month later (April 2021) after hydraulic, electromechanical equipment and automation tests were completed for each treatment unit (January – February 2021). Throughout the demo site monitoring period, operation was only interrupted for few hours to couple of days due to external factors such as regional power cut-outs (by the local power utility), and Antissa sewer system problems (solved by the local water utility). Internal factors such as biological underperformance, hydraulic or electromechanical equipment failure, as well as human resource absence were never encountered. Figure 2.8 shows the flowrate applied to the system, while the influent wastewater temperature and UASB reactor temperature is displayed.

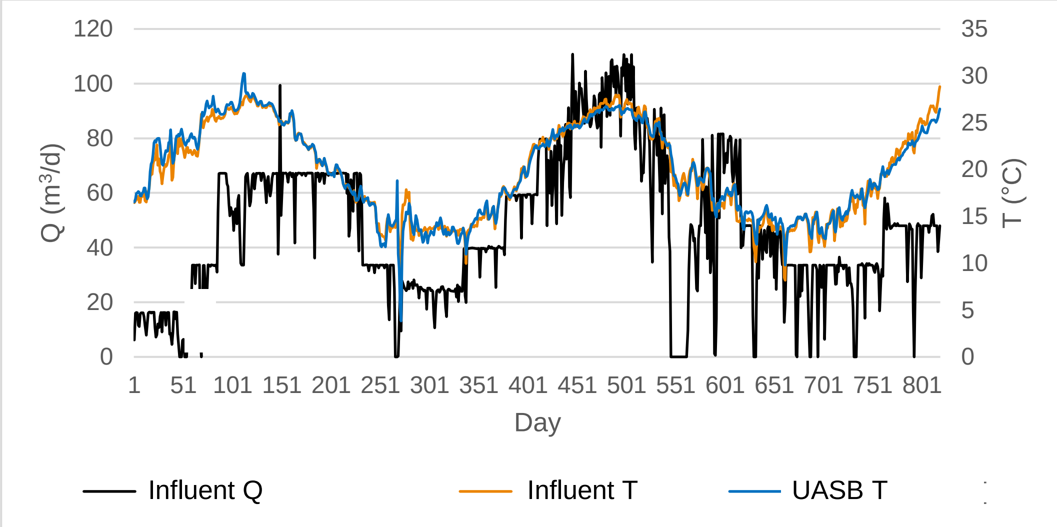


Figure 2.8 HYDRO1 wastewater daily flowrate

During the monitoring, operating periods were separated according to the treatment capacity of the integrated UASB-CW system, to demonstrate the efficiency of the system under increased load during summer period and under low temperature and lower flowrate during winter. As shown in Table 2.1, 6 periods were completed up to the date of reporting, numbered S (start-up), I, II, III, IV, V and I. During the start-up in 2021, a relatively low volume of wastewater was fed to HYDRO1. The system start-up (10/3/2021 – 6/7/2021) was performed with an influent wastewater flow of 16 m^3/d that was gradually increased resulting in an average of 22 m^3/d. During this period, UASB biomass (inoculated with anaerobic sludge) was acclimatized to the specific temperature and wastewater composition and loading. In addition, biofilm was grown onto the CW substrate and plants started to grow and expand inside the beds. During the start-up, constructed wetlands were not studied as two separate systems at that point, but only VSSF unsaturated CW effluent (fully treated water) was monitored. During period I, that began on the 7/7/2021, the flowrate was increased to 65 m^3/d for almost five months and this resulted in an increased OLR to all systems. By that point, effluent from the VSSF saturated CW was, also, monitored. At the end of period I, temperature gradually decreased (late autumn) and test flowrate had to be decreased down to 22.5 m^3/d (decreasing from 1/12/2021 to 17/1/2022) to get a steady performance of the UASB. Periods III and IV, starting on 18/3/2022 and 30/4/2022, respectively, were characterized as transitional phases and the aim was to avoid rapid increase of system loading that was maximized (very close to design value) during the second summer period (V) starting on 1/6/2022, when 82 m^3/d were applied on average while maximum value was greater than 100 m^3/d (for several days). During period VI (winter and spring time), 34 m^3/d were applied to the system to investigate the performance under increased load during winter in comparison with period II (25 m^3/d) and the VSSF SAT CW was bypassed to test the increased solids loading rate (SLR) on the VSSF UNSAT CW that was fed with UASB effluent during that time. As shown in Table 2.2, there was a significant difference in raw wastewater characteristics during summer and winter caused by dilution with stormwater that entered the sewer system (e.g., influent COD values ranged from 200 mg/L, during heavy rainfall days, up to 900 mg/L). The maximum registered wastewater temperature was 29^{o}C during August 2021 (period I) while minimum was 12^{o}C during December 2021 (period II). During the second year of operation aquatic plants reached their nominal growth size while stems were multiplied covering completely the CW beds with new stems.

Table 2.1 Period separation and operational data (average ± st. dev)

	Period						
Parameter	**S**	**I**	**II**	**III**	**IV**	**V**	**VI**
Days	1 - 119	120 - 266	267 - 373	374 - 416	417 - 448	449 - 654	655 - 799
Q_{in} (m^3 d^{-1})	20.1 ± 8.3	65.3 ± 3.7	25.2 ± 1.8	40.8 ± 3.0	59.2 ± 0.2	82.0 ± 18.0	34.2 ± 3.8
Temperature (°C)	22.0 ± 3.5	23.2 ± 3.5	13.5 ± 0.7	15.2 ± 1.7	19.0 ± 1.6	22.7 ± 3.8	15.5 ± 1.9
HRT (h)	50.9 ± 14.3	15.1 ± 1.3	39.4 ± 3.2	24.2 ± 1.5	16.6 ± 0	12.2 ± 1.8	29.3 ± 4.1
Upflow velocity (m h^{-1})	0.28 ± 0.05	0.39 ± 0.07	0.24 ± 0.09	0.36 ± 0.03	0.35 ± 0	0.33 ± 0.06	0.18 ± 0.09
OLR_{UASB} (kgCOD m^{-3} d^{-1})	0.24 ± 0.15	1.16 ± 0.3	0.19 ± 0.07	0.64 ± 0.26	1.13 ± 0.33	1.32 ± 0.31	0.35 ± 0.12
$HRT_{VF,SAT}$ (d)	4.5 ± 1.5	1.9 ± 0.1	5.0 ± 0.3	3.1 ± 0.2	2.1 ± 0	1.5 ± 0.2	n/a
$OLR_{VF,SAT}$ (gCOD m^{-2} d^{-1})	21.8 ± 10.4	69.1 ± 20.2	10.1 ± 1.8	42.1 ± 16.8	97.9 ± 13.1	81.5 ± 22.2	n/a
$SLR_{VF,SAT}$ (gTSS m^{-2} d^{-1})	6.3 ± 1.9	32.1 ± 13.1	2.6 ± 0.8	21 ± 11.8	45.7 ± 6.5	34.1 ± 12.6	n/a
$OLR_{VF,UNSAT}$ (gCOD m^{-2} d^{-1})	n/a	10.9 ± 2.1	2.0 ± 0.5	6.0 ± 1.6	12.8 ± 1.3	17.4 ± 4.0	6.5 ± 1.9
$SLR_{VF,UNSAT}$ (gTSS m^{-2} d^{-1})	n/a	1.5 ± 0.5	0.2 ± 0.1	0.9 ± 04	2.6 ± 1	4.6 ± 2.6	2.3 ± 1.0

Table 2.2 Raw wastewater quality per period (average ± st. dev)

	Period						
Parameter	**S**	**I**	**II**	**III**	**IV**	**V**	**VI**
TSS (mg/L)	219 ± 98	301 ± 85	190 ± 100	302 ± 112	420 ± 99	291 ± 98	176 ± 72
VSS (mg/L)	157 ± 81	256 ± 74	162 ± 82	258 ± 91	363 ± 75	235 ± 86	148 ± 59
BOD_5 (mg/L)	-	251 ± 52	135 ± 35	308 ± 57	353 ± 38	392 ± 82	257 ± 94
tCOD (mg/L)	472 ± 150	722 ± 176	311 ± 116	623 ± 219	779 ± 230	664 ± 147	422 ± 145
sCOD (mg/L)	118 ± 56	175 ± 35	63 ± 20	105 ± 39	127 ± 22	156 ± 53	109 ± 35
NH_4-N (mg/L)	57.5 ± 6.5	67.2 ± 9.8	34.4 ± 8.1	51.9 ± 8.4	65.6 ± 9.7	63.6 ± 8.7	51.2 ± 15.7
NO_3-N (mg/L)	-	-	-	-	-	-	-
TN (mg/L)	-	92 ± 9	51 ± 8	-	85 ± 8	97 ± 12	67 ± 12

	Period						
Parameter	**S**	**I**	**II**	**III**	**IV**	**V**	**VI**
TP (mg/L)	-	10.5 ± 1.2	5 ± 1.3	9.4 ± 1.9	12.2 ± 1.1	9.5 ± 1.6	10.0 ± 1.6
PO_4-P (mg/L)	-	8.0 ± 0.9	3.7 ± 0.9	5.8 ± 0.9	7.5 ± 0.8	6.9 ± 1.3	7.4 ± 0.7
pH	7.3 ± 0.2	7.4 ± 0.1	7.8 ± 0.1	7.8 ± 0.1	7.7 ± 0.1	7.4 ± 0.2	7.6 ± 0.1
Conductivity	1421 ± 102	1443 ± 94	947 ± 172	1250 ± 139	1434 ± 69	1347 ± 200	1223 ± 174
Turbidity (NTU)	-	269 ± 61	129 ± 60	223 ± 59	309 ± 68	215 ± 71	146 ± 54
Alkalinity ($mgCaCO_3$/L)	-	461 ± 67	284 ± 49	365 ± 0	470 ± 0	404 ± 26	367 ± 61

Excess sludge was removed for the first time from the UASB reactor by the end of period I (day 266) when its height exceeded the GLS (Gas -Liquid-Solid) separator level to prevent it from entering the settlement zone of the reactor beneath the overflow channels. The sludge was fed to the SDB – SDRB system. Low sludge removal was justified by the low biomass yield of the anaerobic microorganisms and the need to increase sludge mass in the reactor during the first operation year, combined with very low sludge mass increase during winter period due to the low organic loading of the system. Additional online quality data sensors (pH, COD, Turbidity, NH_4-N, NO_3-N, Conductivity, ORP, DO) and central SCADA system were installed at the beginning of period I to obtain more frequent data on critical parameters. Biogas production monitoring began during period II after the proper setup of the biogas flowmeter and the start-up of biogas upgrade unit. The CW GHG emissions were also monitored during the second year of operation.

Technological systems - Pilot line

The start-up of the electroactive pilot systems took place on 29 March 2021 and shortly afterwards on 20 April 2021 the aerated wetland was set into operation. Planting of the aquatic species *Scirpus lacustris* was carried out on the day of the start-up. The pilot system operated for almost two years (March 2021 – ongoing), while the maximum applied organic loading rate (OLR) was kept constant for a long-time performance. Five operation periods were applied (Table 2.3). Feeding of the systems were carried out with 8 pulses per day (24/06/21-03/03/22) with a time difference per flush (resting period) equal to 3 hours. The pulses were subsequently increased to 73 (03/03/22-28/11/22), 100 (28/11/22-19/02/23) and finally to 150 (19/02/23-on going). Also, the aerated constructed wetland is aerated by artificial means 8 times per day with a total aeration duration of 12 hours/day. The aim of the intermittent aeration is the denitrification of nitrate nitrogen during the hours when aeration is not applied in the system. The values of hydraulic relation time (HRT) presented in Table 2.4. The different values between the systems are due to the different material (between electroactive and aerated), as well as the different volume between the hybrid (half volume) and the other pilots.

Table 2.3. Operational periods and parameters.

Period	Duration	Q (m^3/d)	Average OLR ± Standard deviation ($gCOD\ m^{-3}d^{-1}$)	Average NLR ± Standard deviation ($gNH_4\text{-}N\ m^{-3}d^{-1}$)
1st	24/06/21-27/07/21	0.2	73±10	17±1
2nd	28/07/21-02/09/21	0.3	143±20	22±2
3rd	03/09/21-19/04/22	0.4	165±65	26±8
4th	20/04/22 -06/09/22	0.4	249±102	37±6
5th and 6th	07/09/22-30/06/23	0.5	171±39	43±9

Table 2.4 HRT values of each pilot in relation to flow rate (Q)

Q (m^3/d)	HRT (h)			
	AEW	SAT	HYBRID	UNSAT
0.2	34	48	24	-
0.3	22	32	16	-
0.4	17	24	12	-
0.5	13	19	10	-

➢ ***Agricultural activities (species, plantation dates, harvest periods, failures)***

Before the start-up of the HYDRO2 site, a series of preparation works were concluded. The clearance of the field, the fencing and the installation of the irrigation systems were concluded until March 2021 on the main field and during late May 2021 on the second field. After the finalization of the initial works on the main field, the first planting period started with some bareroot plants like almond, pomegranate, apple trees and aronia, which are appropriate for planting during early spring period. The planting process in the main field was continued during May 2021 with the planting of more than 5000 plants of lavender, rosemary, oregano, sage, goji berry, blackberry, raspberry, a variety of seasonal vegetables etc. The second field of HYDRO2 was prepared for the maize plantation during June 2021 with the sowing of about 5000 zea maize seeds, 600 lavender plants and a number of aronia and myrtus shrubs. The list of the plants that are growing in HYDRO2 agroforestry system since the start-up are presented in Table 2.5.

Table 2.5: HYDRO2 plant species

Catefory of plants	Plant species
Trees	Olive, Fig, Pomegranate, Almond, Apple, Pear, Quince, Hazelnut, Lemon, Laurel, Cherry, Mulberry, Willow, Plum, Loquat, Tabor oak, Plane
Shrubs	Hippophae, Blackberry, Raspberry, Physalis, Goji berry, Myrtus, Elaeagnus, Aronia, Strawberry, Cistus creticus, Allium,
Aromatic plants	Lavender, Oregano, Rosemary, Sage, Savory, Melissa, Mint, Annice, Pelargonium, Basil, Thyme, Calendula, Echinacea, Allium,
Annual plantations	Maize, Barley
	Watermelon, Melon, Tomato, Cucumber, Zucchini, Eggplant, Onion, Lettuce, Pepper, Beans, Cauliflower, Broccoli, Pumkin, Beetroot, Cabbage, Radish, Cale, Leek, Peas, Parsley, Celery, Spinach, Carrot, Potato,

Most of the plants that were planted in the agroforestry system were quite young, bought in small pots, while some species were sowed through seeds. As a result, the first harvesting of them was estimated after 1 to 3 years depending on the plant species. However, for some species like the annual crops (maize) or seasonal vegetables (tomatoes, watermelons, eggplants, etc.), the harvesting period was only a few months after the planting. More specifically, a great mass of seasonal vegetables (>600 kg) was harvested between July-October 2021 while the maize plantation was harvested during November 2021 (>3 tons). These plantations alternated with winter plantations such as barley in place of maize and winter vegetables like cabbage, cauliflower, broccoli etc. in place of tomatoes, watermelons, melons etc.

2.1.2 Monitoring of HYDRO1

➢ ***Operator's monitoring plan***

Monitoring of HYDRO1 was performed both by lab analyses and online probes (Figure 2.9) that were installed in key points. The performance assessment was performed by sampling influent wastewater and effluent of each subsystem i.e., UASB, VSSF saturated CW, VSSF unsaturated CW for lab determination of various pollutants (referred as performance parameters below). Online sensors were installed in the influent, UASB effluent, CW effluent of the system and in the reclaimed irrigation water storage tank.

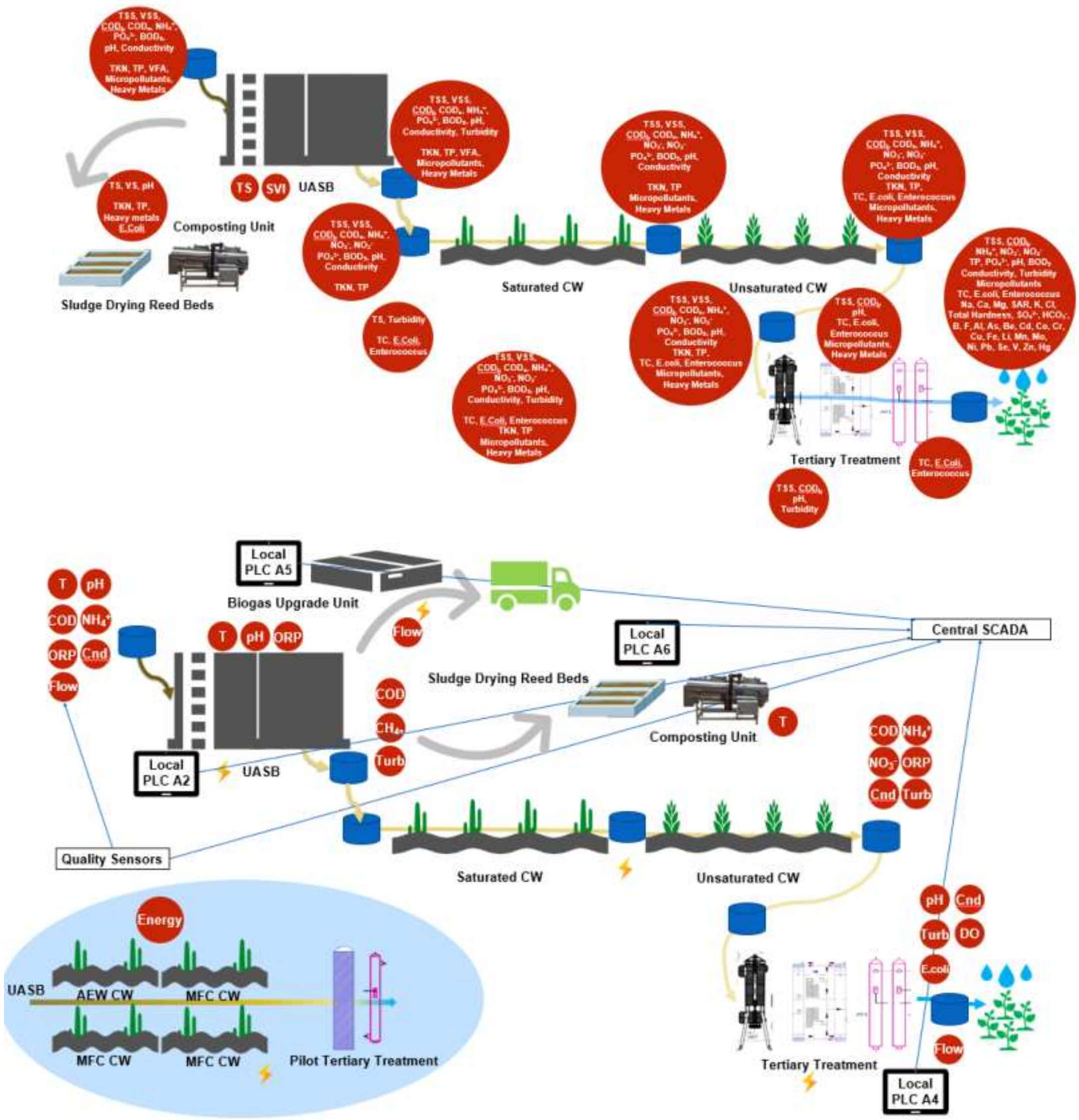
➢ ***Monitoring strategy***

- Online (type of probes, position)

In the influent tank pH, ammonium and nitrate nitrogen and COD were monitored. For the UASB effluent pH, ORP, Turbidity and COD online probes were used to provide real-time data for process instability. In the treated effluent, various parameters were monitored such as COD, ammonium and nitrate nitrogen, turbidity, ORP, conductivity and DO. These data provide information regarding the quality parameters that relate with the reuse legislation.

- Lab analyses (parameters, frequency)

Lab analyses were performed to get the most accurate performance assessment and, also, verify the quality of the online data provided. Parameters that were monitored are described in detail in the following paragraph. The monitoring plan was focused on determination of the performance of each subsystem and its contribution to the overall performance, as well as on the quality of the irrigation water that was produced.



- **Figure 2.9 HYDRO 1 flow diagram with lab sampling points (top) and online sensors (bottom)**

<u>HYDRO1-Demo line</u>

In order to characterize the operation and performance of the HYDRO-1 technology, the following operational and performance parameters were monitored:

<u>Performance parameters</u>

- **COD effluent**: grab water quality sample (2/week),
- **TSS effluent:** grab water quality sample (2/week),
- **BOD_5 effluent:** grab water quality sample (1/month)
- **Turbidity effluent:**
    - o grab water quality sample (2/week)
    - o online sensor
- **Sludge production:**
    - o <u>Height of sludge blanket</u> at different depths of the AnR reactor, from bottom to the top
        - ▪ 0.4 m
        - ▪ 0.9 m

        - 1.4 m
        - 1.9 m
        - 2.4 m
        - 4.0 m (effluent)
    - Total solid concentration of sludge blanket grab water quality sample at each sampling point (each depth) of the AnR reactor (from bottom to the top)
- **Biogas production:** on line flow meter
- **COD removal (COD concentration inlet):**
    - grab water quality sample (2/week)
- **TSS removal (TSS concentration inlet):** grab water quality sample (2/week)
- **N-NH_4 removal:**
    - N-NH_4 concentration influent: grab water quality sample (2/week)
    - N-NH_4 concentration effluent: grab water quality sample (2/week)
- **Water recovered:** online electromagnetic flow meter
- **Resources recovered:**
    - TN concentration effluent: grab water quality sample (2/month)
    - TP concentration effluent: grab water quality sample (2/month)

Operational Parameters

- **Flow influent:** no. 2 flow meters (one for each reactor)
- **pH:** effluent AnR and effluent CW, pH meter
- **Temperature:**
    - Heating tank (influent AnR): temperature sensor
    - Inside AnR reactors: no. 2 temperature sensors (one inside each reactor)
    - Air Temperature: meteorological station provided by the project partner AGENSO
- **Precipitation:** meteorological station provided by the project partner AGENSO
- **Pressure (biogas collection):** pressure sensor

HYDRO1 - Pilot line

For the monitoring of the systems, samples were collected from the influent (septic tank) and treated effluent of each pilot, once per week and analysed for COD, BOD_5, TN, NH_4-N, NO_3-N, PO_4-P, total suspended solids (TSS), volatile suspended solids (VSS), temperature, pH, conductivity, and turbidity. The septic tank is fed daily, so that the systems are continuously supplied. The feeding systems of each pilot are also cleaned to prevent clogging and outlet tanks are also cleaned one day before sampling. Twice per month a control-checking of the flow rate is performed, to ensure that the OLR is the same for all the pilots; also the supply programs (feeding pump and aeration blower) on the control panel were checked.

HYDRO2

The management of the HYDRO2 agroforestry system includes a precise strategy in terms of monitoring:

- Daily monitoring of all the plants condition by the site manager and weekly detailed inspection of the plants by the local agronomist.
- Daily inspection of the irrigation systems (pumps, tanks, piping, soil moisture sensors of the second field etc.) and maintenance.
- Recording of plants growth, possible infestations and pests. Scheduling and planning of the appropriate control strategy for each plant.
- Scheduling for planting and harvesting per plant depending on the daily monitoring.

- Weed control with manual interventions.
- Harvesting and weighing of the crops.

2.2 Overall description of the operation of HYDRO3

HYDRO3 is located in Ano Mera, Mykonos Island. It is an innovative, nature-inspired rainwater harvesting system consisting of a shallow, sub-surface rainwater collector with a surface area of 280 m^2. The rainwater is collected through drainage and transported by gravity pipes into two cylindrical light structure storage tanks, which have a total water storage capacity of 60 m^3 (Figure 2.10-2.12). The harvested water is utilized for irrigating 0.4 ha of oregano cultivation, employing a drip irrigation system. Within each crop row, drip lines are installed to provide irrigation, positioned parallel to the field contours to prevent soil erosion. The distance between drip emitters is set at 0.5 m to ensure appropriate water application to the crops. To monitor the water quality, the crop water needs and optimize irrigation from the storage tanks, various sensor types, such as pH, conductivity, soil moisture sensors, water level sensors, and solenoid valves, have been installed on-site. All the collected data are transmitted to the HYDROUSA platform, enabling performance monitoring of the system and optimization of the field's irrigation schedule.

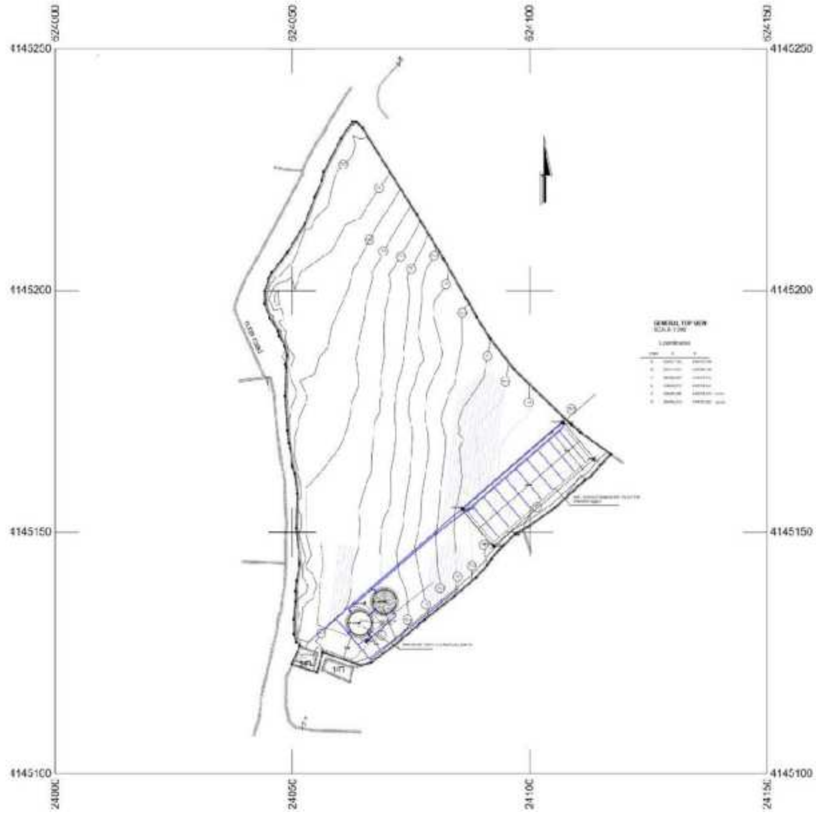


Figure 2.10. HYDRO3 master plan showing the positioning and elevation of the field and location of water collection tanks and irrigation pipes.

HYDRO3 is perfectly harmonised with the landscape architecture. Traditional construction techniques were used, stone works were implemented for the construction of the main entrance, the rubble walls around the site were rebuilt. Additionally, an old warehouse in the southern part of HYDRO3 has been restored and repurposed as storage facilities for agricultural tools (Figure 2.12). It also houses the installation of an oil distillation unit, along with two dehumidifiers (Figure 2.13) and small machinery.

Figure 2.11. Collection area and oregano field in HYDRO3

Figure 2.12.Storage tanks in HYDRO3

Figure 2.13. Restored old warehouse and rubble walls in the premises of HYDRO3 and in the photo below, the irrigation system for the oregano cultivation

The irrigation process operates based on the following logic: The moisture sensor in each plot of HYDRO3 sends a notification to the Ardeusi.gr platform regarding the irrigation requirements and the percentage of soil moisture. If the measurement falls below 10%, a signal is sent to activate the electrovalve for that specific plot. This action results in a decrease in hydraulic pressure, triggering the pump to start. The flowrate of the irrigation pump is 4 m^3/h. The electrovalve remains open for 4 minutes, allowing sufficient time for the water to be absorbed. Consequently, the moisture sensor, positioned 10 cm deep, records the accurate measurement.

Furthermore, the dehumidifier units were installed in June 2021 to collect vapor water. A unit with a capacity of 200 L/d is connected to an external tank of 1.5 m^3. Another unit, producing 50 L/d, fills an internal tank of 30 L. The collected atmospheric water is utilized for the following purposes:

1. Urban use within the estate, including washing oregano and toilet facilities.
2. Distillation, where 80 litres of water are used for every 30 kg of dry biomass.
3. Provision of drinking water for the public, who can freely fill their containers from a tap located prominently outside the estate.

Figure 2.13. Dehumidifiers installed inside the restored warehouse of HYDRO3

2.2.1. Operation calendar since the start-up (technological systems and cultivations)

In HYDRO3, the construction of all systems, including the plantation of oregano crops, the design and installation of the irrigation system, the automation system design, and the selection of sensors, was completed by November 2019. The facility has been operational since December 2019.

Meteorological data were collected for HYDRO3, including sunrise and sunset times, the duration of the day, and the sun's path over the field. This information was used to determine the most suitable direction for plantation, avoiding shading and excessive heat. Data collection spanned the four quarters of the year 2019. Analysis of the collected data revealed a sub-dry to wet period from November to March, followed by a dry period from April to October. Soil samples were analysed to assess their physical and chemical properties. The analysis indicated that the soil pH is close to neutral, ranging from 6.7 to 7.1. This pH level suggests suboptimal conditions for nutrient mobilization. The soil composition analysis showed that approximately 75-80% of the soil is sandy, with 15-20% silt and 4-5% clay. These characteristics indicate that the soil has low water-holding capacity and tends to dry out quickly, especially during the summer. As a result, a drip irrigation system was installed to preserve water.

Several actions were undertaken, including the restoration of an old warehouse, installation of quality sensor parameters, installation of two dehumidifiers, ordering and installation of a distillation unit, and setting up an essential oil laboratory.

The water collection and storage system began operating on November 17, 2019, with works continuing until December 19, 2019. Since then, four years of operational rainy seasons have been completed, with the system collecting 60 m^3 of water each year. During the first summer period (April 2020 to November 2020), irrigation of the oregano field was conducted every 15-20 days using the rainwater collected from the system. In the second summer period, irrigation began in late March 2021, with more frequent application (every 10 days) in June due to extreme weather conditions, such as high temperatures and wind. In the third year of operation, oregano irrigation started in April 2022 and was applied based on soil moisture levels. Based on humidity sensor recordings, it was observed that sections with little soil slope required less water. The irrigation routine was as follows:

- Plots 1, 2, 8, and 9 were irrigated every 7 days.
- Plots 3, 4, and 7 were irrigated every 6 days.
- Plots 5 and 6 were irrigated every 5 days.

➢ ***Agricultural activities***

The cultivation choice was made based on the soil analysis on the site, the weather data and the nature of the island which is highly Perennial plants with high added value are envisioned for this field. Oregano is known for its numerous health benefits, its antibacterial and antimicrobial properties, as well as its potential to alleviate coughs, reduce body odour, soothe digestive muscles, and lower blood pressure. It is also a potent antioxidant, rich in beneficial acids and flavonoids. After thorough research, it was determined that oregano is well-suited to the weather and soil conditions of Ano Mera in Mykonos.

The agricultural site of HYDRO3 was finalized in December 2019. Field preparation was carried out according to the designs, the drip irrigation pipeline network was designed and installed, the type of oregano was selected (*Origanum vulgare* - oregano crop) and the 10,000 seedlings were ordered and planted in December 2019. This successful field preparation is reflected in 2021, during which the oregano cultivation thrived and harvested. Planting seedlings or offshoots can be done in two periods: in October-November and March. Seedlings or offshoots are planted at distances from 60 to 80 cm between the lines and 30 to 40 cm between the plants on the line. In the field, it was planted at distances of 75 cm between the lines and 50 cm on the line. The oregano crop can remain in the field producing good yields for up to 8 years.

Rainwater recovered in HYDRO3 has been used for irrigating the oregano field since the summer period of 2020. From April 2020 to November 2020, the field was irrigated every 15-20 days. In February 2021, weed control measures were implemented, and foliar spraying was conducted using algae extract and amino acids, which are suitable for organic farming according to Regulation (EU) 834/2007 and Regulation (EU) 889/2008. In March 2021, an additional 1,000 plants were planted, incorporating soil conditioners/nutrients and physical soil improvement fertilizers during the planting process.

In early June 2021, a portion of the plantation (20-30% of the plants) showed signs of above-ground drying due to adverse climatic conditions, such as strong winds and unusually high temperatures for that season. To protect the plants, they were sprayed with bordigal pulp, and an order was placed for 1,500 potted oregano plants to fill any potential gaps in October. After allowing sufficient time since the bordigal pulp operation, the oregano was harvested around June 15, 2021, and the production yielded 50 kg of oregano. Of this, 15 kg was provided to local agritourist units and groceries, while the remaining 35 kg was dried and used for essential oil production in 2022. Watering continued on a ten-day basis.

In March 2022, approximately 30-35% of the crop located on a low-slope piece of land was lost due to the rise of the aquifer. In April 2022, the crops were cleared of reeds, and the plants were fertilized every 15 days with an organic mixture of fish and algae. Irrigation was carried out 2-3 times per week. In June 2022, irrigation was halted for a week to allow the oregano plants to accumulate essential oils in the foliage, followed by harvesting. A total of 107 kg of oregano was collected.

2.2.2. Monitoring of HYDRO3

➢ ***Operator's monitoring plan***

HYDRO3 is a subsurface rainwater collection, storage, and irrigation system consisting of the following parts, which are regularly monitored and maintained:

- Collection basin of 280 m^2
- Storage tanks of 66 m^3
- Gravity-fed water collection network
- Crop irrigation network
- Pumping station with a pump
- Monitoring sensors and recording of water quality and quantity parameters through a control box
- Energy-autonomous level and quality parameter sensors operating with solar collectors
- Meteorological station
- Electrical power supply panel
- Nine water distribution solenoid valves with humidity sensors in the oregano cultivation area

The full operation of the system is consistent monitored both through lab analyses and online probes that were installed in the main points of the system in June 2020. In order to ensure the smooth operation of the monitoring system, routine checks and maintenance are conducted, with a particular focus on the sensors and meteorological station. Monthly, their measurements undergo verification and cross-referencing with both laboratory results and a portable device. Immediate calibration is performed if necessary. Regular inspection and maintenance of the electrovalves, connected to the pumping station, are also essential. Any network leaks result in a pressure drop, activating the pump. The HYDRO3 system incorporates nine electrovalves linked to the irrigation network, enabling water distribution to different cultivation sections based on soil moisture sensor readings. This approach helps conserve both energy and water resources

Monitoring strategy –

The monitoring of HYDRO3 demo site was conducted through the industrial and low-cost sensors installed and through sampling campaigns for laboratory analyses.

Quantity Monitoring

- Ultrasonic level meters in the two collecting tanks

- Meteorological station in the field
- Soil moisture sensors (oregano field)

Quality monitoring

- Online monitoring - industrial and low-cost sensors (Conductivity, pH, T, turbidity) in the two collecting tanks (Figure 2.14).
- Sampling campaigns - laboratory analysis

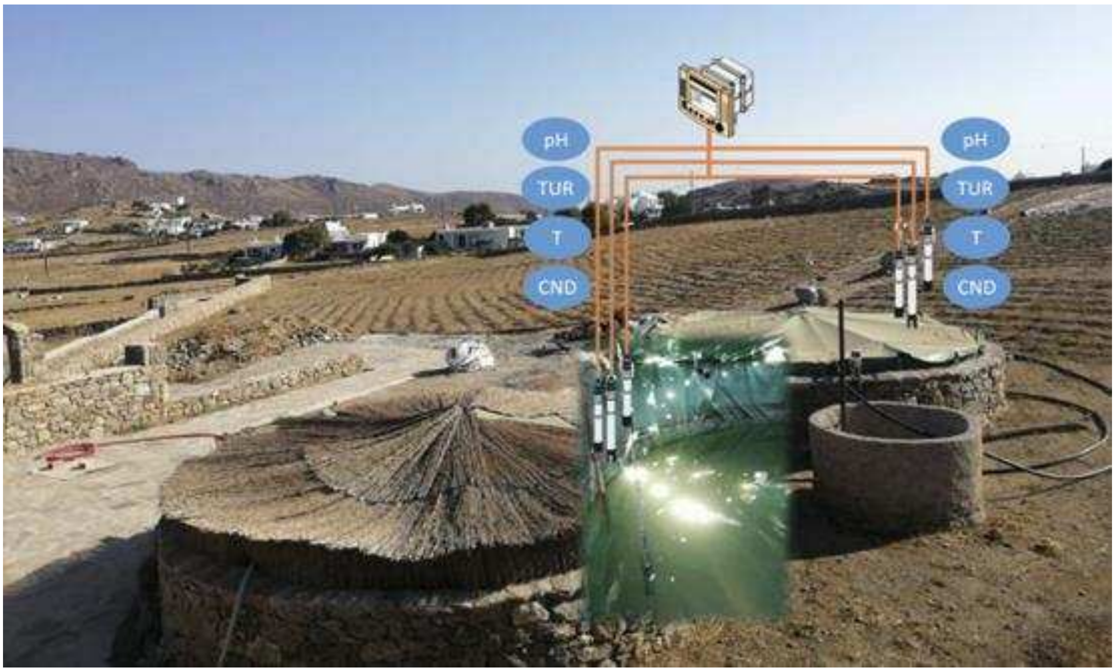


Figure 2.14. Industrial quality sensors installed in the tanks of HYDRO3

All the parts of HYDRO3 pilot site are being monitored and controlled also by low-cost systems. More specifically, the low cost system was used for monitoring weather data, tank water quantity (level sensor), and tank water quality (pH, turbidity) as well as for controlling the irrigation at the site which is divided into 9 plots (Figure 2.15).

Figure 2.15. Low-cost system installation at HYDRO3 site

Regarding the laboratory analysis, the sampling points for HYDRO3 are shown in Figure 2.16 below. To ensure the good quality of irrigation water and its compliance with the limits set by Greek and EU water reuse regulations (CMD No 145116, 2020/741), various analyses were conducted on all the collected samples. These included typical physicochemical analysis, analysis for heavy metals and major ions, and microbiological analysis for TC, *E. coli*, and *Enterococcus*. The purpose of these analyses was to verify that the water is suitable for irrigating oregano cultivation.

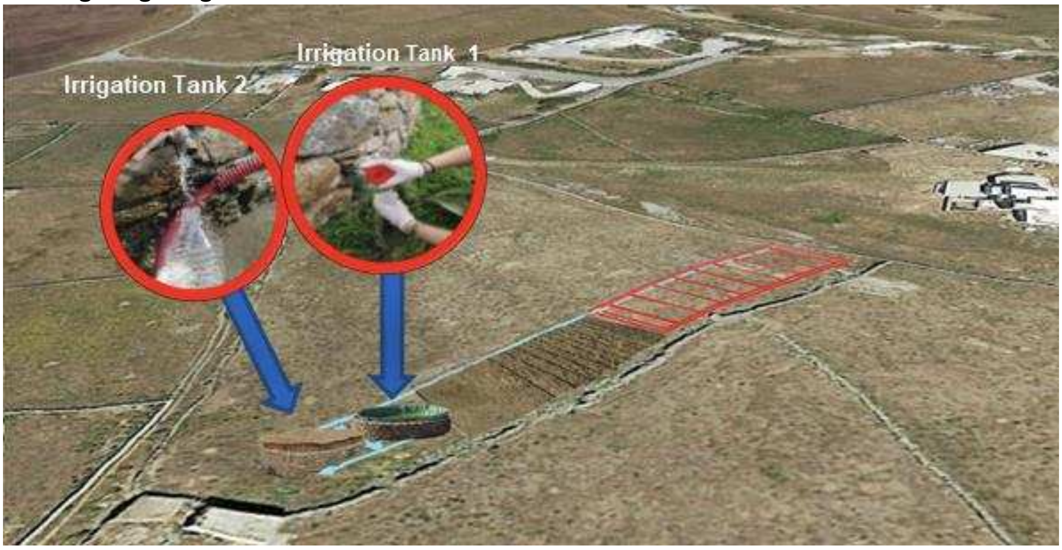


Figure 2.16. Sampling points for laboratory analysis at HYDRO 3 site

2.3 Overall description of the operation of HYDRO4

The aim of HYDRO4 is to design, implement and optimize a residential-scale prototype decentralized, flexible and autonomous rainwater harvesting, storage and recovery system in the highly touristic Mediterranean island of Mykonos (Cyclades, Greece). This system demonstrates how a residential rainwater collection system can be upgraded to optimize the low-cost rainwater harvesting infrastructure and the natural services provided by the subsurface geological conditions, with a positive impact on the environment. The principal concept is to store excess water during the winter months to reuse it in the summer, that is to maximize the existence of the natural resource throughout the year and to increase the water management efficiency in water scarce areas. To achieve this, a configuration has been constructed from mainly the existing infrastructure, in order to enhance the buffering against evaporation and water loss and extend water availability towards the dry (summer) season.

The ultimate aim is to address water scarcity issues that have become more prevalent in semi-arid regions and establish new circular water management systems and actions in the water sector to achieve sustainable environmental and economic development of these regions. Especially for the Mediterranean Basin, where high temperatures and minimal rainfall characterize the summer climate (Ulbrich et al., 2012), recent studies point to future trends towards even drier conditions with increased frequency of extreme rainfall events (Giorgi & Lionello, 2008). The total precipitation is expected to decrease, as longer dry spells and reduced rainfall intensity have been observed (Cramer et al., 2022). Therefore, these regions suffer from the limitation and irregular distribution of their water reserves, while the increasing touristic activities during the summer season put additional stress on their water supplies, both in terms of quantity and quality. The Mediterranean islands face even greater challenges and experience more severe water scarcity issues due to their relatively smaller size and isolation. To address such issues, transformative adaptation water management solutions, within the concept of CE are urgently required to increase community resilience, to enable effective and far-reaching changes, to adapt to the projected climate change and to carry out a sustainable transition.

To address the aforementioned matters, in HYDRO4, three separate but interrelated subsystems have been designed, constructed, tested and optimized. The general principle is to make the most of the infrastructure of the system - tanks, terraces, bioswale to collect and store rainwater for irrigation and aquifer recharge. The subsystems are illustrated in Figure 2.17 and are described in detail subsequently.

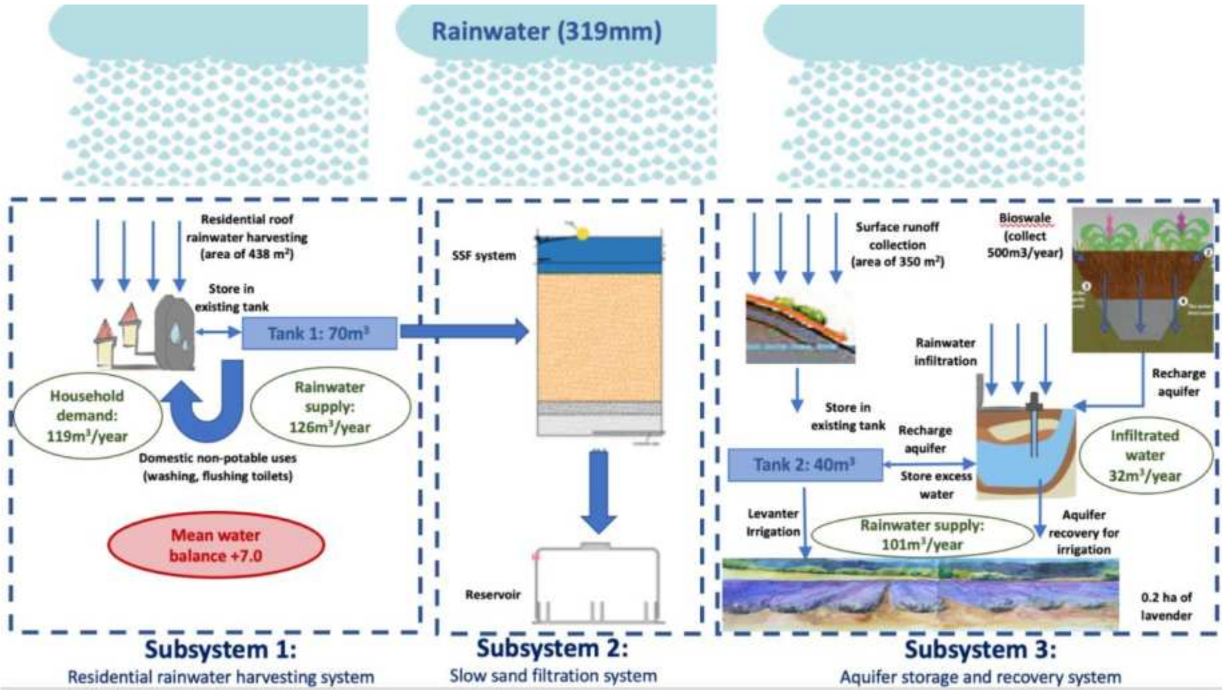


Figure 2.17. Schematic illustration of the three subsystems of HYDRO4

In **subsystem 1** rainwater is harvested from the residential rooftops of the site property, sent through a manhole and a buffer tank in a tank (Tank 1) to be stored and reused for domestic non-potable purposes in the local residences (e.g., washing, flushing toilets, etc.), Figure 2.18 presents the respective configuration of subsystem 1.

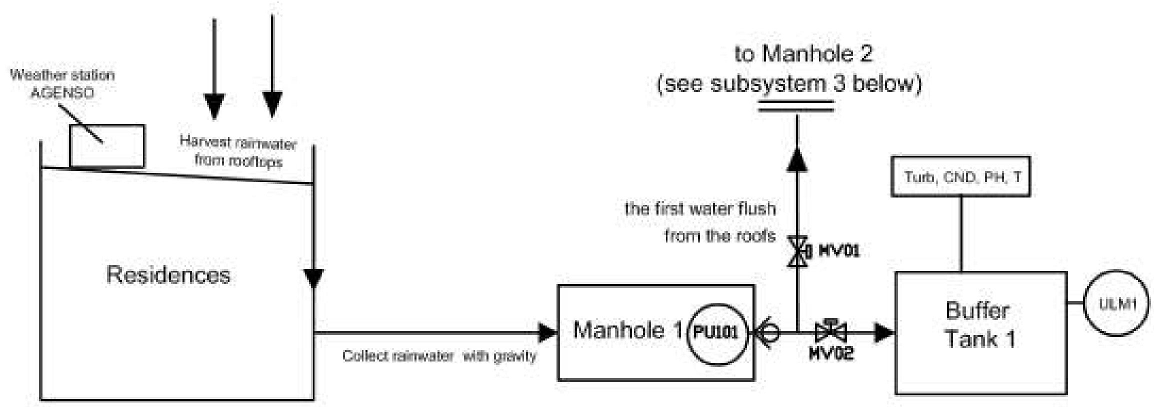


Figure 2.18. Subsystem 1: Residential Rainwater Harvesting system

Subsystem 2, the Slow Sand Filtration (SSF) system, is practically a water purification system that converts raw water such as rainwater into a potentially potable product. The working principle is that raw water flows through a sand-bed system. Various biological, physical, chemical and mechanical processes take place and purify the water to be used for potable use, in cases where water quality monitoring and respective legislation allow it.

Figure 2.19. Subsystem 2: Slow Sand Filtration system

In **subsystem 3**, the aquifer storage and recovery system, rainwater is collected, stored and reused when needed. This is performed through two sources:

(a) By collecting the **surface runoff** of the impermeable surfaces of the residences yards in the wet period, storing it in a tank and reusing it for irrigation purposes during the dry period; once the tank is full, excess water is transferred to recharge the aquifer (subsurface "basin") in the optimum site location in terms of maximum storage capacity and recovery potential, identified through geophysical surveys, from which water is recovered from the artificial recharge (AR) well and reused for irrigation in the dry period. The practice is that Tank 2 (that collects surface runoff) should always be full and for irrigation the stored water in the subsurface is primarily used.

(b) By collecting rainwater through a **bioswale system**, an open-channel linear drainage system, storing in an open tank and once the tank is full, excess water is recharged in the subsurface "basin" (same optimum location) to be recovered and reused in the dry period. When water is needed for irrigation, this is recovered from the AR well first and the open tank secondarily. When water is recovered in the AR well, this is sent back to the open tank so that it is always full.

The configuration diagram of subsystem 3 is illustrated in Figure 2.20.

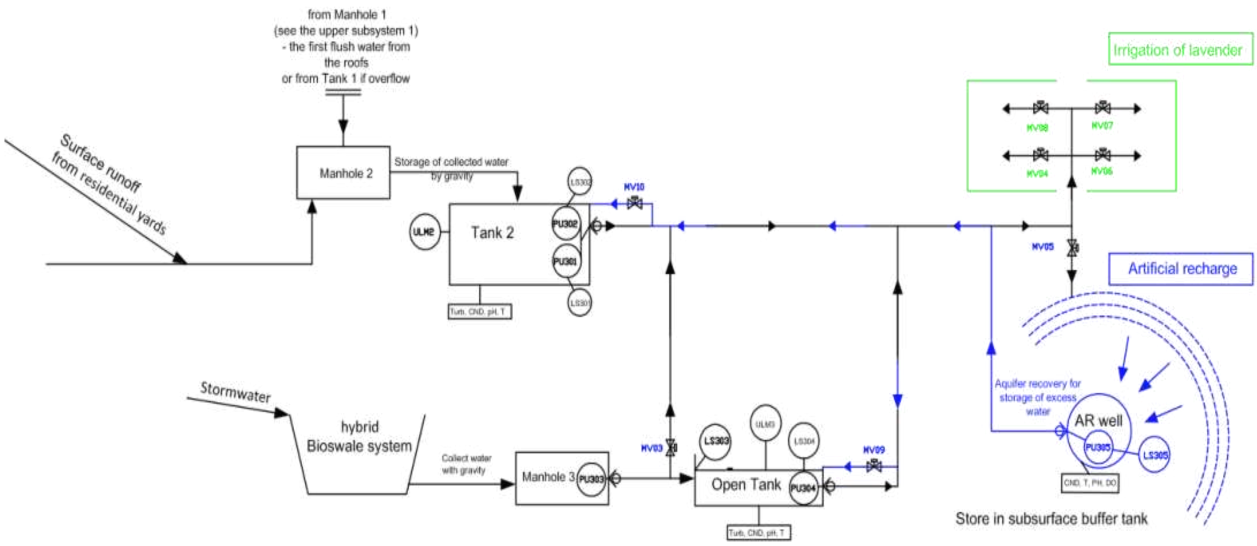


Figure 2.20. Subsystem 3: Aquifer storage and recovery system

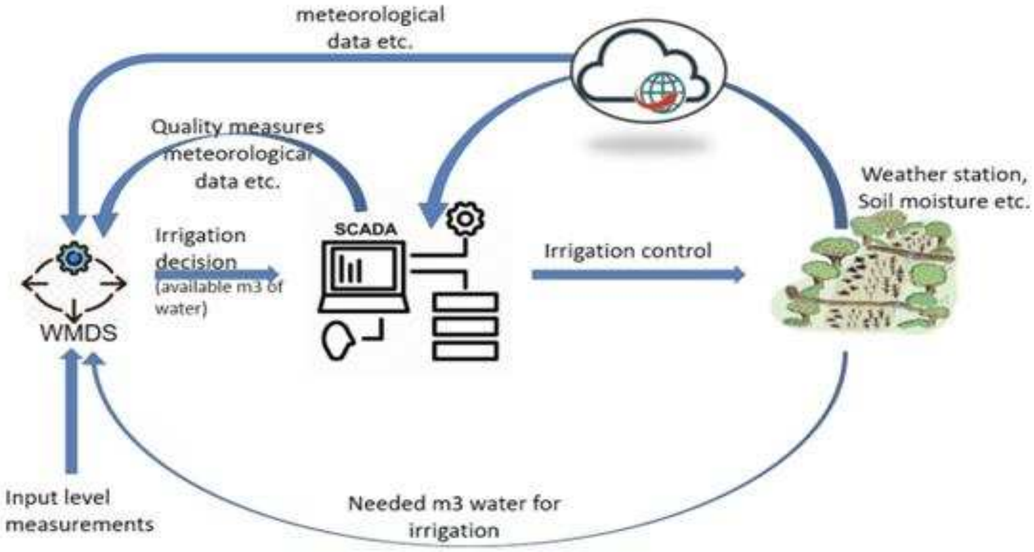


Figure 2.21. Conceptual diagram of HYDRO4 water managing system

The HYDRO4 rainwater storage and recovery system is designed to be implemented in various scales and can be potentially replicated in other water scarce areas.
Figure 2.22 shows all the subsystems of HYDRO4 and the general layout of the demosite.

Figure 2.22. HYDRO4 subsystems and lavender cultivation.

2.3.1. Operation calendar since the start-up (technological systems and cultivations)

The start-up HYDRO4 was conducted in October 2020. During the winter period of 2020-2021, rainwater was collected in Tanks 1 and 2, for domestic and irrigation purposes respectively. The entire configuration is monitored both in terms of water quantity and quality, through a dedicated sensors' scheme and the data are stored and managed through a PLC system, which was fully installed in **June 2021**. By November 2020, Ultrasonic Level meters have been installed in the tanks for measuring the water quantity Pressure Level meters were set in the wells and a Meteorological station was installed on-site. As for the quality, online monitoring was implemented through industrial and low-cost sensors for conductivity, pH, temperature and turbidity that were installed by November 2021. Additionally, sampling and analysis schemes of the main physicochemical parameters have been conducted in the NTUA laboratories since November 2020. In total during the wet periods which have been monitored, about **509 m^3** of rainwater as well as stormwater was collected and was sent to the aquifer for recharge. The raw data are collected and processed, and modelling work was performed to assess the aquifer behaviour regarding the optimal storage capacity and recovery potential as well as the operation and optimization of the system.

As mentioned, the entire configuration is controlled by a PLC system, based on a logic of HYDRO4 control systems which was initially designed according to the water resources management schemes that were decided to be implemented and later optimized based on subsequent measurements and assessment. The system has been fully automated and operational for more than 2 years and has shown satisfactory performance and stability.

Subsystem 1

The construction of the residential rainwater harvesting system commenced in June 2020. The collection of rainwater from the roofs of buildings and the system was operational since winter 2020-21 and same extra modifications were implemented by April 2021 (Figure 2.23). The area of roofs that were restored to be used for the rainwater collection is equal to 438 m^2. Regarding the water collection from the roofs of the buildings, the calculation is done by adding the value of the buffer tank water volume and the surfaces that flow naturally into Tank 1 and are adjacent to it. When the PLC was installed in June 2021, all operations were performed uninterruptedly according to the water management scheme that was designed.

Monitoring activities have been performed in Tank 1, in terms of quantity (water level) as well as quality (pH, conductivity and turbidity). The respective sensors are operational and monitoring the entire year. Additionally, samples of the water in Tank 1 are regularly collected at approximately a monthly basis to perform analysis in the NTUA laboratories for the quality of the water from the roofs. Further water meters were installed in February 2022, so as to obtain more accurate results on the water quantities that are collected, stored and reused.

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Figure 2.23. Rainwater collection system from rooftops and buffer tank

Subsystem 2

The slow sand filtration system (SSF) was built in April 2021 (Figure 2.24). First, hydraulic tests were conducted on the system, finalizing the operation conditions.

The SSF system consists of a tank inside of which lies a ‘bed’ of sand (i.e., media), supported by gravel, lying on a suitable under-drainage floor. The treatment processes in SSF are physicochemical (filtering, adsorption) and biological. Thus, the biological growth on the filter media effects higher quality effluent but at the same time it results in the clogging of the filter, particularly at the upper surface of the bed. Eventually the filter is clogged completely, so it must be cleaned. Periodically removing the top layer of sand by manual or mechanical ‘skimming’ allows the filter to continue to function efficiently. Water monitoring during the ripening period is important in determining when treated water is of drinking water quality.

From the operational viewpoint, physical parameters such as influent turbidity levels remain relatively low and constant in order to avoid rapid filter clogging and the requirement for skimming.

However, due to some failures the system was fully operational in March 2022.

The system is monitored through laboratory analysis with respect to the quality of water produced and compared to drinking water quality.

Figure 2.24. Slow sand filter installation

Subsystem 3

The Aquifer Storage and Recovery system started to be developed from November 2020 when the Bioswale system was built. In February 2021, the manhole was constructed for the collection of the surface runoff along with the pumping and the piping equipment that was installed, finalizing the entire subsystem by April 2021. By June 2021, this subsystem was fully operational and controlled by the PLC system in order to perform all automated actions (Figure 2.25).

Water collected from the **bioswale** is mainly stormwater and is sent with gravity to the open tank (10 m^3) that acts as a buffer tank and then to recharge the aquifer. In December 2020, after the Bioswale was constructed, there was the first major rainfall event (about 81 mm) of the wet year 2020-2021, which tested the system and was proven to be very efficient both in terms of a flood protection measure as it prevented the flooding of an adjacent olive tree crops, and in terms of stormwater collection. As at that period the pumping systems had not been installed, to avoid the flooding of the HYDRO4 field, a temporary network of pipes and a pump was installed to send the collected stormwater in the bioswale system to the aquifer recharge site and store it in the subsurface. A year later, during the next wet period 2021-2022, in December 2021 another less significant event occurred (about 34 mm) which resulted in preventing the flooding of the lavender field, but also in collecting stormwater to be stored in the subsurface. Next, another event took place in mid-January 2022 (about 46 mm) and the water collected in the bioswale was diverted to the open tank and then pumped to the AR site for artificial recharge in the aquifer. At the end of the same month, a major rainfall event occurred (about 84 mm) which resulted in collecting and storing in the subsurface the stormwater collected from the bioswale system. In total the stormwater that was collected by the bioswale system amounted to 470 m^3 for all the wet periods.

Figure 2.25. Bioswale system construction, collection in the open Tank collection and AR well.

The **surface runoff** from the residential yards has been collected through a manhole in Tank 2 (40 m^3) since April 2021, when subsystem 3 was operational and the piping and pumping systems were installed (Figure 2.26). The rainwater from Tank 2 was sent partly to recharge the aquifer and partly for irrigation needs. Unlike the bioswale system, the surface runoff collection system is operational even during low rainfall events. Indicatively, some rainfall events that took place in the wet periods are January 2021, April 2021, November 2021, December 2021, January 2022, February 2022 and November 2022. From all the events (minor and major) about 80 m^3 were collected in the wet periods and was stored in Tank 2.

Monitoring activities have also been performed in Tank 2, in which rainwater has been collected from surface runoff, and in the wells, in terms of quantity (water level) as well as quality (pH, conductivity and turbidity of water). The respective sensors are operational from November 2021 and monitoring the wet periods to optimize the operation of this subsystem. Additionally, samples of the water in Tank 2 have been regularly collected (at a monthly basis) to perform laboratory analysis for the quality of the water.

When the PLC was installed, all operations were performed uninterruptedly according to the water management scheme that was designed.

Figure 2.26. Rainwater collection of Surface runoff (manhole 2, collection pipes andTank2)

Agricultural activities (species, plantation dates, harvest periods, failures)

As the project engages also agricultural practices, the elements of plantation, growth, harvesting and exploitation potential of particular crops were explored to ensure sustainability of the area but also identify optimum business models for exploitation of the water management optimization schemes. For HYDRO4 the aromatic plant of Lavender was selected based on the local weather and soil requirements (Figure 2.27).

Figure 2.27. Preparatory activities and plantation of lavender

In the HYDRO4 agricultural site, at a land area of about 0.2 ha, initially 6,000 plants of *Lavandula angustifolia* (Lavender) were ordered and the irrigation system was designed (drip irrigation). The plan was to proceed with the plantation of lavender and the final installation of the drip irrigation system in early spring of 2020. However, due to COVID-19 travel restrictions these activities were postponed for autumn 2020. The lavender plants were sent to Mykonos in October 2020, but again due to travel restrictions they were not planted and were put to hypnosis. However, the lavender plants did not recover from hypnosis. Therefore, lavender plants were reordered and replanted in March 2021. The designed irrigation system was installed in March 2021 together with the soil preparation steps and the lavender replantation activities.

The prevailing weather conditions did not allow the plants to grow properly and eventually led to their withering. In May 2021, 6,000 new plants were ordered in order to be planted during the period of 2021. The soil was prepared for the new planting of lavender in early December 2021, expecting the first rains of the wet season. The area was cleared of weeds and then the soil was dug around the irrigation lines (Figure 2.28).

Almost 2,000 meters of drip lines were installed for the application of water to the crops. The drip emitters distance was 0.5 m in order to provide appropriate water application to the crop (Figure 2.28). In addition, a water pump was installed for pumping the water to the drip irrigation lines from the aquifer. Finally, various sensor types were installed in the site (e.g., soil moisture sensors, water level sensors, solenoid valves etc.) for monitoring crop water needs and optimizing water irrigation schemes.

Figure 2.28. Irrigation system of the lavender field

During December 2021, the planting of two of the four sets of lavender plants took place. These were plants with larger root systems and were already 8 months old. After the planting phase, irrigation was regularly during the dry season of 2021.

At the end of January 2022, for the prevention of severe weather phenomena with very low temperatures and snowfall, the roots of the plants were covered with straw for their protection, which resulted to have only the lavender leaves dried out, but not the entire plant, at a rate of 60%. At the end of February 2022, the next two sets of lavender were planted and the same planting procedure was followed. Irrigation followed throughout the existing and new crop.

In April 2022, cleaning the crops from weeds and fertilizing the plants with an organic mixture of fish and algae every 15 days took place. Irrigation was performed 2-3 times per week. In the beginning of September 2022, irrigation was stopped for a week for the lavender plants to raise essential oils in the foliage and the harvesting followed.

2.3.2. Monitoring of HYDRO4

- ***<u>Operator's monitoring plan/ monitoring srategy</u>***

Regarding the monitoring of HYDRO4, several parameters both for quantity and for the quality of water have been measured. For measuring the water quantity, Ultrasonic Level meters were installed in the tanks, Pressure level meters in the wells and a Meteorological station. As for the quality, both online monitoring - industrial and low-cost sensors (Conductivity, pH, T, Turbidity) are used (Figure 2.29).

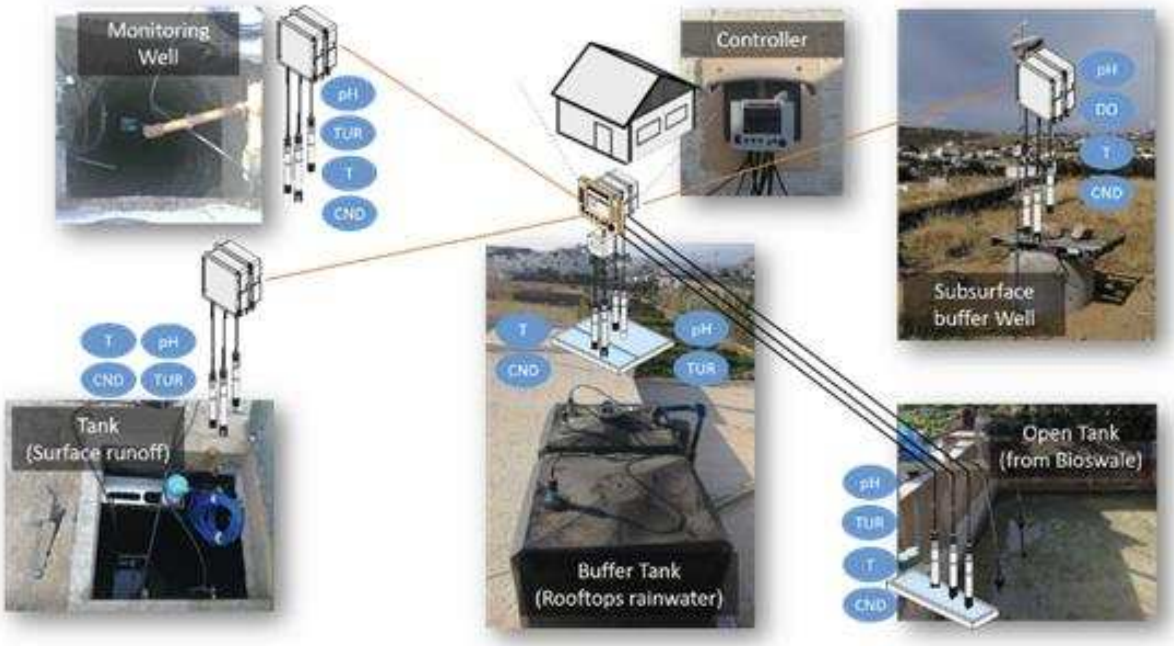


Figure 2.29. On-line probes installed in HYDRO4

In parallel with online quantity and quality monitoring, several sampling campaigns have been conducted since October 2020 to ensure the smooth operation of the systems and the high quality of the recovered water. The sampling points for HYDRO4 are depicted in Figure 2.30. The conducted analysis encompasses typical physicochemical parameters, heavy metals, major ions, and microbiological parameters (TC, *E. coli*, *Enterococcus*) for all samples, aiming to guarantee the irrigation water's good quality and compliance with Greek and EU water reuse regulations (CMD No 145116, 2020/741). Additionally, for the SSF effluent, which is tested for potable use, the samples are analysed for organic and inorganic compounds as per the EU Directive (EU) 2020/2184.

Figure 2.30. Sampling points in HYDRO4 demo site

Water sampling at the HYDRO4 site was conducted bi-monthly to monitor water quality parameters. Physicochemical analysis was performed on all samples, while microbiological analysis was conducted monthly. The sampling locations include the artificial recharge well (AR), Tank 2, the Open Tank where water was collected from the bioswale, the Tank1 where is collected from the rooftops of the houses and the SSF system.

Weekly monitoring involves checking the water level using portable field instrument to measure the distance from the top of the sensors to the water surface. A parallel check was performed with the low-cost and industrial monitoring system to ensure accurate and synchronized data recording. Additionally, the operational performance of the systems is assessed based on quality parameters' data from industrial and low-cost sensors, following a specific field procedure. Portable multi-meters were used to measure pH and conductivity at each sampling point, while oxygen was measured in the wells (AR, Well 1). The recorded data from the low-cost controller and PLC were cross-checked.
The various water quality parameters recorded using industrial quality sensors installed in tanks and wells at specific locations are listed below:

- AR well: Conductivity, Temperature, pH, Dissolved Oxygen (DO)
- Tank 2: Turbidity, Conductivity, pH, Temperature
- Open Tank: Turbidity, Conductivity, pH, Temperature
- Tank 1: Turbidity, Conductivity, pH, Temperature

In addition to water quality monitoring, flowmeters have been installed at multiple points, and their values were recorded weekly. These include two flowmeters in the AR (one for lavender irrigation and one for aquifer recharge), one in Tank 2, one in the open tank, one in the bioswale, and one in Tank1 for water collection from houses' roofs.

All the above mentioned measurements recording on field was a parallel process with the sampling campaigns The recording of the values was done at the same time with the water quality measurement by multi-meter. The data collected are gathered in an excel file in order to compare the values and to check the proper operation of all sensors.
In order to fully control and understand the operation of processes and sensors in the field a calendar was used, in which the sampling dates were recorded in parallel to the collection of meteorological data, the irrigation schedule, the emptying process of tanks in case of maintenance, the overflows etc that have been occurred in the previous days or if there was a specific event such as some failure at an intermediate date.
This comprehensive monitoring approach ensures regular assessment of water quality, system performance, and flow rates at various points within the HYDRO4 site.

2.4 Overall description of the operation of HYDRO5

The HYDRO5 demonstration site is implemented within the area next to the local reverse osmosis (RO) plant present in Tinos Island, located in the Cyclades archipelago.
It includes two technologies for the production of freshwater and tropical fruits, as follows:

- A desalination system, named Mangrove Still System (MSS)
- An agricultural site composed by a greenhouse producing tropical fruits, named Productive GreenHouse (PGH) and an appropriate irrigation system.

Figure 2.31 illustrates the general layout of HYDRO5.

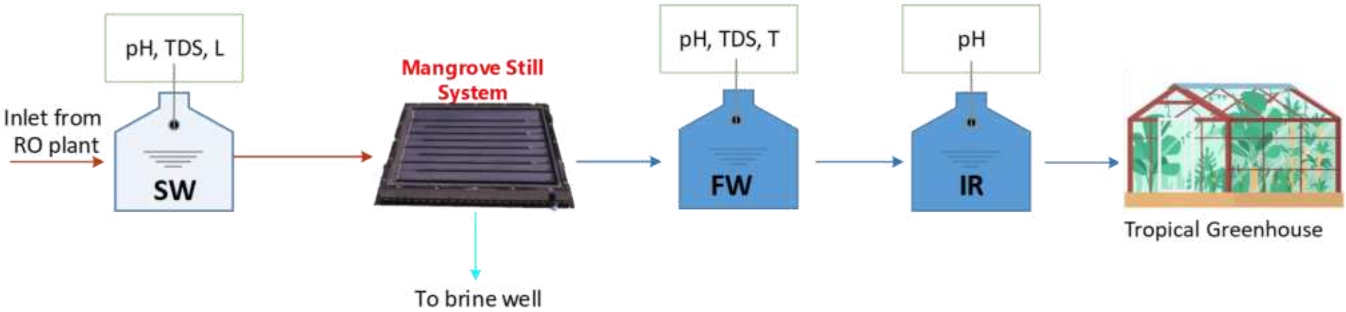


Figure 2.31 Scheme of the overall system

The whole logic of the HYDRO5 follows the points below:

- MSS's seawater tank fills up by pumping seawater from the nearby Reverse Osmosis plant of Tinos Municipality.
- The seawater is then driven to the Mangrove still units where the evaporation/condensation process takes place and brine and freshwater are generated. The system has been configured in order to guarantee an optimal feeding plant pressure ranging between 1 and 3 bar.
- Brine and freshwater are collected in the dedicated tanks
- Brine is discharged to the Reverse Osmosis's disposal well or, according to a Circular approach, it can be pumped back to the seawater tank where the loop is closed, undergoing a further evaporation/condensation process.
- The salt factory is activated by deviating the brine flowing out from the units, through the 2 ways-valves. Once the trays are filled, the fans are switched on, starting the salt production process.
- A tap water emergency feeding system to the water storage tank next to the PGH, has been implemented in case of lack of producing enough or adequate FW quantities from the MSS system.

The installed technologies, although independent from each other, work in an integrated manner thanks to the automation system, which allows the management of the inlet and outlet flows from the saltwater source down to the irrigation of the PGH. Figure 2.32 highlights some of the basic sub-systems of HYDRO5.

Figure 2.32. Main sub-systems of HYDRO5

2.4.1. Operation calendar since the start-up (technological systems and cultivations)

➢ **MSS operational phases applied**

The system was successfully installed in September 2020 and run continuously since then, except the period October 2020 - May2021 when the system was off.

Below the main actions and troubleshooting of the system are reported:

March 2019 - October 2020:

- Prototyping and testing the technologies to be installed.
- System installation in Tinos Island to achieve the foreseen KPI's
- Trial operation of the system for a total of 20 days

October 2020 - May2021

- System turned off, cleaned and put in security

May 2021 - March 2022

- Finalizing of the installation of the control/monitoring systems.
- Launch of the overall HYDRO5. Sufficient operation of the automation system of the combined technologies, allowing the management of the inlet and outlet flows and continuous operation of the system
- November 2021-> Problem reported on the signal cable which controls the intercommunication of the PLC and the devices hampered system's functioning – and salt crystallization within the units, interrupted the continuous MSS operation -> Restoration by deep cleaning.- problem solved
- Minor events of pumps' shutdown due to sensing system malfunctioning.

March 2022 - May 2022

- An optimization plan was conducted to improve system's efficiency and the system run continuously.
- A malfunction reported on the SW tank overflow, due to connection malfunction among Raspberry node and PLC -> SW overflowed into the PGH, causing harm to some fruit Passiflora and Gingers plants.

June 2022 – November 2022:

Further operation optimization plan of the system mainly focusing on the automation system (MSS & PGH).

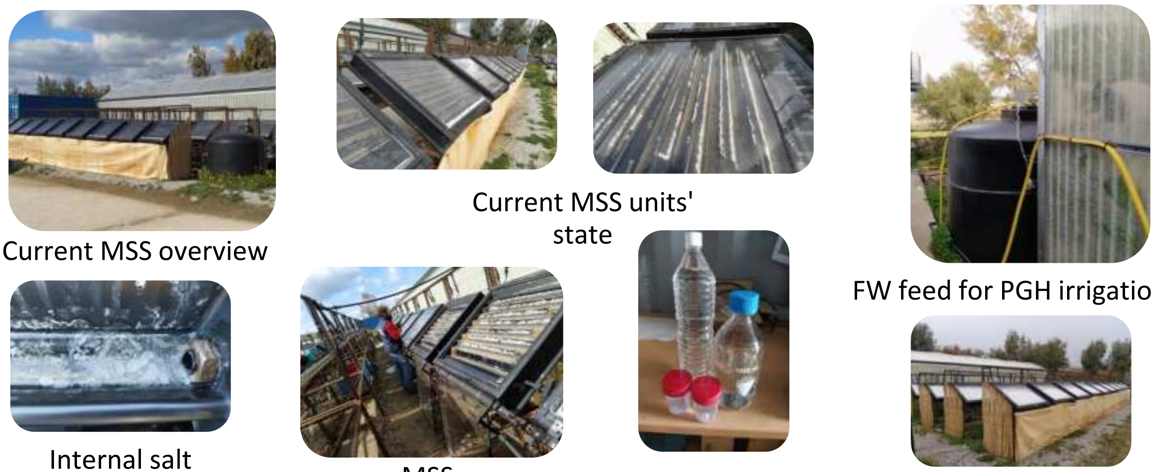
- Floater-controlled valve implementation to the SW tank.
- Fresh water tank online flux-meter implementation along with its PLC representation.
- Update of the Raspberry nodes' online communication so as to auto-refreshing their function.
- Lifting of brine buffer tanks in order for brine to flow by gravity, reducing power consumption.
- Speeding of network/Wi-Fi so as to achieve the optimum sensor response.
- Replacement of solar panel charge devices with advanced ones, to secure optimal battery autonomy.
- Programmatic Code readjustment to ensure optimal system interconnection.
- Fully Pumps' check, anti-corrosion sealing and overall maintenance.
- Modules' structure fabric coating to cover their rusty view.
- Gravel paving of the demonstration area.
- General interior and exterior area cleaning in accordance to a clear relevant plan.
- Total inside out cleaning of panels by removing the crystallized salts and flushing the whole system to avoid pipe blockages and a FW conductivity rise.

December 2022 - up to now

- Continuous function and proper daily maintenance of the whole system without any issues arising.
- Day after day application of units' by-pass to avoid internal blockage due to salt film formation-> Result: significantly lower fresh water conductivity.

- Scheduled MMS maintenance for internal salt residues.

Figure 2.33 Illustrates some recent photos regarding MSS status.



Current MSS overview

Current MSS units' state

FW feed for PGH irrigation

Internal salt film formation

MSS maintenance

FW sampling

Winter 2023 in HYDRO5

Figure 2.33. MSS system in operation.

➢ **Agricultural activities (species, plantation dates, harvest periods, failures)**

<u>The major activities regarding PGH are summarized to the following:</u>

<u>December 2019:</u>

- Planning and design phase of the greenhouse.
- Purchase of a greenhouse from a contractor in Athens.

<u>February 2020:</u>

- Soil works for the site of the PGH by replacing the rocky top-soil up to a depth of 30 to 40 cm with a mixture of compost and good agricultural local top-soil.
- PGH's point-fundaments and the main load carrying metal columns were constructed.

<u>September 2020:</u>

- PGH installation was completed.
- First plants from the nursery in Crete arrived and planted on site, which included:
    - 27 Bananas
    - 42 Passiflora (29 of one type, 13 of another)
    - 32 Pepino
    - 60 Ananas
    - 17 Dragon fruit
    - 56 Ginger and Curcuma mix

<u>November 2020 - December 2020:</u>

- A severe spider-mite infestation affected Pepino and Papaya plants resulting in Pepinos' total failure.
- Papaya trees recovered after spraying crop protection oil and synthetic pyrethroids.

<u>May 2021</u>:

- Installation of ventilation window automated control
- Spraying of shading paint cover on the PGH roof
- Application of soil amendments to lower the high soil pH
- Application of organic fertilizer based on chicken manure
- *Aloe-Vera* and *Aloe Arborescens* were planted as companion crops

<u>July 2021 - August 2021:</u>

- Heat stress of some plants, resulting to bananas leaves' discoloration, some brown/black young leaf shoots and premature fruit drop of some Ananas.
- Minor Electrical failure of window automatization and restoration

September 2021:

- Installation of an automated irrigation system, where a soil humidity sensor controls the irrigation pump.
- 2nd round of planting accomplished including:
    - 24 Ananas
    - 15 Physalis peruviana
    - 10 Ginger
    - 10 Elettaria cardamomum
    - 10 Curcuma longa
    - 10 Colocasia esculenta
    - 1 Guava tree, 1 Cherimoya tree, 1 Coffee plant & 2 Passiflora
- Superficial salt-water overflow incidents from the MSS affected mostly Ginger and Curcuma plants.

November 2021 - December 2021:

- Papayas setting their first fruits.
- Mulch laid into the PGH soil for root antifreeze protection and evapotranspiration reduction.

February 2022 - March 2022:

- 1st round of general harvest accomplished.

May 2022:

- Failure of some Ginger plants and Passiflora fruits, due to SW tank's overflow.

June 2022:

- About 100 new Aloe Vera Plants were planted.
- A Summer school on-site visit was performed along with another site partners, where a 2nd round of general harvest accomplished.
- General optimization activities were carried out including repainting of the GH, chicken manure application, copper-based fungicide and pyrethrum insecticides spraying for crop protection.
- The overall PGH status was upgraded and a regular maintenance plan was applied.

July 2022 - September 2022:

- Some ripe banana and papayas fruits were successfully harvested and offered to Municipality workers.

October 2022:

- An incident of Aphids and Greenhouse whitefly into some *Aloe Vera* plants, efficiently treated by spraying soap water and natural pyrethrin pesticide (pyrethrum).
- An on-site visit and HYDRO5 presentation in the context of permaculture design courses organized by HYDRO6 partners (Tinos Eco-lodge).

November 2022 - January 2023:

- Another round of crops was harvested.
- An on-site visit demonstration and workshop was accomplished by the Environmental team of the technical school of Tinos. The students harvested *Aloe Vera* leaves and some ripe bananas were offered to the students. An Aloe-Apple marmalade and an Aloe soap were produced after offering the harvested *Aloe Veras'* leaves to the local market.
- Ripe Ginger plants were harvested, dried, cut into smaller pieces and replanted.
- Harvest cardamom leaves offered to a local traditional store in order to dry them as herb for beverages.
- An organic liquid potassium fertilizer applied at the end of December as cold preventive measure.

February – April 2023:

- Another aphids' incident occurred into some *Aloe Vera* plants. Soap water and paraffin oil applied in cycles to eliminate it.

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- An issue of *"Anthracnose"* (black/brown small or larger spots) into some non-ripe fruits of a large banana bunch was presented, resulting into losing some of those -> Spraying with copper-based fungicide and removal of the infected fruits to avoid any expansion.
- General chlorosis issue probably due to winter stress is presented mainly as bananas and papayas leaves discolouring/wilting. Colocasia, Guava tree, Coffee plant and Cherimoya tree are struggling under the winter weather conditions.
- An organic liquid fertilizer applied at the end of March.
- Four ripe banana bunches were harvested and offered to: (i) Municipality workers & local citizens (ii) Tinos social kitchen (iii) Tinos kindergarten and (iv) Tinos 2nd elementary school (in parallel with a HYDRO5 presentation).
- fertilization season, using organic bio-stimulants and chicken manure, took place on April-May 2022.

- Current PGH cultivation includes:
  - 12 *Aloe Arborescens plants*
  - 176 *Aloe Vera* plants (diverse size)
  - 16 Bananas *[Musa acuminata]* + their pups
  - 7 *Ginger Galaga plants*
  - 6 Papaya trees [*Carica papaya*]
  - 3 non-fruit Passifloras [*Passiflora Alata*]
  - 1 fruit Passiflora *[Passiflora edulis]*
  - 10 Ananas/Pineapples *[Ananas Comosus]* (1 ripped)
  - 8 Dragon fruits plants
  - 4 *Colocasia esculenta*
  - 1 Guava tree [*Psidium guajava]*
  - 1 Arabian Coffee plant
  - 1 Cherimoya tree [*Annona cherimoya*]
  - 30 Cardamom plants *[Elettaria cardamomum]*

Figure 2.34 provides representative photos of the PGH, while Figure 2.35 presents the main products along with community engagement activities.

Current PGH overview

Current cultivation state

Soil sampling

Aloe pups' replanting

PGH maintenance

A ripe Banana bunch

Winter 2023 into PGH

Figure 2.34. Representative photos of PGH

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Elementary School on-site visit


Papayas & Bananas harvest


Aloe gel extraction


High School on-site visit


Bananas' offer to the local social kitchen


Aloe soap production


Bananas' offer & presentation to local Kindergarden


Ripe Bananas

Figure 2.35. Main agricultural products of HYDRO5 and community engagement activities

2.4.2. Monitoring of HYDRO5

➢ ***Operator's monitoring plan***

The main activities for the monitoring & maintenance of HYDRO5 are listed in the Table 2.6:

Table 2.6. Monitoring and maintenance activities in HYDRO5

General activities	Frequencies	Estimated time	Comments
MSS			
General check for leakages (units, salt factory, hydraulic connections)	2 time per week	30 min	Paying attention to possible salt crystallization on the hydraulic connections
General check of the units	2 times per week	1 hour	Paying attention on the salt formation
General check of the rainwater collectors	Every month	30 min	Remove leaves, branches etc, which might obstruct the outlet
General check of pump status	Every month	30 min	Paying attention to rust formation
General check of filters and cleaning	Every 2 months	1.5 hours (10-15 mins per filter (7))	Paying attention on uninstallation and installation to the connected hydraulic components (pipes, connections)

General activities	Frequencies	Estimated time	Comments
		MSS	
Glass cleaning	Every 2 months	4-5 hours (3/4 mins per glass)	Avoid scratches, use of appropriate tools (micro-fibre fabric/windscreen wiper
Removal of weeds	Every 2 months	1-2 days	Avoid damages to structures, pipes, cables.
Anti-rust treatment	Twice	10+ hours (depending on the status)	Only in the most susceptible areas emerged from the general check Scratch the area before application (removal of rust) Applying anti-rust coating, let it dry and then painting
System shutdown	In case of conductivity rise of the produced FW	5-7 days	Removing glass panels and store them within the warehouse Cleaning the units Removing pumps (where possible), cleaning (emptying from saline water) and storing them within the warehouse Protecting the inverters Flushing the hydraulic circuit
General check of the condensation units	Twice per week	15 min	Ice-buildup, status of fans, paying attention to cooling power (potentially broken Peltier elements at PC or lack of cooling liquid at CC)
General check of water conveying system	Twice per week	5 min	Leakages, performance of pumps
Check of water meters –Record data	Twice per week	5 min	Blockages, cable connections
Check of monitoring system	Daily	5 min	Ensure system is online and writing date. Read out data.
Check of sensing system	Daily	5 min	Ensure its proper interconnection, representativeness and response.
Overall interior and exterior facilities' cleaning	Once per week	15 min	Continuous care for the cleanliness and appearance of HYDRO5 area.
General activities	**Frequencies**	**Estimated time**	**Comments**
		PGH	
Inspection of PGH cultivation progress	Once per week	5min	
Check of irrigation electro-valves proper connection &function	Once per week	10min	
Removal of PGH weeds and wilting leaves	Once per 2 week	1-2 days	Regular removal not to affect the growth of the cultivation

General activities	Frequencies	Estimated time	Comments
			by uptaking nutrients or attracting parasites
Pesticide application for general crop protection	Every 1-2 months	1 hour	Plant foliar spraying of copper based fungicide or pyrethrum & paraffin oil.
Fertilization of the Cultivation	4-5 times per year	1 hour (superficial) 3 days (basic)	Organic fertilizing (N, P, K, organic matter and free amino agents) for cold protection or general plant protection. Application of chicken manure or super eco vas for basic fertilization to boost the growth of the crop.

➢ ***Monitoring strategy*** -

The monitoring of HYDRO5 was implemented using on-line measurements and laboratory analyses. The parameters under consideration are listed below:

- ***Online measurements***
  - Industrial sensors into SW, FW and Brine tanks for conductivity, pH and temperature measurements
  - Level sensors into SW, FW, Irrigation tanks and Brine, FW buffer tanks
  - Low-cost pH, turbidity, temperature, water level and TDS sensors into FW and Irrigation tanks
  - PGH and outside weather stations
  - PGH soil moisture sensors on each PGH plot
  - FW and Irrigation water flux–meter
  - Portable TDS sensor

- ***Lab analysis***
  - Twice per month physicochemical water quality analysis: Samples were collected from 3 points of the system: Fresh Water Tank (FW), Sea Water Tank (SW) and Brine
  - Monthly microbiological analysis: Samples were collected from Fresh Water Tank (FW)
  - Annual micro-pollutants' analysis: Samples were collected from Fresh Water Tank (FW), including control sample of tap water

Figure 2.36. The main online probes of HYDRO5

2.5 Overall description of the operation of HYDRO6

HYDRO6 (Figure 2.37) is located within a remote eco-tourist facility in Tinos Island. In HYDRO6 water is first collected and then recovered after usage within a system of loops that are interconnected and allow increased business diversification where eco-tourism is integrated with agricultural production. The business model developed within HYDRO6 is less vulnerable to fluctuations within the tourism sectors, as it generates income diversification, reduces costs, and increases biodiversification of the natural environment, without stressing the water provision system from the public grid. To reduce the overall water withdrawal, the water used in the facility derives from: 1) surface water from rain captured through a rainwater harvesting-storage system and a stream, 2) vapour condensation unit for direct water production. These technologies are nature-based and rely on minimal use of energy that is provided through solar panels. The anthropogenic cultural landscape of the locality where HYDRO6 is being demonstrated (Tinos) and the natural habitat are carefully integrated and valorised into the design of the technology through technical measures (i.e., usage of local materials, building techniques, and traditional craftsmanship) and social adaptation (i.e., behavioural and cultural integration of changes toward alternative sanitation concepts).

Figure 2.37: Overview map of HYDRO 6

The operation of HYDRO6 can be divided in two different parts, the water loops consisting of NBS technologies and the technical infrastructure like the energy system etc. and on the other hand the agricultural systems formed by the different cultivations. The technical infrastructure is maintained on a regular basis and occurring errors follow a linear troubleshooting strategy leading mostly to a successful rectification of the problem within a foreseeable time frame. The agricultural systems are much harder to manage and the variety of unforeseeable problems that occur is significant, while troubleshooting and solutions do not always follow a linear logic due to the high complexity of the interacting factors within the system. Also, the reoccurring task such as seeding, planting, weeding, pest scouting and harvesting are high and need a significant effort and time demand from the operator.

Overall, it can be stated that the operation of HYDRO6 is fairly complex due to the many different activities, the diverse knowledge needed and the experience that has to be gained in order to operate the whole system. The last three years of partial and two years of full operation have shown that beside complexity the system performs very well and can be characterized as robust with overall minor operating problems.

The water loops can be divided into two loops with similar characteristics. The first is the one that was existing before the HYDROUSA project which was upgraded and the second that was entirely designed and built throughout the project. The loops consist of an extensive rainwater harvesting and storage system where all build surfaces are utilized to collect rainwater and two cisterns store the water for consumption within the dry period. The sanitation loop where two independent constructed wetlands treat the sewage water and output it into storage tanks used for irrigation after disinfection through UV-treatment. The new sanitation loop only treats grey water due to the implementation of a composting toilet within the new lodge. In addition, vapour condensation systems for direct drinking water quality water production were implemented. A detailed flow chart is shown in Figure 2.38 illustrating the different loops, the agricultural production, the energy system and the organic matter flow.

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The automation logic of HYDRO6 is to keep it as simple as possible and use automated controlled process only where it is really beneficial to the operating procedure. Automation is used in pump control via pressure sensors for the water network, pump control via timers for the feeding system of the vertical flow CW, irrigation controllers for handling the different irrigation zones and some power lines that are controlled by the state of charge of the battery system in order to optimize energy usage. The minimization of automated processes derives from the need to maintain, control, repair and understand the whole system at a local level in order to ensure continuous operation with reduced reliance on non-resident experts. Furthermore, the energy consumption of complex automated processes is considerable within an off-grid energy system.

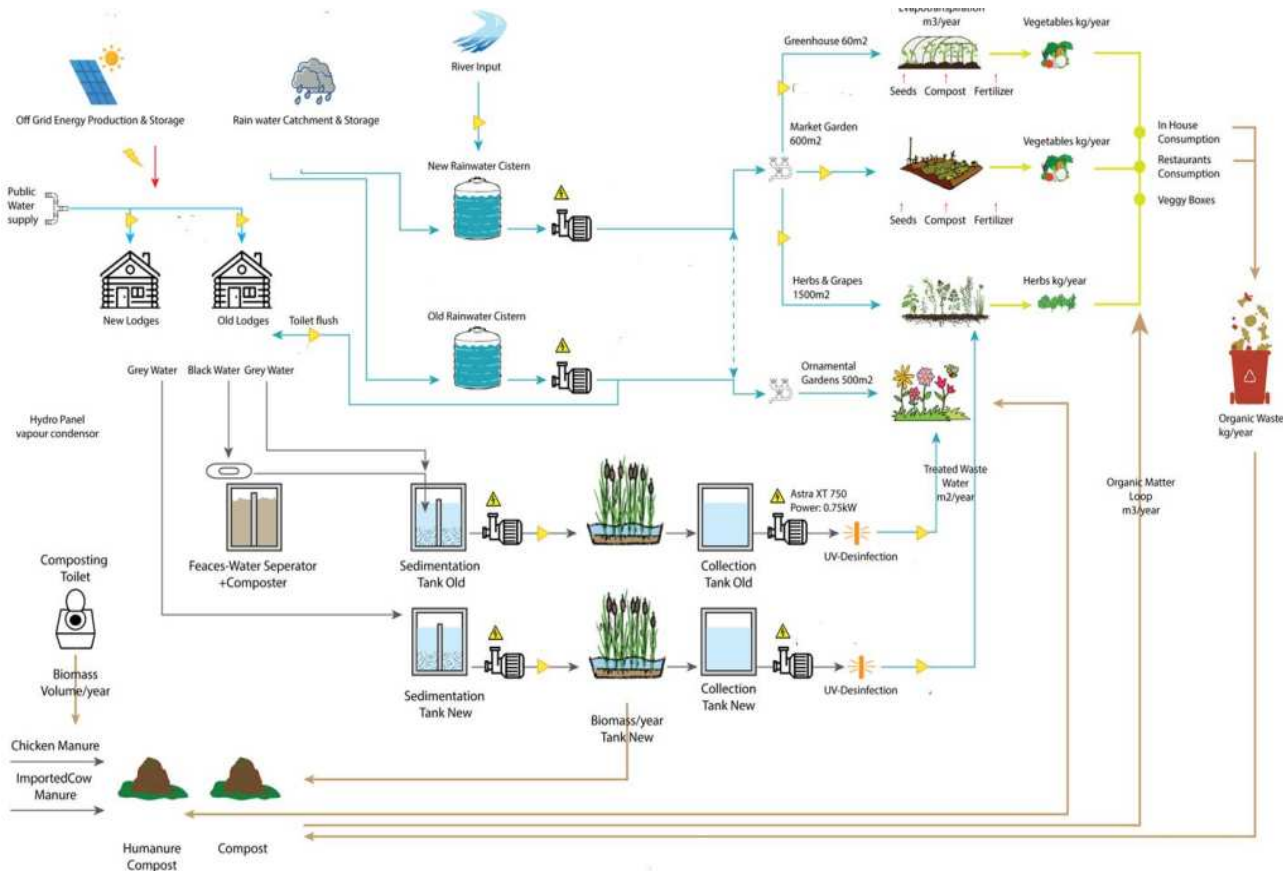

Figure 2.38: Flow Chart of HYDRO6

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Figure 2.39. Overview of HYDRO6 demo site.

2.5.1. Operation calendar since the start-up (technological systems and cultivations)

October 2018 – May 2019

- Renovation of small stable and operation as a hosting room for volunteers
- Fog catcher experimental Nets were installed

December 2018 – May 2019

- Design and construction of Greenhouse and start of operation,

January 2019 – May 2019

- Completion of study by two Agronomists for the planning and design of market garden, herb plantations and grapes at ELT

January 2019

- Installation and operation of first meteorological station
- Propagation of herb plants from the existing gardens in order to produce healthy and well adapted plants

March 2019

- Installation and operation of experimental fog catchers investigating condensation
- First soil samples from garden areas
- Landscaping and stone wall construction for future herb plantation

March 2019 – July 2019

- Construction of open Cistern that collects water from greenhouse roof, new lodge and start of operation.
- Implementation of integrating the new water supply network into to the existing one

April 2019
- Construction of chicken coop and first chicken are born

May 2019
- Implementation of the first market garden with irrigation system setup and soil improvements
- 1st market garden operation and management of a growing season

June 1019
- Installation of central irrigation system inside the Greenhouse for deploying water to all irrigated sectors

September 2019 – January 2020
- Herb plantations of oregano, lavender, Dictamnus, sage thyme, helychrisum, capers and artichokes
- Installation of additional irrigation zones

September 2019 – July 2021
- Design and renovation of bigger stable and operation as a guest house from August 2021.
- January 2020, design, construction and operation of sewage treatment of new lodge in August 2021

March 2020
- Purchase of pickup truck for delivery of agricultural products and transport of materials

April 2020
- Setting up the contacts and the organization of selling vegetables, first orders from local restaurants for veggie deliveries

April 2020
- Design and implementation of Grape plantation and additional irrigation zones

September 2020
- The condensation systems were set up by a team from ALCN (MuFu/ Water Flower)

October 2020
- Water flower / MuFu active and passive up and running

November 2020
- First operation of veggie box delivery to households

November 2020
- Start of water monitoring, taking and sending samples to NTUA according to the monitoring plan

September 2020
- Researching specialized equipment and tools for the market garden, reorganization plan for the veggie box delivery market outlet
- Purchase of garden tools for market garden, wood-chipper, weeders, clippers etc.

January 2021
- Purchase of special boxes that can be used for many years and can be folded to lower storage area for veggie box house deliveries.
- February 2021
- Building of propagation tables and production of veggies from seeds and setting up a dedicated area for propagation with storage and equipment

March 2021
- Moving of chicken coop and creation of 2nd market garden
- Condensation was observed on all the systems, and from the Water Flowers significant amounts of condensate was collected. The condensation on the MuFu did not lead to measurable runoff.

July 2021
- Installation of IoT sensors and operation of water monitoring from AGENSO
- Installation of industrial sensors in the new rainwater cistern and in the sewage system of renovated new lodge

October 2021

Two PV-driven vapour condensation systems were installed (Zero Mass Water Hydropanels) at HYDRO6, for drinking water needs of the Ecolodge customers.

November 2021

- Purchase of distiller for essential oils and 1st distillation in June 2022

December 2021

- Improvements in the irrigation system setup, increasing filter size and changing to disk filters, integration of a dosage pump for fertigation through the drip lines

June 2022

- Three-day Demo site event with Impact Hub Athens and NTUA at HYDRO6
- Agricultural activities (species, plantation dates, harvest periods, failures)

2.5.2. Monitoring of HYDRO6

➢ ***Operator's monitoring plan***

Water sampling at the HYDRO6 site was conducted bi-monthly to monitor water quality parameters. Physicochemical analysis is performed on all samples, while microbiological analysis is conducted monthly.

Twice per month the water level monitoring was conducted measuring the distance from the level meter comparing it with the low-cost control system to ensure the accuracy of the recorded data. Additionally, the operational performance of the systems was assessed based on data from industrial and low-cost sensors for quantity and quality parameters. Portable multi-meters are utilized to measure pH and conductivity at each sampling point. The recorded data from the low-cost and industrial sensors are cross-checked.

The data collection from the sensors was a parallel process in each sampling and involved extracting the values of the industrial level meters, recording the water meters and the quality data. The collected data are gathered in an Excel file to compare the values and ensure the proper operation of all sensors.

To comprehensively control and understand the operation of processes and sensors in the field, a calendar is used. In this calendar, sampling dates are recorded in parallel with the collection of meteorological data, the irrigation schedule, the cultivation data and any specific events that may have occurred.

The monitoring strategy for measuring the volume flows of rainwater and reclaimed water is currently based on the utilization of low-cost ultrasonic distance sensors, which have been developed specifically for this project. In HYDRO6, three of these sensors were strategically positioned, with the first sensor commencing data recording in July 2021. The initial setup phase was successful, and minor errors were promptly rectified. However, several issues have been observed over time due to the nature of the technology employed. These issues include misalignment of the sensor holder caused by strong winds, the presence of insects constructing nests on or in front of the sensor, the accumulation of water droplets due to condensation, significant temperature fluctuations, material degradation, corrosion on battery contacts, and weak mobile network coverage resulting in inaccurate distance measurements.

➢ ***Monitoring strategy***

The systems are monitored online through industrial and low-cost sensors, that are installed in the cistern and the treated water tank, for quantity measurements (ultrasonic level sensors, flow meters) and quality measurements (pH, conductivity, turbidity, temperature), shown in Figure 2.40. Quality probes in HYDRO6In addition, soil moisture sensors are installed in the cultivations and a weather station to monitor the meteorological parameters (Figure 2.41, 2.42). Moreover, a portable multi-probe sensor was used to check frequently the probes' operation.

Figure 2.40. Quality probes in HYDRO6

Figure 2.41. Low-cost system installation at rainwater cistern

Figure 2.42. Monitoring of water quality and quantity at tank (left), weather station and soil moisture sensor at vegetables garden (right)

The sampling campaign in HYDRO6 started in October 2020, and was conducted twice per month (that could differentiate depending on the sampling point) in order to monitor the wastewater treatment process and the quality of irrigation water. The selected sampling points are presented in Figure 2.43. Sampling points in HYDRO6 demo site.

- Typical Physicochemical analysis
- Heavy metals
- Major ions
- Microbiological analysis (TC, E.Coli, Enterococcus)

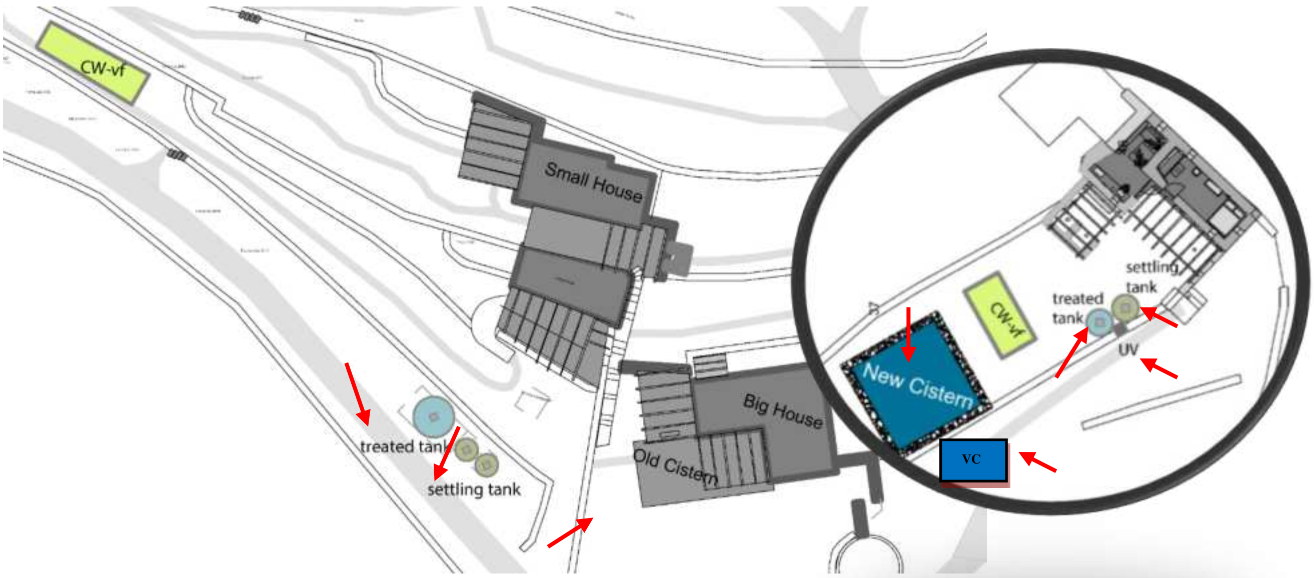

Figure 2.43. Sampling points in HYDRO6 demo site.

3. PERFORMANCE OF HYDROS

3.1 HYDRO1 Performance

Demo line

The UASB performance refers, mostly, to the removal of total suspended solids (TSS) and anaerobic degradation of organic carbon expressed as chemical oxygen demand (COD) or 5-day biochemical oxygen demand (BOD_5). In addition, organic nitrogen and phosphorus that are in particulate form are expected to settle, due to solids entrapment, in the UASB reactor, hydrolyse and/or solidify to inorganic forms. TSS removal range was 56 – 83 % except from period IV that it was decreased to 50% due to the increase of organic loading rate (OLR) in the reactor, while the temperature was still below 20 °C. TSS removal was maximum during period II (lowest OLR applied), mostly due to the lower upflow velocity (V_{up}) that was applied during that period (0.24 m/h instead of 0.35 m/h on average for other periods). COD removal efficiency followed the trend of TSS and ranged from 59% to 64 % except from the start-up period (43%) when biomass was acclimatized and period IV that was reduced to 44% due to the overload of the system. BOD_5 removal ranged at 62 – 72% except for transitional periods (III & IV) that was reduced to 40%. Total nitrogen (TN) removal was 13% - 20% except for transitional periods that previously retained organic nitrogen was hydrolysed with the aid of gradual temperature increase, thus increasing the TN value in the UASB effluent. Total phosphorus (TP) removal was dependent on organic phosphorus content of the influent wastewater and possible transformation to orthophosphates inside the reactor and was among 5% and 25%.

The overall performance of HYDRO1 (UASB-CW) was very high at all periods, documenting the contribution of the constructed wetlands as secondary treatment. TSS removal was almost complete reaching 97 – 99 % at all periods. Same was the trend for COD and BOD_5 that were removed at a range of 91 – 96% and 94 – 98%, respectively. Total removal of TN and TP was only limited (14 – 34% and 12 – 44%, respectively in total) and the two-stage constructed wetlands system was able to remove some due to the filtration of remaining, if any, organic part, plant uptake, adsorption of NH_4-N and PO_4-P, mainly by sand, and partial denitrification (possibly endogenous) of the nitrified ammonium nitrogen in the saturated zone found at the bottom 30 cm of the second-stage VSSF unsaturated CW (Figure 3.1).

CW performance refers to most conventional parameters' removal, since the complex physicochemical and biological regime inside a CW bed enables the removal of various pollutants with different mechanisms. TSS are mostly filtered inside the bed, thus reducing also COD and BOD_5 concentration. Also, COD removal is achieved anaerobically in case of VSSF saturated CW, aerobically in case of VSSF unsaturated CW or even anoxically in case of saturated zones with simultaneous nitrate nitrogen presence. Ammonium nitrogen (NH_4-N) and orthophosphates (PO_4-P) can be adsorbed in the CW substrate or precipitated, depending on the filling materials used. NH_4-N can also be transformed to nitrate nitrogen (NO_3-N) under aerobic conditions (in case of VSSF unsaturated CW). VSSF saturated CW was able to remove 77 – 88% of TSS content of the UASB effluent. It was slightly reduced (69%) during period V due to the overload of the system during the previous period IV, when the TSS concentration coming out of the UASB was >200 mg/L. Regarding COD and BOD_5, maximum removal was observed during period IV (68% and 67%, respectively) indicating the high buffering capacity in the case of an increased load coming out of the UASB reactor (COD > 400 mg/L), while minimum removal was observed during the subsequent period V (47% and 48%, respectively) due to hydrolysis of the particulate COD captured during period IV in combination with the decreased HRT (1.5 d). No NH_4-N removal or transformation was observed, indicating the prevailing of anaerobic conditions, low adsorption capacity of gravel and the minor significance of plant uptake. Only minor TN removal was observed mostly attributed to further filtration of organic nitrogen. TP removal was also not observed, since orthophosphates could not be adsorbed and almost no organic phosphorus was left in the UASB effluent. For periods I – V VSSF unsaturated CW with its intermediate sand layer could filter the TSS that were left in the saturated CW effluent increasing overall CW TSS removal efficiency to 92 – 98%, thus resulting in final effluent values of TSS <10 mg/L. COD and BOD_5 removal efficiencies were also increased to 83 – 92% and 90 – 95% after the second stage unsaturated CW. Regarding ammonium nitrogen, that was only treated in the unsaturated CW stage, the removal efficiency during the start-up was almost complete (99%), indicating that both adsorption and nitrification were acting simultaneously on the treatment. During the rest periods ammonium nitrogen was transformed to nitrate nitrogen at a rate of 87 – 97%. Since no organic nitrogen was detected in the VSSF saturated CW effluent, the TN removal that was attributed to the VSSF unsaturated CW was the result of partial denitrification taking place in the 30cm saturated zone at the bottom of VSSF unsaturated CW. During period V no saturation was applied at the bottom and as such TN removal contribution of VSSF unsaturated CW was minimum due to denitrification zone absence (Figure 3.2). During period VI, VSSF unsaturated CW treated the UASB effluent directly, thus the SLR was increased in comparison with the equivalent period II when VSSF SAT CW was used as well. Still, under the winter operation conditions (Q, loading, T), VSSF UNSAT CW achieved 92%, 77%, and 94% removal for TSS, COD and BOD_5, respectively. Nitrification performance was not compromised, and removal of ammonium nitrogen was on average equal to 95%. Most importantly, a) reuse regulation requirements were once again met since TSS, BOD_5 and Turbidity were on average 4, 5 mg/L and 4 NTU, respectively, and b) bypass of the VSSF SAT CW is feasible if operational conditions respect the loading requirements for long term stability and clogging preventions for VSSF UNSAT CWs (20 gCOD m^{-2} d^{-1}).

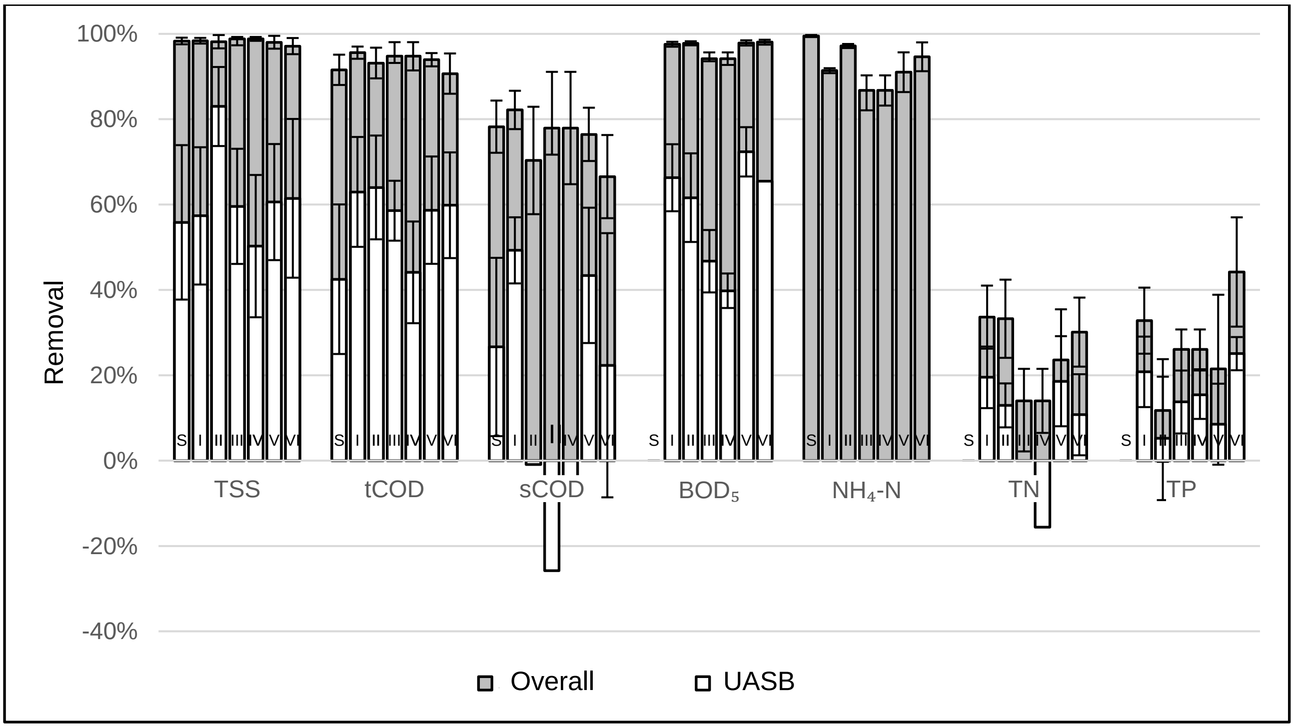

Figure 3.1 UASB and overall performance on conventional pollutants' removal

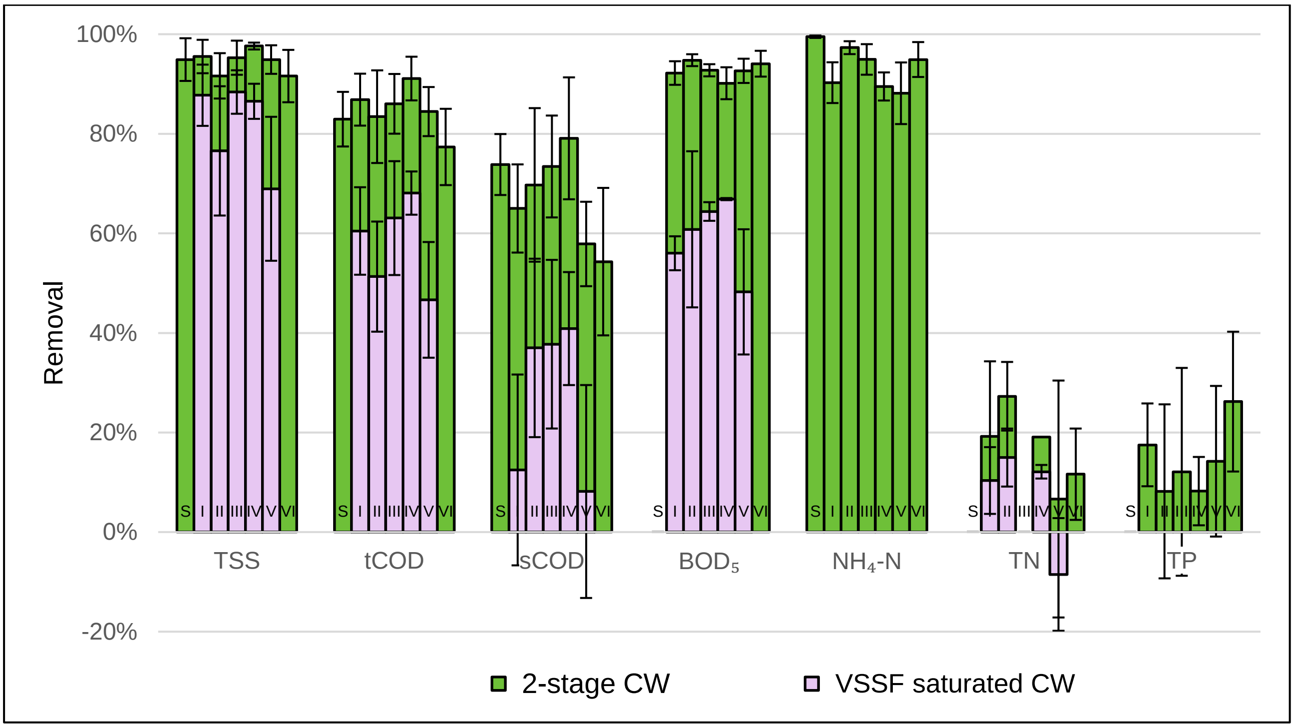

Figure 3.2 VSSF saturated CW and overall CW performance on conventional pollutants' removal

Figure 3.3 presents the anaerobic biomass and pH distribution inside both UASB units. The Figure also shows that total biomass in the reactor increased significantly since the start-up as biomass in terms of volatile solids (VS) expanded in terms of concentration at all height levels. Accordingly, pH in the reactor remained at the optimum levels for methanogenesis and was a bit decreased at periods I & V (summer periods) when anaerobic biomass was more active. Minimum pH value for all periods was observed at the bottom of the reactor where sludge was thicker (sludge bed).

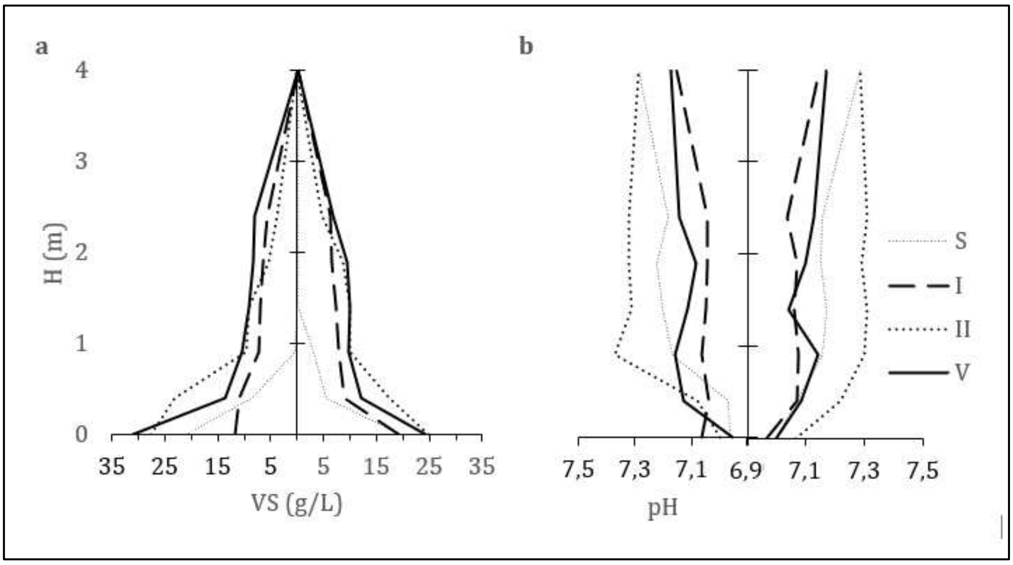

Figure 3.3: a) Sludge blanket, and b) pH profile inside both UASB reactors.

UASB biogas production is presented in Figure 3.4 as daily average production for 11 months in total. The daily production was different each month mostly due to temperature variation. In addition, biogas production was related to the applied OLR in the UASB. Maximum daily biogas flow was 16.1 m^3/d during period IV (average T= 19°C, OLR = 1.13 kg COD m^{-3} d^{-1}) when biogas production was due to both degradation of the influent and previously entrapped organic matter, thus poorly correlated to the observed COD removal during that period. During period V the applied OLR (1.32 kg COD m^{-3} d^{-1}) was constant throughout the whole duration and the only variant parameter was temperature each month. Thus, as expected, the maximum biogas production was observed in August (14.5 m^3/d) when reactor temperature was, also, maximum (T = 27 °C). The decreasing biogas production during fall and winter months shows that UASB methanogenic activity decreased significantly with temperature but since COD removal remained high, it was supposed that particulate COD was entrapped in the reactor.

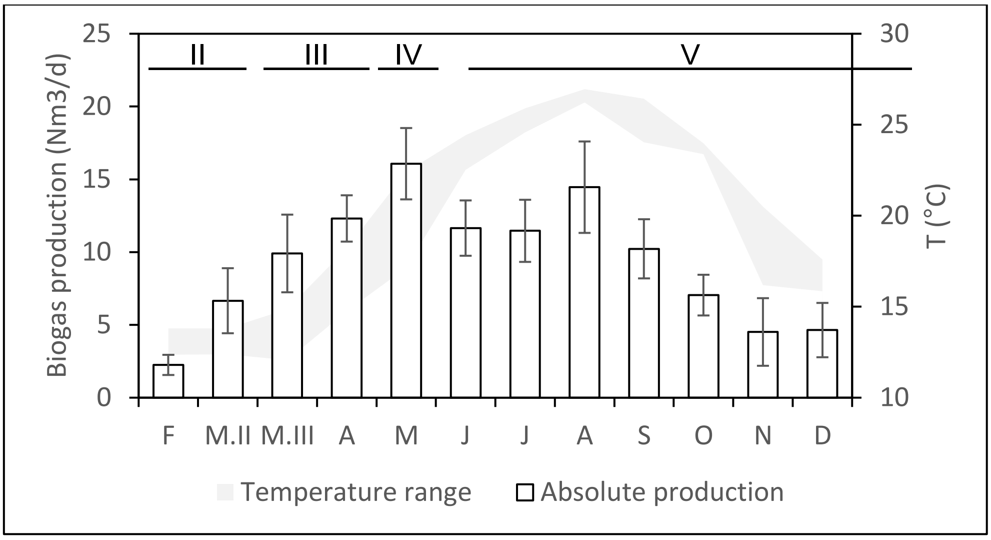

Figure 3.4 Biogas production per month

Besides the reclaimed biogas, excess sludge was also treated and transformed to compost. Table 3.1 presents the main quality characteristics of the dried UASB sludge and the final compost that was produced.

Table 3.1 Dried UASB sludge and compost quality parameters

Parameter	SDB sludge	Compost
TS (%)	57 ± 8	67 ± 15
VS (% of TS)	60 ± 3	24± 5
pH	8.0 ± 0,1	6.8 ± 0,1
Conductivity (mS/cm) (1:5 dilution)	3.1 ± 0,21	2.0 ± 0,2
TKN (g/kgDS)	57 ± 40	16 ± 3
TOC (g/kgDS)	318 ± 10	244 ± 45
TP (g/kgDS)	6.2 ± 0.2	3.2 ± 0.2
Ca(g/kgDS)	28 ± 12	30 ± 28
Na (g/kgDS)	0.6 ± 0.1	0.8 ± 0.4
K (g/kgDS)	1.6 ± 0.6	3.55 ± 0.3
Mg(g/kgDS)	3.2 ± 1.3	4.7 ± 2.1
Cu (mg/kgDS)	170 ± 57	102 ± 25
Zn (mg/kgDS)	900 ± 283	545 ± 106
Pb (mg/kgDS)	45 ± 18	37 ± 6
Cd (mg/kgDS)	1.06 ± 0.35	0.74 ± 0.02
Cr (mg/kgDS)	24 ± 11	25 ± 1
Ni (mg/kgDS)	18 ± 8	18 ± 3
Hg (mg/kgDS)	0.71 ± 0.38	0.57 ± 0.06
As (mg/kgDS)		11± 1
B (mg/kgDS)	13 ± n/a.	9.9 ± n/a.
E. coli beta-glucuronidase (+) (cfu/g)	7900	290
Salmonella spp (+/-)/25g	n.d.	n.d.

Based on the above it is concluded that the produced compost quality characteristics are within the limits that have been set in Greek legislation for the agricultural use of sludge (Ministerial Decision 41828/630/2023).

The sludge drying reed bed and the composting system were practically set in continuous operation during the last year of operation of HYDRO1. In the preceding period, in order to enhance UASB reactors operation, the removal of anaerobic sludge and its diversion to the SDRB was low. During the full operation of the sludge treatment line the total compost being produced summed up to 1250 kg. Part of this compost was used to fertilize several trees in HYDRO2 (Figure 3.5)

Figure 3.5. Compost production and use in HYDRO2

Excluding the start-up period, COD mass fractions in the UASB expressed as percentage of the influent COD are shown in Figure 3.6. According to the results, during period I there was a significant difference in COD mass balance arising from the inaccurate biogas measurement at that period and possibly influent COD entrapment in the reactor. During period V and period VI (almost steady state operation in summer and winter, respectively) COD mass balances revealed had only small gaps, thus indicating optimum performance of the system during these periods. During periods II (stable winter operation), III & IV (transitional periods from winter to summer loading of HYDRO 1) effluent COD fractions exceeded the corresponding influent COD. This was mostly attributed to the increased biogas production during these days, coming from previously entrapped (possibly during period I) COD in the reactor.

Nitrogen mass balance in the VSSF unsaturated CW (Figure 3.7) revealed that transformation of influent ammonium nitrogen to nitrate nitrogen form through aerobic autotrophic nitrification, which was the dominant mechanism in the bed. The gap for each period was the amount of denitrification achieved by the saturated zone at the bottom. This was confirmed by the results of period V where minimum deviations were observed, as no saturation zone was applied, thus leading to full nitrification and no denitrification.

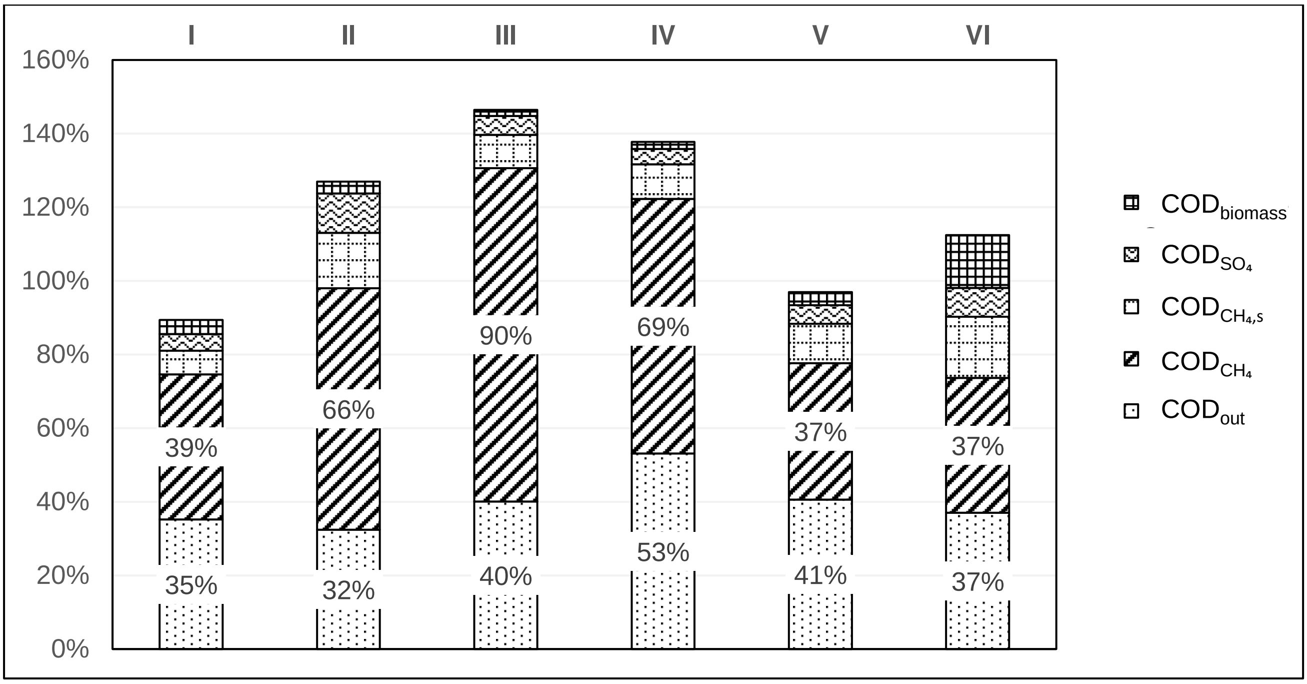

Figure 3.6 UASB COD mass balance

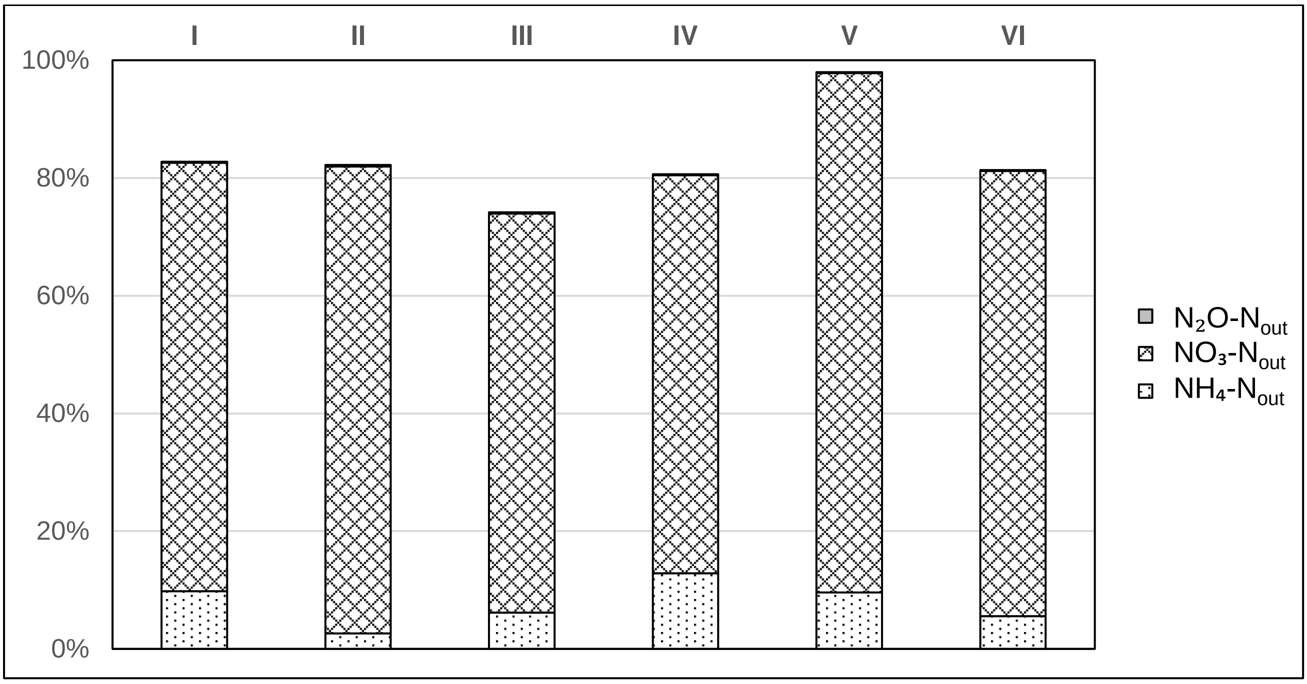

Figure 3.7 VSSF Unsaturated CW nitrogen mass balance

HYDRO1 performance assessment included a monitoring campaign of heavy metals' fate, which revealed that none of the measured metals were removed by the UASB process, while CW removal was high for every parameter. Due to the absence of illicit industrial discharge, heavy metals in the influent were detected in concentration levels that are considered non-threatening according to the Greek regulation limits (Table 3.2).

Table 3.2 Heavy metals' concentration for all treatment steps

Parameter	Inlet tank (influent)	UASB effluent	VSSF UNSAT effluent	T1 (irrigation water tank)	*Greek Regulation Limits 145116/2011*
Cu (μg/L)	15 (±1.0)	24 (±11)	4.3 (±0.23)	4.4 (±0.35)	200
Cd (μg/L)	<0.25	<0.25	<0.25	<0.25	10
Cr (μg/L)	2.0 (±0.26)	3.8 (±0.52)	1.1 (±0.12)	0.94 (±0.060)	100
Co (μg/L	0.63 (±0.040)	0.74 (±0.16)	1.5 (±0.058)	1.4 (±0.10)	50
Pb (μg/L)	4.7 (±1.3)	6.0 (±3.1)	1.3 (±0.058)	1.1 (±0.23)	100
Mo (μg/L)	0.73 (±0.010)	0.86 (±0.15)	0.41 (±0.020)	0.53 (±0.15)	10
Ni (μg/L)	<5.0 (±1.0)	6.4 (±1.2)	8.3(±0.1)	8.5 (±0.3)	200
Se(μg/L)	1.8 (±0.058)	1.8 (±0.15)	1.4 (±0.058)	1.4 (±0.056)	20
Zn (μg/L)	112 (±23)	131 (±60)	22 (±2.5)	32 (±7)	2000
Fe (μg/L)	480 (±149)	586 (±338)	85 (±21)	69 (±1.5)	3000
Al (μg/L)	306 (±40)	376 (±162)	92 (±58)	60 (±8.7)	5000
As (μg/L)	6.4 (±0.35)	7.0 (±0.95)	7.8 (±0.35)	7.7 (±0.32)	100
Hg (μg/L)	0.13(±0.012)	0.17(±0.031)	<0.10	<0.10	2
B (mg/L)				0.11 (±0.012)	2
F (mg/L)				0.80 (±0.031)	
Phenols (mg/L)				0.37 (±0.013)	
CN- (mg/L)				<0.010	

The performance evaluation of HYDRO1 included monitoring of the greenhouse gases (GHGs) that were emitted from the constructed wetlands. More specifically, both the saturated and unsaturated VSSF CWs were tested for carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) emissions. Analyses were performed on-site with an FTIR gas analyser (Gasmet DX4015) using the closed hood gas accumulation method for soil emissions. In practical terms, a series of representative sampling points were selected for each CW and the surface was covered with a hood that was connected to the gas analyser, measuring real-time increase of the gas concentration inside the hood (Figure 3.8).

Figure 3.8 GHG sampling with the Gasmet DX4015 FTIR analyser and closed hood cover

The gas flux was determined linearly as the slope of the concentration – time curve. Gas fluxes were expressed as mass of gas per time and surface area (mg GAS/m2-h). The sampling for GHG emissions in both summer (high flowrate) and winter (low flowrate), as well as the investigation of temporal variance in the case of the intermittently fed unsaturated VSSF CW provided data that could aid the estimation of the CW CO2 equivalent emissions in annual basis. Table 3.3 shows the difference among saturated and unsaturated CW in both summer and winter period. Figure 3.9 presents the temporal variance of unsaturated CW emissions (e.g., for N2O emissions) and the need to take this effect into consideration when estimating the continuous operation in annual scale estimation, since a decrease is expected especially for larger resting periods, mostly applied for lower flowrate in winter. Finally, the annual CO2 equivalent takes into consideration operation with high flowrate for 270 days per year and for the rest low flowrate is assumed. Detailed calculations and final estimated value are presented in Figure 3.9.

Table 3.3 GHG emissions in terms of mass flux for each CW type and period

CW type	Period	CH_4-C	N_2O-N	CO_2-C
		(mg m^{-2} h^{-1})		
VSSF UNSAT	Summer	20.2 ± 5.2	0.50 ± 0.12	220.9 ± 102.6
	Winter	0.4 ± 0.1	0.27 ± 0.10	159.1 ± 60.8
VSSF SAT	Summer	153.4 ± 68.1	0.56 ± 0.32	253.1 ± 80.5
	Winter	95.7 ± 44.9	0.06 ± 0.04	79.9 ± 47.5

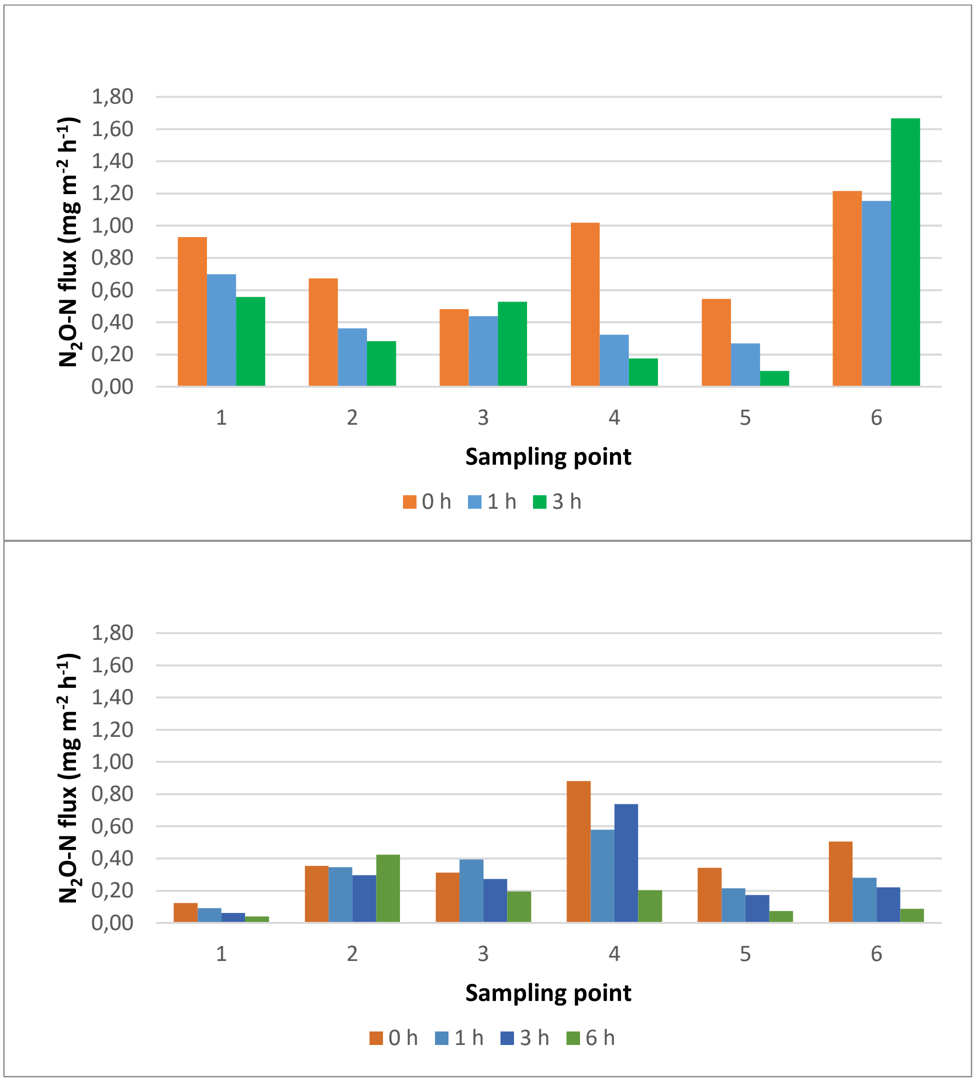

Figure 3.9 Temporal variance of N_2O emissions in summer (top) and winter (bottom) for the various sampling points in the unsaturated VSSF CW

Table 3.4 GHG emissions from CW treatment in HYDRO 1

Estimation of:			**Total $kgCO_{2,eq}$ per system and pollutant**			**$CO_{2,eq}$ yield ($kgCO_{2,eq}/m^3$)**
Summer - High Q						
CW type	Area (m^2)	Days	CH_4-C	N_2O-N	CO_2-C	
Unsaturated	600	270	1963	579	859	0.14
Saturated	250	270	6213	270	410	0.28
Period total			8176	850	1269	0.42
Winter - Low Q						
Unsaturated	600	95	14	110	218	0.12
Saturated	250	95	1364	10	46	0.21
Period total			1377	120	263	0.33
Annually			9554	970	1532	0.40
Total annually	12056					

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

Based on the results, average onsite GHG emissions of 0.4 $kgCO_{2eq}/m^3$ have been calculated for HYDRO1. By considering the average specific energy consumption of 0.27 kWh/m^3 for HYDRO1 and the emission factor of 0.6 $kgCO_2eq/kWh$ (Greek energy mix) the total GHG emissions of HYDRO1 are estimated at 0.57 $kgCO_{2eq}/m^3$, a value which is significant lower (five times lower) than the reported ones (2.8-3.8 $kgCO_{2eq}/m^3$) for conventional wastewater treatment systems with similar or even higher treatment capacity (Goliopoulos et al., 2022).

Pilot line

The highest COD removal rate was observed at the aerated CW (85-90%) during the first three periods and at the saturated system (86%) during the last period (Figure 3.10). The lower efficiency of the unsaturated constructed wetland, regarding COD removal (45-57%) for the first three periods was possibly due to the poor solids' retention, affected by the percolation velocity and the granulometry. However, even the unsaturated electroactive CW was capable of removing up to 80 g COD m^{-3} d^{-1} without clogging issues, which was significantly higher than the design parameter for passive CW, that proposes an average OLR of 20 gCOD m^{-3} d^{-1}. In addition, during the last two periods wastewater feeding was split in a greater number of pulses (from 8 to 73 and 100 pulses), which contributed to the increase in the performance of the unsaturated module. The saturated and hybrid CWs were capable of removing 200 g COD m^{-3} d^{-1}. The unsaturated CW removed 25 gNH_4-N m^{-3} d^{-1} through nitrification for the peak ammonium loading rate applied. Lower NH_4-N removal efficiency was observed for the hybrid system (25-48%) which is justified by the half volume of the aerobic zone, but improved during the 5th period when the number of pulses increased (63%) (Figure 3.10). The nitrification takes place and all the ammonia removed, becomes nitrate and denitrification rate is zero. The flooded zone of the hybrid CW was under anoxic conditions and nitrates produced at the aerobic zone were removed via denitrification. Regarding the nitrification and NH_4-N removal in the unsaturated pilot before and after the change of pulses, the removal improved from 45 to 70% (4th period). The best ammonium removal was observed during the 5th period for the aerated pilot and it was equal to 31 gNH_4-N m^{-3} d^{-1}. As expected NH_4-N was not removed at the saturated CW. The TSS removal efficiency was high (> 70%) at the saturated pilots (Figure 3.10) for all the operational periods, as opposed to the unsaturated pilot, where the removal of TSS was 45-57%. The increase of pulses (4th and 5th operational period) improved significantly the TSS removal of the unsaturated pilot to 84%. The removal of PO_4-P was not stable in any pilot. In the first months of operation a removal was observed (<25%) which was due to adsorption of the material.

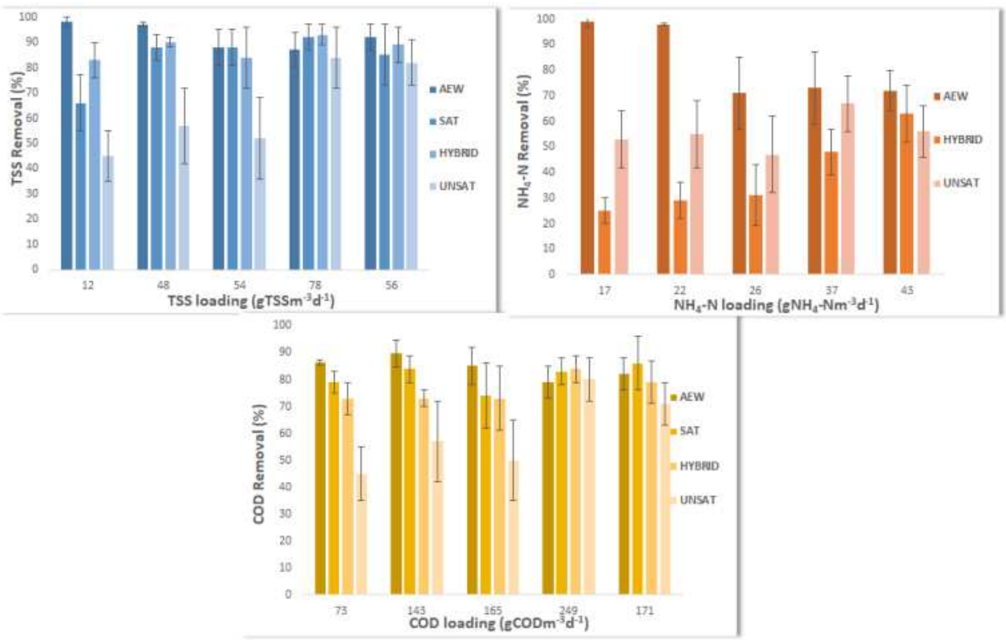

Figure 3.10 TSS, NH_4-N and COD removal in relation to different loading rates

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Figure 3.11 presents the different loading rates and removals of COD and NH_4-N at unsaturated electroactive pilot, aerated pilot and a conventional unsaturated wetland. The electroactive pilot and aerated pilot were capable of treating 12 times more COD and 3 times more NH_4-N that the conventional ones.

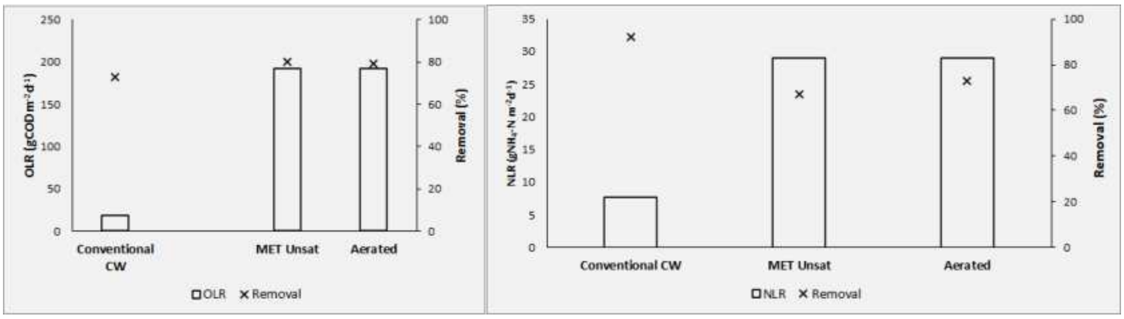


Figure 3.11 Loading rates and removal of COD and NH_4-N at unsaturated electroactive pilot, aerated pilot, and a conventional unsaturated constructed wetland.

Additional analyses were carried out to assess the fate of heavy metals, like aluminium (Al), lead (Pb), copper (Cu) and zinc (Zn) in the pilot systems (Figure 3.12). Based on the results it is anticipated that the saturated electroactive pilot achieves significant removal compared to the other three pilots.

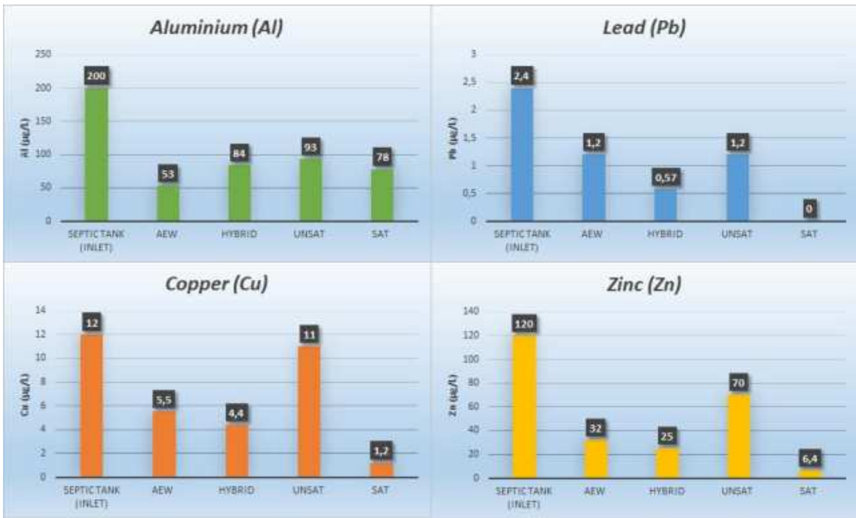


Figure 3.12 Concentration of heavy metals (inlet and outlet of pilot CWs).

Analyses were carried out to investigate the microbial parameters in the pilot line (Table 3.5). Higher removal of total coliforms (TC), Escherichia coli (E. coli) and Enterococci observed in the saturated pilots (AEW and SAT).

Table 3.5 Microbial parameters

	Removals (Log10)			
Microbial parameters	**AEW**	**SAT**	**HYBRID**	**UNSAT**
TC	1.1	1.4	0.6	0.6
E. coli	1.3	1.7	0.8	0.5
Enterococci	1.9	2.5	1.8	1.3

3.1.1 Water recovered

Water Quantity

The total wastewater volume that has already been treated through the HYDRO1 system is equal to 34,400 m^3. During the 1st year of operation (March-December 2021) the demonstration unit managed to treat up to 11,600 m^3 of municipal wastewater originating from Antissa village. During the 2nd year of operation (2022), HYDRO1 demo site treated more than 19,200 m^3 of wastewater while during the first 5 months of 2023 the reclaimed water produced from HYDRO1 was more than 3,500 m^3.

Considering that there are some water losses due to evapotranspiration, the available meteorological data from the 2 weather stations installed at the site were used in the respective equations to estimate the amounts of water lost. The estimation so far state that the average water losses due to evapotranspiration are between 4.5-5% resulting to a total amount of recovered water equal to 32,600 m^3.

The reclaimed water that is produced in HYDRO1 is stored in a cement tank with a total volume of approximately 35 m^3 and then is used to irrigate HYDRO2 site. The surplus water that is not used for irrigation (especially during winter period) is discharged by an overflow to the nearby river. Through the installed irrigation flowmeters and the daily inspection of the irrigation controller it is estimated that the average volume of the reclaimed water that has been used to irrigate the 1ha HYDRO2 area is equal to 6,500 m^3/year. Figure 3.13 presents the average daily volume of reclaimed water used for the irrigation of HYDRO2 during each month.

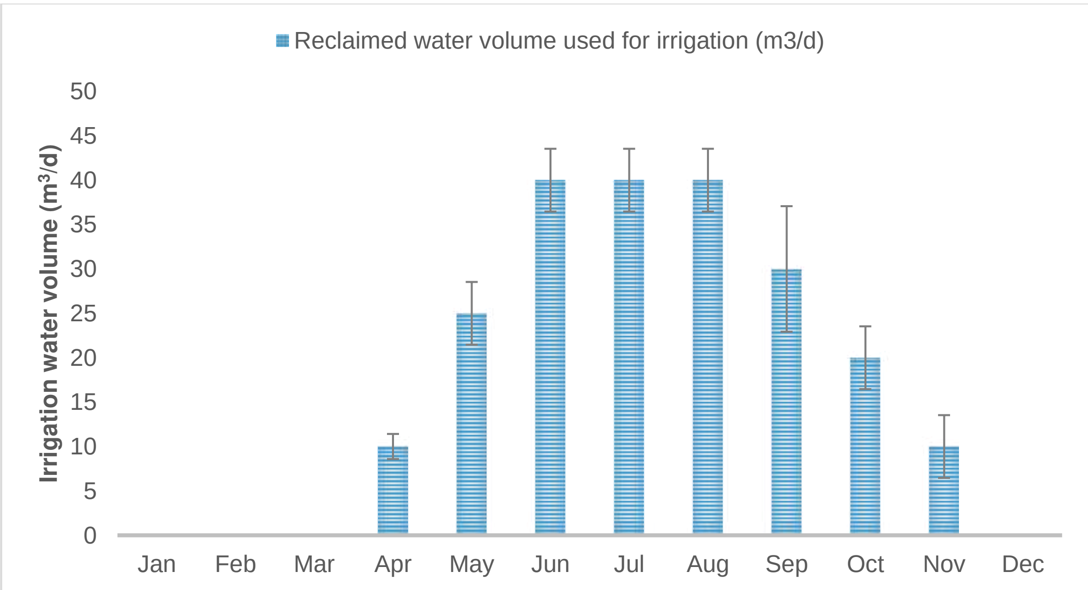


Figure 3.13: Irrigation water volume (m^3/d) fluctuation in accordance with the period.

Water Quality

Table 3.6 summarised the main quality characteristics of the reclaimed water. A it can be observed the treated effluent meets the TSS requirements for Class A irrigation (< 10 mg/L) at all periods, while BOD_5 requirements (<10 mg/L) were not met during periods III & IV (previously mentioned as transitional) and turbidity requirements were not met only during period IV. These results regarding the increase in BOD_5 and turbidity indicated that wastewater temperature should exceed 20°C before increasing the load of HYDRO1, setting the process limitation in terms of loading in areas where temperature can be lower or higher than 20°C throughout the season. Also, according to results at lower temperatures (period II) system sizing can be adjusted for areas with low temperature to comply with the legislation limits.

Table 3.6 Average quality characteristics of treated effluent from HYDRO1

Period	S	I	II	III	IV	V	VI
Days	1 - 119	120 - 266	267 - 373	374 - 416	417 - 448	449 - 654	655 - 799
TSS (mg/L)	3 ± 1	5 ± 2	2 ± 1	4 ± 1	5 ± 1	5 ± 2	4 ± 3
VSS (mg/L)	3 ± 1	3 ± 1	2 ± 1	4 ± 1	4 ± 1	4 ± 2	3 ± 2
BOD_5 (mg/L)	n/a	6 ± 2	3 ± 0	13 ± 3	20 ± 3	7 ± 2	5 ± 3
tCOD (mg/L)	35 ± 12	32 ± 11	19 ± 8	32 ± 9	35 ± 14	39 ± 10	34 ± 7
sCOD (mg/L)	34 ± 13	31 ± 11	18 ± 8	31 ± 8	26 ± 12	35 ± 7	34 ± 4
NH_4-N (mg/L)	0.3 ± 0.1	6.1 ± 2.7	0.9 ± 0.5	3.4 ± 1.6	8.7 ± 2.4	5.7 ± 3.2	2.9 ± 2.1
NO_3-N (mg/L)	30.4 ± 2.5	45.3 ± 6.6	25.9 ± 6.3	39.1 ± 4.5	45.7 ± 6.2	52.3 ± 8.8	41.1 ± 8.2
TN (mg/L)	n/a	59 ± 8	36 ± 5	n/a	73 ± 1	70 ± 7	46 ± 4
TP (mg/L)	n/a	7.1 ± 0.8	4.4 ± 0.8	6.8 ± 0.5	9 ± 0.4	7.2 ± 1	5.4 ± 0.6
PO_4-P (mg/L)	n/a	7.1 ± 1.2	4.3 ± 0.7	6.8 ± 0.6	8.7 ± 0.4	7 ± 1.2	5.0 ± 0.8
pH	7.6 ± 0.1	6.9 ± 0.2	7.3 ± 0.1	7.2 ± 0.1	7 ± 0.1	6.5 ± 0.2	6.6 ± 0.2
Conductivity (μS/cm)	1108 ± 74	1277 ± 68	852 ± 97	1050 ± 112	1260 ± 36	1170 ± 114	1021 ± 116
Turbidity (NTU)	n/a	4 ± 1	3 ± 1	4 ± 1	7 ± 3	3 ± 1	4 ± 1
Alkalinity (mgCaCO₃/L)	n/a	199 ± 40	139 ± 30	163 ± 0	120 ± 0	112 ± 13	87 ± 39

The quality of recovered water was also monitored with online sensors that provided crucial information for operators of HYDRO1 & HYDRO2. Continuous graph of turbidity measurement at the treated effluent is presented on Figure 3.14. In addition, online sensors provided information on crucial influent parameters such as the COD concentration that directly affected the integrated system performance (Figure 3.15).

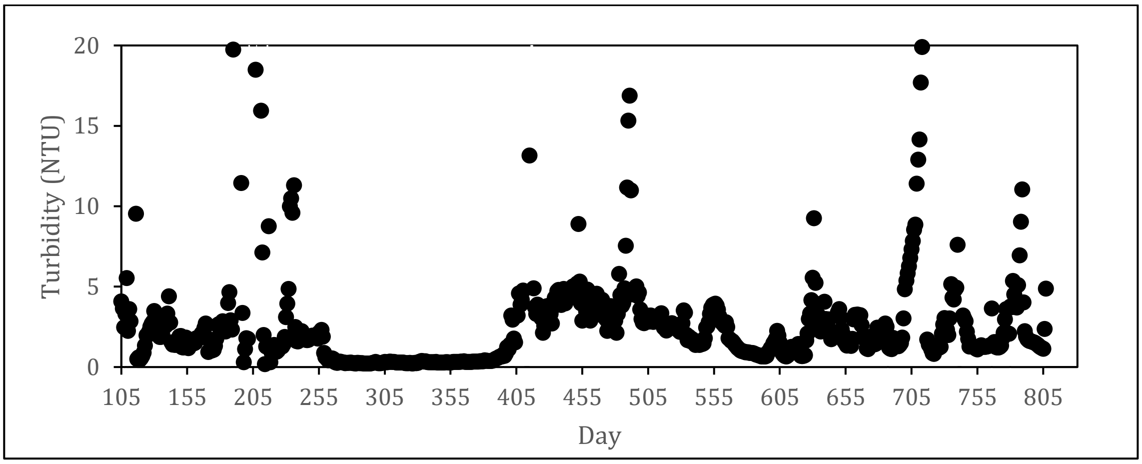


Figure 3.14 Reclaimed water online turbidity measurement

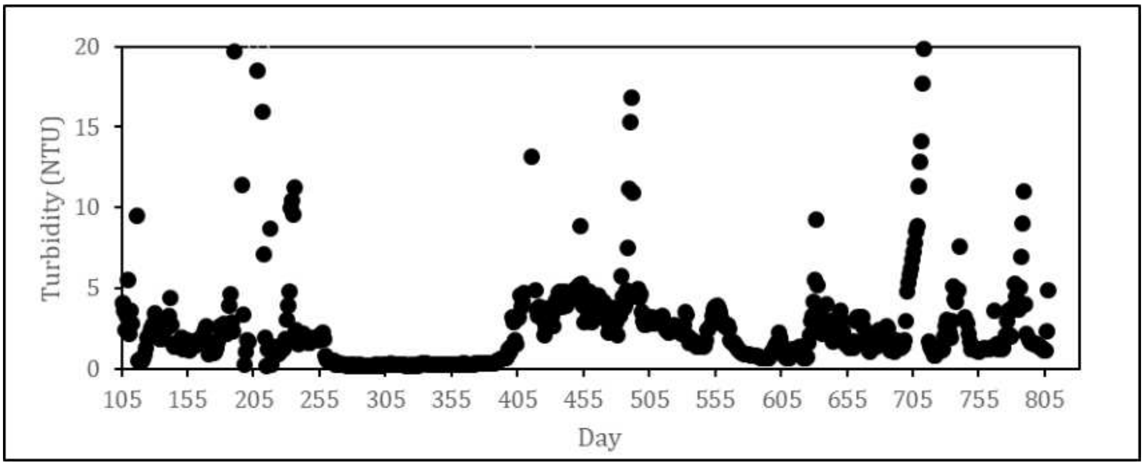


Figure 3.15 Influent COD concentration online measurement

The accuracy of online sensors' values was periodically crosschecked with lab data as it can be observed in Figure 3.16. In some cases, online sensors performed well without calibration (e.g., online COD in influent), while in some others calibration was needed to get accurate values (e.g., nitrate nitrogen in outlet where after calibration online values were closer to the lab values).

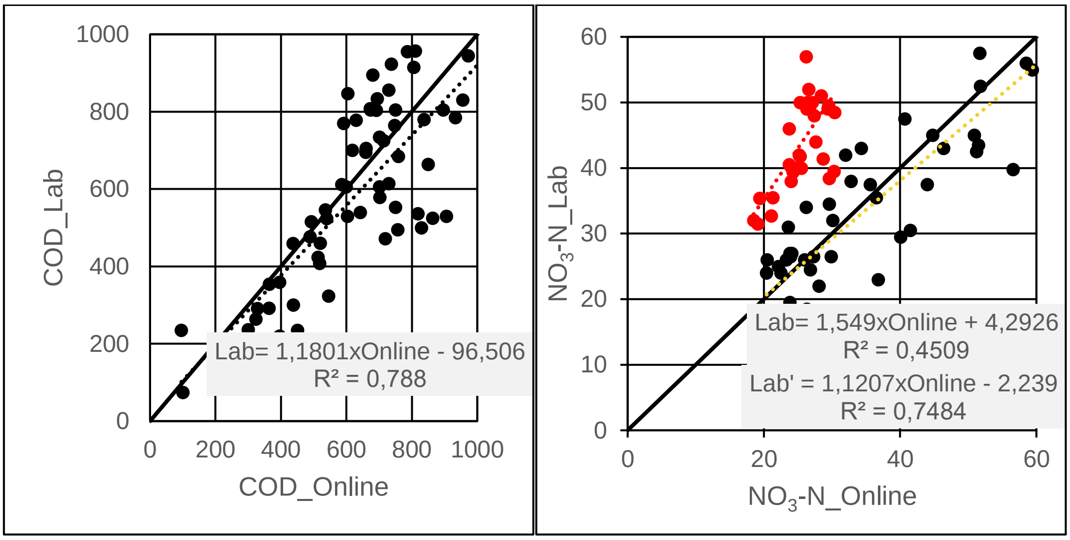


Figure 3.16 Comparison of online and lab values for influent COD (left) and outlet NO_3-N (right)

The monitoring of microbiological parameters in HYDRO1 was performed with both lab-scale analyses and online measurements. Lab-scale analyses were performed in grab samples that were collected in sterilized containers, while on-site measurements were conducted with the use of the FLUIDION ALERT system, which is a fully-automated in-situ microbiology lab (Figure 3.17). This system is comprised of sample collection pumps, reactor cells filled with biological reagent and the measuring device and was installed in the irrigation tank.

Figure 3.17. FLUIDION ALERT system and measuring vials after the analysis

Lab analysis was conducted to assess the salinity and sodium hazard of the reclaimed water used for irrigating the agroforestry system. The results, including also conductivity, Cl- (chloride ion) levels, and pH measurements, are presented in Table 3.7. The reclaimed water was classified as moderate quality, with no restrictions on cultivation according to FAO standards, meeting the requirements for agroforestry cultivation.

Table 3.7. Physicochemical analysis results for the reclaimed water of HYDRO1

	pH	Conductivity (mS/cm)	Cl- (mg/L)	Total hardness ($mgCaCO_3$/L)	Na (mg/L)	Ca (mg/L)	Mg (mg/L)	Sodium adsorption ratio (SAR)
HYDRO1 reclaimed water	7.3 (±0.2)	1249 (±21)	115 (±29)	320 (±18)	102 (±4)	93.4 (±2.8)	21.2 (±0.6)	2.4 (±0.1)

The results of the monitoring of the microbiological quality of wastewater (raw, partially treated, treated effluent) are summarized in Figure 3.18 and Table 3.8 (T1 refers to the irrigation tank where the effluent of HYDRO1 after UV disinfection was collected). As it can be observed, both influent and UASB and constructed wetlands effluents are characterized by a high variability of pathogens concentrations, which was not the case in the final effluent indicating the crucial role of the UV system for removal of all pathogens and, especially, *E. Coli* which is selected as the indicator in the EU legislation (Figure 3.18).

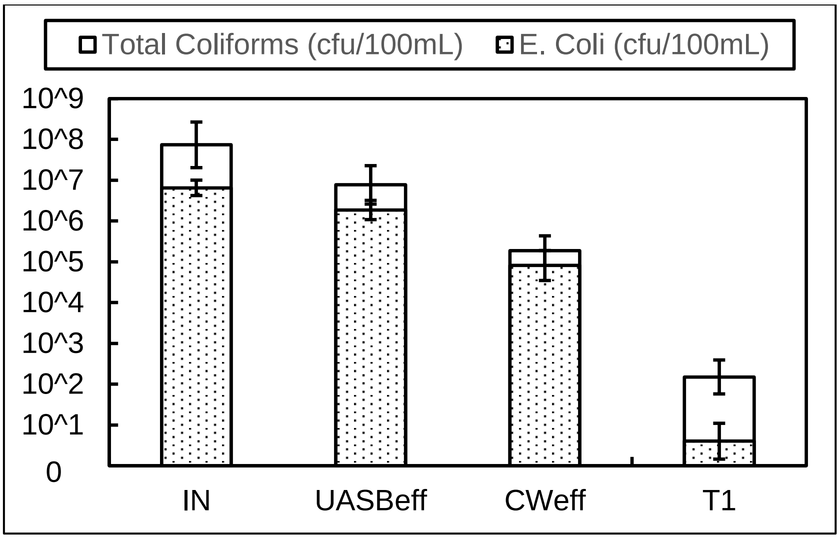


Figure 3.18. Total coliforms & *E. Coli* concentrations in HYDRO 1

Table 3.8. Statistics for Total Coliforms & *E. Coli* concentrations through HYDRO1

(cfu/100mL)		IN	$UASB_{eff}$	CW_{eff}	T1
Total Coliforms	Average	73782862	7695324	186493	150
	St. dev.	193639276	15053170	246791	241
E. Coli	Average	6504364	1864940	81299	4
	St. dev.	3545326	1344821	108242	5

The contribution of UASB in pathogens removal was relatively low (0.98log and 0.54log for TC and EC respectively), while being most profound in Constructed Wetlands (1.62log and 1.36log for TC and EC respectively). As expected, UV system was the main contributor of pathogens removal and achieved 3.09log and 4.31log on average for TC and EC respectively. Based on the results it is anticipated that HYDRO1 can efficiently conform with the requirements of the EU regulation for Class A irrigation water (*E. Coli* ≤ 10 cfu/100mL for the 90% of the samples).

3.1.2 Crop yield

Even though most of the plants were quite young during the start-up of the system, the development process for most of them was quite fast. In parallel, the annual crops plantations of maize during the summer period and barley during the winter period, along with the seasonal vegetables that were also planted during the 2 years of operation, contributed to a significant crop yield so far. Table 3.9 presents the overall yield produced in HYDRO2 between June 2021 and June 2023.

Table 3.9: HYDRO2 overall yield during the 2 years of operation.

Plant	Total harvest (June 21- June 23) (kg)	Total harvest2021 (kg)	Total harvest 2022 (kg)	Harvest 2023 (up to June) (kg)
Maize (biomass)	6,400	3,100	3,300	-
Barley (biomass)	1,940	-	1,100	840
Watermelon	852.6	488.6	364	-
Tomato	632	226	406	-
Zucchini	581.9	206.9	375	-
Eggplant	425	182.2	242.8	-
Mellon	488.2	110.2	378	-
Oregano	385.6	2.6	130	253
Pepper	220.5	49	171.5	-
Pumpkin	292	82	210	-
Cabbage	289.8	-	289.8	-
Lavender	755	5	200	550
Cucumber	95	42	53	-
Lettuce	102	12.2	89.8	-
Sage	250	3.5	95.5	151
Cauliflower	75.5	-	75.5	-
Aronia	54.8	5.6	49.2	-
Broccoli	54.5	-	54.5	-
Melissa	47	-	47	-
Onion	48.5	3.5	45	-
Goji berry	29.3	3.1	26.2	-
Leek	28.2	-	28.2	-
Cale	16.5	-	16.5	-
Beetroot	14	-	14	-
Mint	28.5	4.3	24.2	-
Rosemary	375	-	125	250
Blackberry	13.2	2.4	10.8	-
Savory	11.1	-	11.1	-
Pomegranate	10.2	-	10.2	-
Strawberry	28	-	28	-
Physalis	9.6	5.4	4.2	-
Radish	9.3	-	9.3	-
Raspberry	6.6	2.2	4.4	-
Fig	6.4	-	6.4	-
Apple	4.3	-	4.3	-

Plant	Total harvest (June 21- June 23) (kg)	Total harvest2021 (kg)	Total harvest 2022 (kg)	Harvest 2023 (up to June) (kg)
Hippophaes	3.8	-	3.8	-
Annice	3.8	-	3.8	-
Pelargonium	3.6	-	3.6	-
Basil	3.5	2.2	1.3	-
Pear	3.4	-	3.4	-
Parsley	3.2	-	3.2	-
Olive	2.2	-	2.2	-
Spinach	1.8	-	1.8	-
Celery	1.2	-	1.2	-
Thyme	1.2	-	1.2	-
Allium	0.8	-	0.8	-
Total yield (kg)	**14,608.6**	4,538.9	8,025.7	2,044

HYDRO2 demo site was very successful in terms of crops production since more than 14 tons of crops were harvested and donated to local farmers and families in Antissa during the 2 years of operation.

Maize plantation experiments

During the operation of the agroforestry system a series of parameters regarding the effect of the reclaimed water on the plants were examined. A basic investigation on the effect of the reclaimed water in terms of fertigation was implemented in the second field of HYDRO2 on the maize and barley annual plantations. The experimental investigation included a 1000 m^2 area cultivated with maize during the summer period and barley during the winter period where half of the area was irrigated with reclaimed water while the other half area was irrigated with conventional tap water. No significant extra fertigation was applied in both plots of plants and only minor interventions (the same in both plots) were applied when needed. Figures 3.19 and 3.20 present the results of the maize and barley plantations in terms of plants growth and yield.

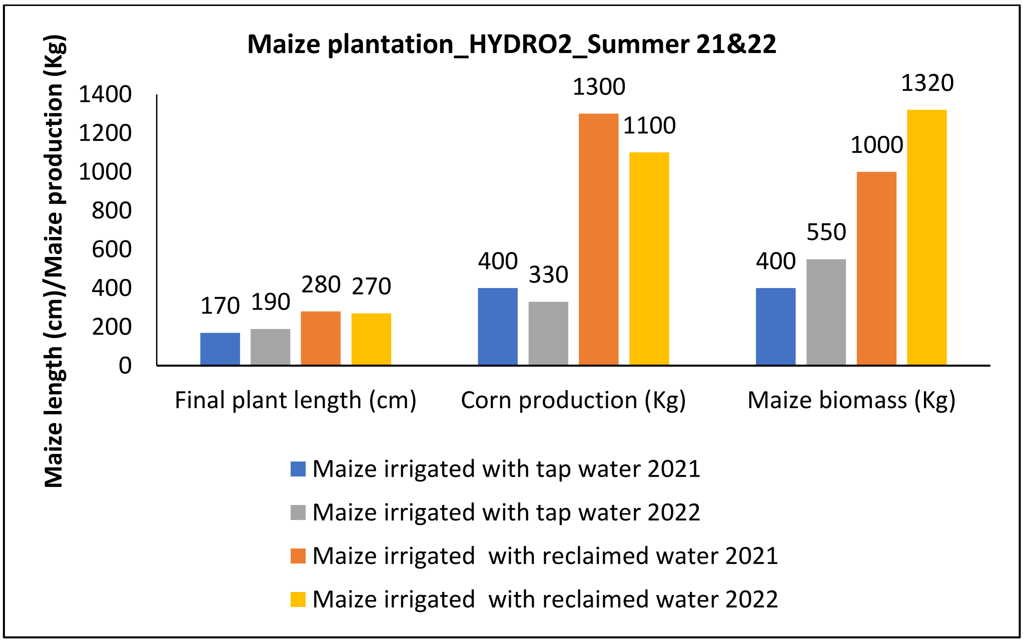


Figure 3.19: Maize plantation irrigated with reclaimed water vs maize irrigated with tap water

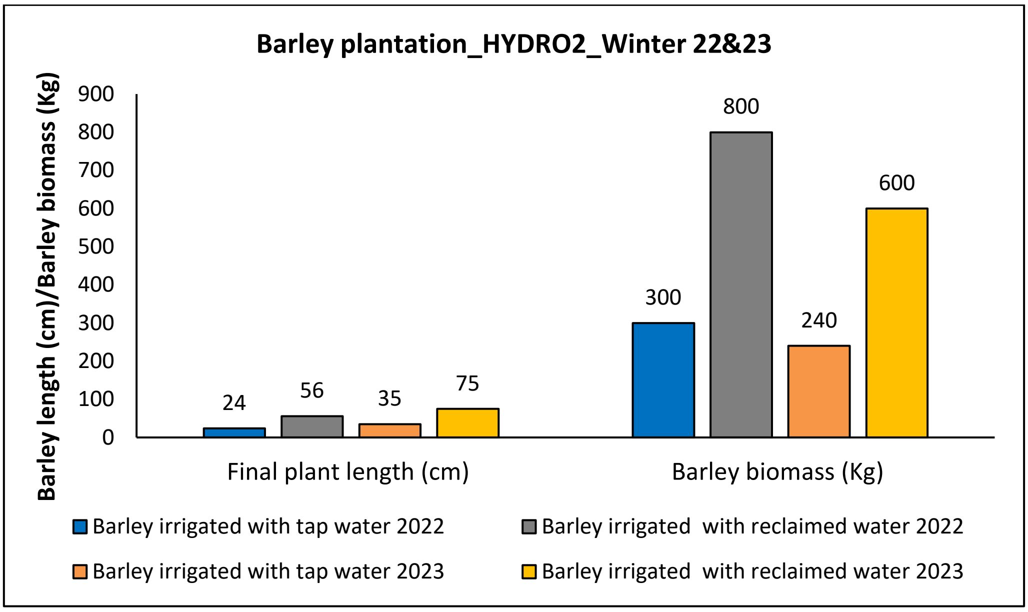


Figure 3.20: Barley plantation irrigated with reclaimed water vs barley irrigated with tap water

From the above figures it is quite clear that the use of reclaimed water could contribute to both better health and growth of the irrigated plants as well as in terms of produced biomass compared with the use of conventional tap water. A conventional maize plantation requires great amounts of fertilizers that had to be provided in order to achieve high yields. These amounts of fertilizers could totally be saved if fertigation water such as reclaimed water from wastewater treatment is used.

3.1.3 KPIs status

Table 3.10 summarizes the KPIs achieved throughout the operation of HYDROs 1 and 2. As evidenced, all KPIs achieved were very satisfactory with respect to the expected values originally set with the exception of compost production. The slightly lower COD and TSS removal achieved by the UASB than the expected one is not an issue, since the subsequent CWs are able to achieve the required removal of these parameters. Therefore, the integrated UASB-CW process meets the targeted COD and TSS removal.

During the first periods of operation of HYDRO1 and in order to enhance UASB reactors performance, the removal of anaerobic sludge and its diversion to the SDRB was practically low. For this reason, the full operation of the sludge treatment line took place only during the last year of operation of HYDRO1 and the total compost being produced summed up to 1250 kg. It is worth noting that a possible change in the mode of operation of HYDRO1 with the aim to maximize surplus sludge production (in order to increase compost production) will definitely compromise its whole performance with respect to both pollutants removal and energy recovery (i.e., biogas production).

Table 3.10. Evaluation of key performance indicators for HYDRO1&2

Performance indicator	Expected	Achieved
HYDRO1 - treated wastewater (UASB)	10 m^3/d (winter) 100 m^3/d (summer)	>35 m^3/d (winter) >100 m^3/d (summer)
HYDRO1 - energy recovery	90 kWh/d	100 kWh/d (summer period)
HYDRO1 - UASB COD & TSS removal	>70% COD removal >70% TSS removal	>60% COD removal >60% TSS removal
HYDRO1 - treated wastewater (UASB-CW)	10 m^3/d (winter) 100 m^3/d (summer)	>35 m^3/d (winter) >100 m^3/d (summer)
HYDRO1 - UASB-CW COD & TSS removal	>90% COD removal >90% TSS removal	>95% COD removal >95% TSS removal
HYDRO1 – compost production	>10 tonnes/year	>1.2 tonnes/year
Cultivation	1ha	1ha
Production of fruits, herbs, vegetables (with biomass)/ha	>10 tons	14.6 tons

3.2 HYDRO3 Performance

3.2.1. Water Quantities recovered

As described previously HYDRO3 is located in Ano Mera, Mykonos Island. It is an innovative, nature-inspired rainwater harvesting system consisting of a shallow, sub-surface rainwater collector and drainage system where rainwater is transported by gravity pipes into two cylindrical light structure storage tanks. The harvested water is utilized for irrigating 0.4 ha of oregano.

The quantity monitoring of the system is conducted through the online probes installed in the site, consisting of ultrasonic level meters, flow meters, meteorological station in the field and soil moisture sensors in the oregano field in order to enable automated drip irrigation.

The system was directly operational (collecting rainwater) when the hydraulic connection of the tanks to the collector was finalized. The system started collecting and storing water as early as November 17, 2019. It is worth noting that part of the water collected from the system was used for the construction works that were conducted in parallel. Thus, four years of operational raining seasons have been completed and the system collected 60 m^3 each year. The water was used in summer periods for the irrigation of the 0.4ha oregano field planted next to the collection system.

Figure 3.21 displays the data for the water tank level which are plotted against the daily rainfall data for a four-month period in 2021 (from January 1, 2021, to April 30, 2021). The graph illustrates a clear correlation between the increase in water tank level and the recorded rainfall events. It demonstrates that during rain events, water is efficiently collected, resulting in a rise in the water tank level. This indicates the effectiveness of the water collection system.

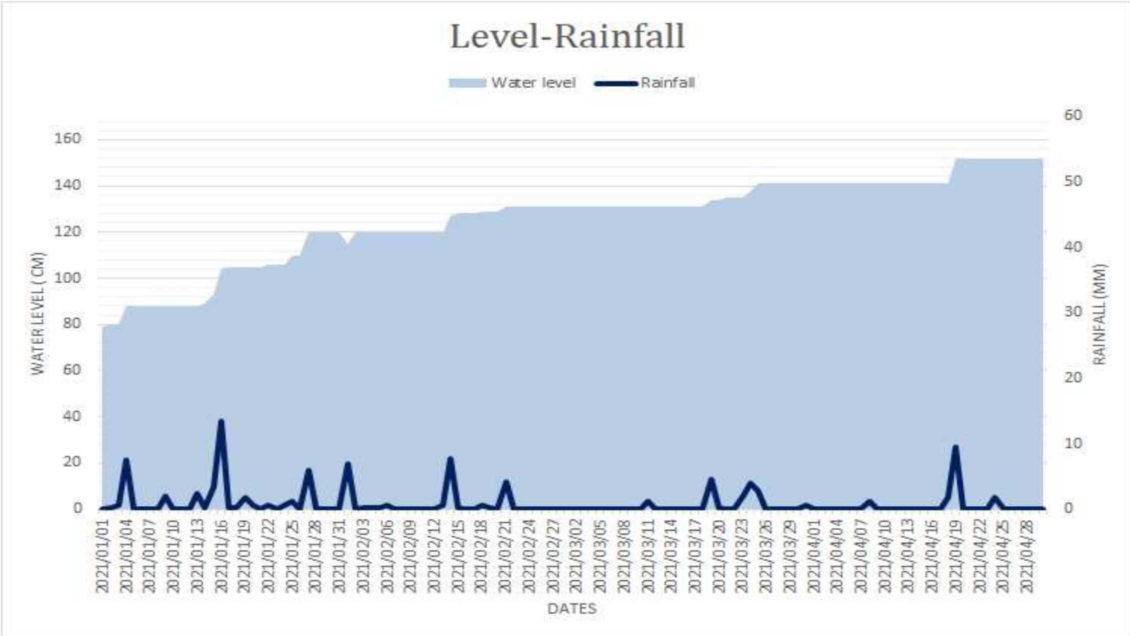


Figure 3.21: Level meter values in the HYDRO3 Collecting Tank plotted with the respective rainfall data in the field.

Accordingly, Figure 3.22 presents the water level increase in HYDRO3 during the wet season of 2022-2023. The blue peaks represent the rise in water volume following each rainfall event. It can be observed that the system steadily fills up until mid-February, reaching its peak level of 170 cm. Subsequently, the water level gradually declines due to the increased demand for water resulting from new planting activities. Furthermore, it is evident that there is a lack of precipitation for the remaining period.

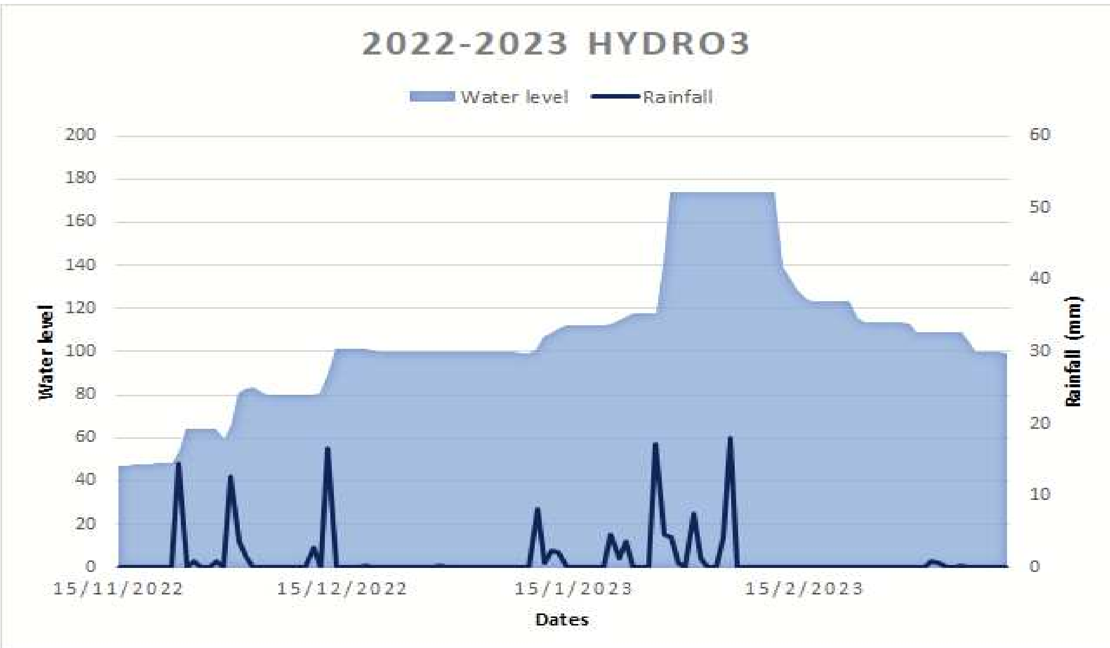


Figure 3.22: Rainfall events correlated with the water level rising in Tank1 of HYDRO3 system.

In Table 3.11, the recovery rate is calculated for selected rainfall events, which amounts to approximately 81% (± 6%). The losses primarily occur due to soil retention and evaporation. Notably, even for intense rainfall events, the recovery rate remains high, indicating the efficient drainage capacity of the soil. The design process accounted for a losses factor of 0.2 (20% losses), which closely aligns with the actual data.

Table 3.11. Recovery rate for the rainwater collection system

Date	Rainfall (mm)	ΔH (cm)	Rainwater collected volume (m^3)	Theoretical volume	Recovery rate %
01/15/21	3.3	4	0.8	0.9	85
01/04/21	7.5	8	1.6	2.1	74.8
19/4/21	9.6	11	2.2	2.7	80.3
24/11/21	14.7	17.8	3.5	4.1	84.8
12/04/21	21.3	27	5.3	6	88
23/11/2022	13.2	15.7	3.69	3.08	83.36
30/11/22	12.3	14.6	3.44	2.82	82.05
2/12/22	1.2	1.44	0.34	0.294	87.61
11-13/12	15	17.8	4.2	3.85	91.58

The harvested water from vapour within HYDRO3 is monitored through the flowmeters attached in the two dehumidifiers units. Within a full year time around 28.4 m^3 of vapour water is harvested (July 2022 to June 2023). The collected water is used as drinking water for the visitors of HYDRO3 or for the needs of the distillation process. In addition, a special tab is installed that allows access to the produced drinking water to local residents or tourists passing by HYDRO3 (Figure 3.23)

Figure 3.23. Drinking water tap outside the demo site HYDRO3

The monthly monitoring of the dehumidifier units' production is shown in Figure 3.24. The units are not working continuously as the needs of HYDRO3 are fully covered implementing intermittent operation.

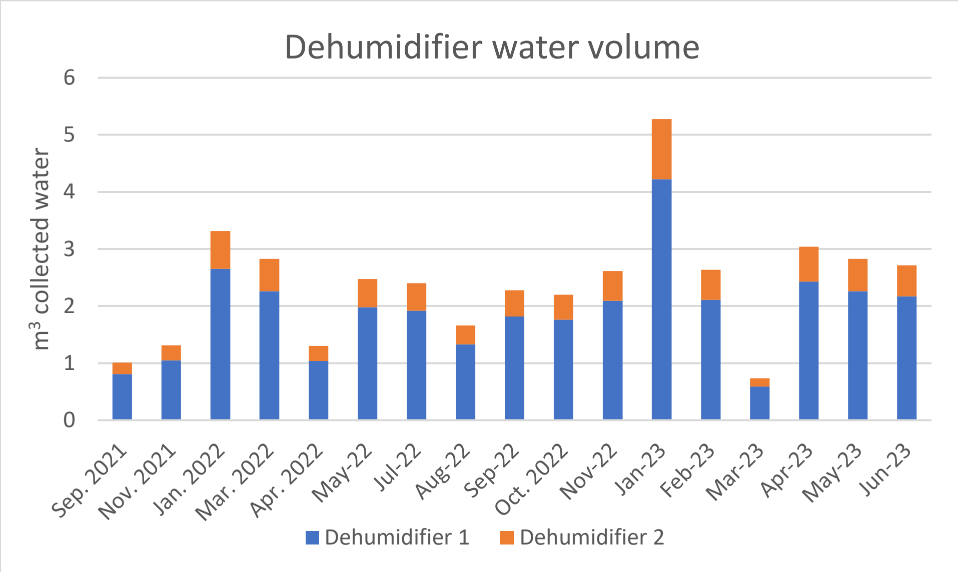


Figure 3.24. Monthly records of the quantity produced from the dehumidifier units installed in HYDRO3

3.2.2. Water Quality

In addition to quantity monitoring, quality monitoring is conducted using online sensors (both industrial and low-cost) as previously described. The monitoring plan involves the simultaneous collection of online data, in situ measurements, and lab analysis, enabling the operator to identify any potential system operation failures or issues with the online sensors. Figure 3.25 illustrates the evolution of conductivity as obtained from the online sensors, operator's measurements, and lab analysis of the collected samples. In this particular case, the measurements are aligned, indicating that the monitoring process proceeded without any problems.

The operation of the low-cost sensors developed within the project was compared to the data from industrial sensors that were installed at the same points. Figure 3.26 presents an example of this comparison, specifically for the pH and EC sensor. The graphs demonstrate a perfect correlation between the two types of sensors, indicating the reliability of the low-cost monitoring system.

Figure 3.25 : Collected data for E.C (industrial sensors, operator's and lab measurements)

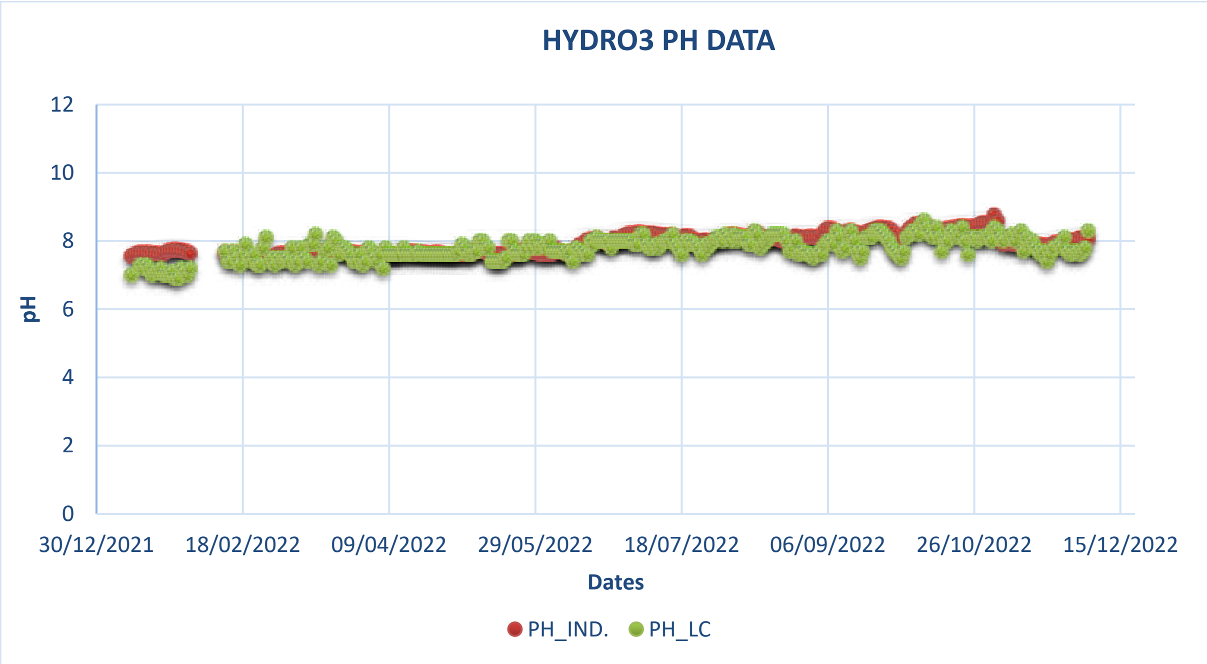


Figure 3.26: Correlation of low-cost and industrial monitoring pH sensors data.

The system's monitoring was also achieved through sampling campaigns for laboratory analysis that started in October 2020 and were conducted twice per month. Table 3.12 presents the results of the lab analysis for the quality characteristics of the rainwater collected from Tank 1 and Tank2 and the dehumidifier.

Table 3.12. **Quality analysis of rainwater collected in Tank 1 and Tank2 of the system**

	Tank 1	*Tank 2*	Irrigation water FAO & 145116/2011		
			No limitations	Slight to moderate restriction	Severe restrictions
pH	7.4 (± 0.2)	7.5 (± 0.1)	6.5-8.5		
Conductivity (mS/cm)	0.516 (± 0.144)	0.526 (± 0.128)	< 0.7	0.7 -3.0	> 3.0
Turbidity (NTU)	1.9 (±0.8)	1.6 (± 0.7)			
Alkalinity (mg $CaCO_3$/l)	118 (±54)	111 (±38)			
Cl^- (mg/L)	74 (±28)	88 (±31)	<140	140-350	>350
SO_4^{2-} (mg/L)	29 (±17)	27 (±6)			
NO_3-N (mg/L)	1.13 (±0.47)	0.86(±0.51)	<5	5-30	>30
TN (mg/L)	1.16 (±0.48)	0.91(±0.61)			
TP (mg/L)	< 0.1	< 0.1			
TSS (mg/L)	1.2(±0.8)	1.0(±0.7)			
TDS (mg/L)	414 (±13)	361 (±35)			

	Tank 1	Tank 2	Irrigation water FAO & 145116/2011		
			No limitations	Slight to moderate restriction	Severe restrictions
Total hardness (mg $CaCO_3$/L)	144 (±37)	130 (±18)			
Ca^{+2}(mg/L)	39.4 (±10)	33.4 (±5)			
Mg^{+2}(mg/L)	11.1 (±2.9)	11.2 (±2.6)			
Na^{+}(mg/L)	54.9 (±11)	60.1 (±12.1)			
K^{+}(mg/L)	2.7 (±1)	3.0 (±0.8)			
SAR	1.9 (±0.6)	2.3 (±0.4)			
TC (as mean value) (CFU/100 ml)	1007	1063			
E. Coli (as mean value) (CFU/100 ml)	16	23			
Enterococci (as mean value) (CFU/100 ml)	95	18			

The analysis of experimental results clearly indicates the high quality of the rainwater collected, fully satisfying the needs for irrigation use, recording values close to those reported in literature (Farreny et al., 2011; Bank et al., 2011; Sazakli et al., 2007). The collection through the subsurface system filters the rainwater concluding to low turbidity and low concentration of suspended solids. In addition, the sand and gravel layers on the collection surface enrich the water collected with ions essential for plants. The lower turbidity values recorded in the 2nd tank can be attributed to some limited sedimentation in the first tank. Dissanayake et al., (2021) reported on the effect of the number of tanks on the quality of the rainwater collected showing that the first tank of a multi-tank system retains the majority (> 60%) of the incoming particulate pollutants. Similarly in the present study the value of conductivity, classifies water exclusively in category C2 in terms of salinity risk, at the same time that some samples of the first tank fall into a lower quality category (C3). Regarding the recorded values for Ca, Mg, Na and K, these are very close to the results presented by Celle-Jeanton (2009) for rainwater characteristics in the Mediterranean region. In this research the presence of calcium is attributed to land sources (dissolution of limestone or alluvial carbonate sediments) while chlorides, magnesium and sodium to the effect of marine aerosols in the area. The presence of potassium in the samples of the same study was equally low and is reported to be mainly due to terrestrial releases. The Wilcox diagram (Figure 3.27) classifies the collected rainwater in category C2-S1, i.e., water with minimal risk of alkalinization and moderate risk of salinization. Regarding the microbiological results (TC, *E. Coli, Enterococcus*) that was obtained during the monitoring period, the mean values for both tanks is at level of 1000 CFU/100 ml for Total Coliforms and 16-23 CFU/100 ml *E. Coli*. While there is no regulation relating to rainwater collection implying limits for irrigation use, the above results range within expected values for natural surface water as reported for example in Council Directive 75/440/EEC (1975) Concerning the Quality Required of Surface Water Intended for the Abstraction of Drinking Water in the Member States (Natural surface Water quality _TC: 50-5000 CFU/100 ml, *E. Coli*: 20-2000 CFU/100 ml).

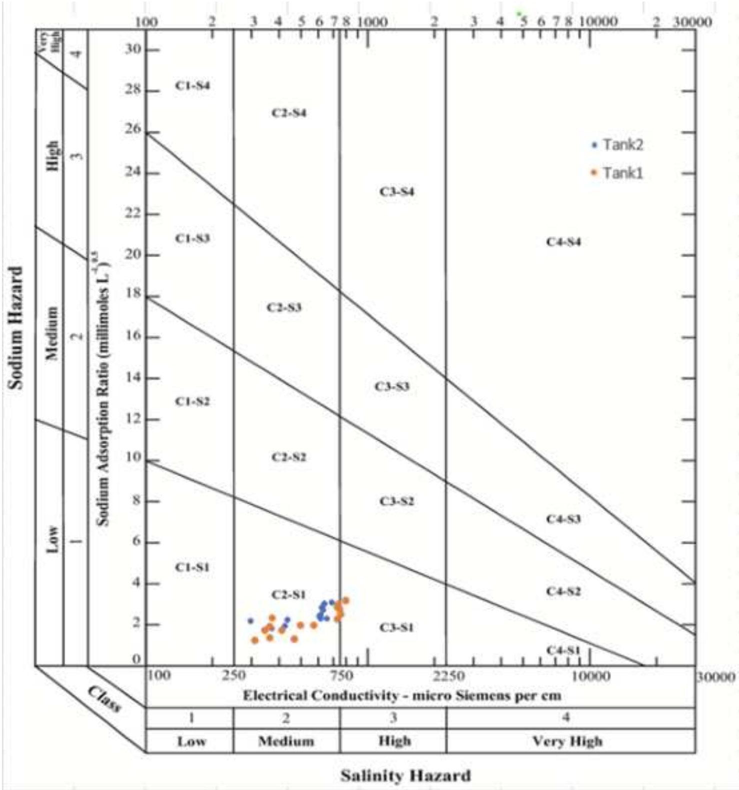


Figure 3.27 Wilcox diagram for rainwater collected in Tank 1 (orange) and Tank 2 (blue).

Additionally, heavy metals have been analysed for the rainwater collected in the two tanks of HYDRO3, shown in Table 3.13 in comparison with the irrigation water quality guidelines of FAO and Greek Common Ministerial Decision of 08/03/2011, 145116/2011. The reported concentrations for all the analysed heavy metals are below the limits, causing no threat to the cultivation, based on both guidelines.

Table 3.13: Heavy metals and ions 'concentration in the harvested water of HYDRO3 compared with the relevant guidelines

Parameter	Tank 1	Tank 2	Greek Regulation Limits 145116/2011	FAO
Cu (μg/L)	5.6 (±2.3)	15.8 (±1.6)	200	200
Cd (μg/L)	<0.25	<0.25	10	10
Cr (μg/L)	<1.6	<1.6	100	100
Pb (μg/L)	<3.0	<3.0	100	500
Ni (μg/L)	<5.0	<5.0	200	200
Mn (μg/L)	15 (±5.7)	13 (± 4.1)	200	200
Zn (mg/L)	0.15 (±0.080)	0.23 (±0.084)	2.0	2.0

Parameter	Tank 1	Tank 2	Greek Regulation Limits 145116/2011	FAO
Fe (μg/L)	29 (±22)	<20	3000	5000
Al (mg/L)	<0.020	0.020	5	5
Hg (μg/L)	<0.5	<0.5	2	-
B (mg/L)	<0.05	<0.05	2	<0.7 no restriction 0.7-3, slight to moderate restriction >3.0 severe restriction in use
F (mg/L)	0.30 (±0.04)	0.39 (±0.04)	1	1
CN (mg/L)	<0.010	<0.010	-	-
Phenols (mg/L)	0.12 (±0.02)	0.14 (±0.01)	-	-

The dehumidifier samples' analysis shows that the produced water is of high quality, with low conductivity values (average of 68.1 μS/cm) and low total hardness (9.5 mg $CaCO_3$/L). This source was used as potable water; thus, the characteristics of the dehumidifier samples are shown in Table 3.14 compared with the drinking water directive limits.

Table 3.14. Quality of the water produced form the dehumidifier unit of HYDRO3 compared to drinking water regulation limits

Parameter	Dehumidifier	Limits Drinking Water Directive EU 2020/2184	Parameter	Dehumidifier	Limits Drinking Water Directive EU 2020/2184
pH	7.36 (±0.01)	≥ 6,5 and ≤ 9,5	Al (μg/L)	<20	200
Conductivity (μS/cm)	68.1 (±3)	2500	Sb (μg/L)	<0.1	10
Turbidity (NTU)	0.34 (±0.1)	Acceptable to consumers and no abnormal change	As (μg/L)	0.32	10
TSS (mg/L)	<1		B (mg/L)	<0.05	1.5
NO_3-N (mg/L)	0.74 (±0.02)	11.3	Cd (μg/L)	<0.25	5.0
SO_4^{2-} (mg/L)	<4	250	Co (μg/L)	1.2	-
Cl^- (mg/L)	1.5 (±0.5)	250	Cu (μg/L)	11	2000

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

Parameter	Dehumidifier	Limits Drinking Water Directive EU 2020/2184	*Parameter*	Dehumidifier	Limits Drinking Water Directive EU 2020/2184
TP (mg/L)	<0.1	-	**CN (μg/L)**	0.0	50
Alkalinity ($mgCaCO_3/L$)	200 (±35)	-	**Cr (μg/L)**	<1.6	25
Total hardness ($mgCaCO_3/L$)	9.5 (±2.9)	-	**F (mg/L)**	<0,1	1.5
Na^+ (mg/L)	1.66 (±0.4)	200	**Mn (μg/L)**	<2.0	50
TC (CFU/100 ml)	0	-	**Mo (μg/L)**	0.47	-
E. Coli (CFU/100 ml)	0	0	**Se (μg/L)**	<0.5	20
Enterococci (CFU/100 ml)	0	0	**Pb (μg/L)**	<3.0	10
			Ni (μg/L)	<5.0	20
			Hg (μg/L)	<0.5	1.0
			Zn (mg/L)	<0.1	-
			Fe (μg/L)	<20	200

Further analysis on the organic compounds of the drinking quality water produced in the dehumidifier unit was conducted and the results are shown in Table 3.15, compared with the regulation limits of the Drinking Water Directive (2020/2184). For the majority of the compounds the concentration was below the detection limits and in no case, this exceeded the parametric value of the Directive. However, some compounds from the PAH group (Polycyclic aromatic hydrocarbons) were quantified, Benzo[b]fluoranthene-Benzo[g,h,i]perylene -Indeno(1,2,3-cd) pyrene; but still below the set limit.

Table 3.15: Analysis of organic compounds in water produced in the dehumidifier system.

Parameters	Average values	Limits 2020/2184	**Parameters**	Average values	Limits 2020/2184
Total Petroleum Hydrocarbons (TPH) (mg/L)	0.12		Quintozene	<0.003	0.1
Bromate ($\mu gBrO_3/L$)	<0.1	10	Tetrachlorvinphos	<0.003	0.1
Trihalomethanes (THM) (μg/L)			Tetradifon	<0.003	0.1
Chloroform	<0.5		Triadimefon	<0.003	0.1
Bromodichloromethane	<0.5		Trifluralin	<0.003	0.1
Dibromochloromethane	<0.5	100	Vinchlozoline	<0.003	0.1
Bromoform	<0.5		Organophosphate pesticides (OPPs) (μg/L)		
Total Trihalomethanes	<2.0	100	Azinphos-Et	<0.003	0.1
Acrylamide	<0.01	0.1	Azinphos-Me	<0.003	0.1
Epichlorohydrin	<0.01		Bromophos-Et	<0.003	0.1
Polycyclic aromatic hydrocarbons (PAH) (μg/L)		0.1	Bromophos-Me	<0.003	0.1
Naphthalene	<0.05		Chlorfenvinphos	<0.003	0.1
Acenaphthylene	<0.005		Cadusaphos	<0.003	0.1
Acenaphthene	<0.005		Chlorpyrifos-Et	<0.003	0.1

Parameters	Average values	Limits 2020/2184	Parameters	Average values	Limits 2020/2184
Fluorene	<0.005		Chlorpyrifos-Me	<0.003	0.1
Phenanthrene	<0.01		Diazinon	<0.003	0.1
Anthracene	<0.005		Ethion	<0.003	0.1
Fluoranthene	0.01		Ethoprophos	<0.003	0.1
Pyrene	<0.005		Etrimfos	<0.003	0.1
Benzo[a]anthracene	<0.01		Fenamiphos	<0.003	0.1
Chrysene	<0.01		Fenthion	<0.003	0.1
Benzo[b]fluoranthene	<0.002	0.1	Heptenophos	<0.003	0.1
Benzo[k]fluoranthene	<0.002		Malathion	<0.003	0.1
Benzo[g,h,i]perylene	<0.002		Methidathion	<0.003	0.1
Indeno(1,2,3-cd) pyrene	<0.002		Parathion-Et	<0.003	0.1
Benzo[a]pyrene	<0.001	0.01	Paraoxon-Me	<0.003	0.1
Dibenzo[a,h]anthracene	<0.002		Phorate	<0.003	0.1
Halogenated pesticides (μg/L)					
Aldrin & Dieldrin	<0.003	0.03	Phosalone	<0.003	0.1
Bromopropylate	<0.003	0.1	Phosmet	<0.003	0.1
Chlordane cis & trans	<0.003	0.1	Phosphamidon	<0.003	0.1
Chlorothalonil	<0.003	0.1	Pirimiphos-Et	<0.003	0.1
Cyfluthrin	<0.003	0.1	Pirimiphos-Me	<0.003	0.1
Cyhalothrin-λ	<0.003	0.1	Prothiophos	<0.003	0.1
Cypermethrin	<0.003	0.1	Pyrazophos	<0.003	0.1
DDT/DDD/DDE	<0.003	0.1	Quinalphos	<0.003	0.1
Deltamethrin	<0.003	0.1	Triazophos	<0.003	0.1
Dinitramine	<0.003	0.1	Organonitrogen Pesticide (μg/L)		
Diniconazole	<0.003	0.1	Atrazine	<0.01	0.1
Endosulfan (sum of isomers α-, β- & sulfate)	<0.003	0.1	Bitertanol	<0.01	0.1
Endrin	<0.003	0.1	Benfuracarb	<0.01	0.1
Ethalfluralin	<0.003	0.1	Carbaryl	<0.01	0.1
Fenarimol	<0.003	0.1	Carbofuran	<0.01	0.1
HCH -α	<0.003	0.1	Cyanazine	<0.01	0.1
HCH -β	<0.003	0.1	Cyproconazole	<0.01	0.1
HCH -γ (lindane)	<0.003	0.1	Cyprodinil	<0.01	0.1
Heptachlor	<0.003	0.03	Fenoxycarb	<0.01	0.1
Heptachlor epoxide endo	<0.003	0.03	Fludioxonil	<0.01	0.1
Hexachlorobenzene (HCB)	<0.003	0.1	Metalaxyl	<0.01	0.1
Iprodione	<0.003	0.1	Metribuzin	<0.01	0.1
Penconazole	<0.003	0.1	Myclobutanil	<0.01	0.1
Profenofos	<0.003	0.1	Pirimicarb	<0.01	0.1
Procymidone	<0.003	0.1	Prometryn	<0.01	0.1
Pyrifenox	<0.003	0.1	Simazine	<0.01	0.1
Quinoxyfen	<0.003	0.1	Terbuthylazine	<0.01	0.1
			Tebuconazole	<0.01	0.1

3.2.3 Crop yield

The agricultural site of HYDRO3 was finalized in December 2019. Field preparation was carried out according to the designs, the drip irrigation pipeline network was designed and installed, the type of oregano was selected (*Origanum vulgare* - oregano crop) and the 10,000 seedlings were ordered and planted in December 2019. The recovered rainwater was used for the irrigation of the oregano field already from the summer period of 2020, specifically from April 2020 to November 2020. In March 2021, 1,000 more plants were planted, this time with the addition of soil conditioners/nutrients and physical soil improvement fertilizer was applied during the plantation process.

At the beginning of June 2021, part of the plantation (20-30% of the plant) exhibited drying of the above ground part due to the adverse climatic conditions (very strong wind and very high temperatures for the specific season). 1,500 oregano plants were bought in pots and replanted. On 15 June 2021 the oregano was harvested yielding at about 50 kg.

Figure 3.28 Oregano harvesting in HYDRO3

In March 2022, we lost 30-35% of the crop that was at the piece of land with low slope due to the rise up of the aquifer. In June 2022 irrigation was stopped for a week so that the oregano plants raise essential oils in the foliage and the harvesting followed. A total of 107 kg of oregano was collected. Finally, in June 2023 the harvested of oregano resulted in 330 kg production.

3.2.4 KPIs status

Table 3.16 presents the KPIs achieved throughout the operation of HYDRO3. As evidenced, all KPIs achieved are very satisfactory and well above the expected values that were originally set.

Table 3.16. The key performance indicators for HYDRO3

Performance indicator	Expected	Achieved
HYDRO3 – rainwater harvested	> 50 m^3/year	60 m^3/year
Condensed vapour water	> 20 m^3/year	28.4 m^3/year
Oregano cultivation	0.4 ha	0.4 ha irrigated
Production	> 800 kg oregano/year/ha >320 kg/year for 0.4 ha	825 kg oregano/year/ha (330 kg/year)

3.3 HYDRO4 Performance

3.3.1. Water Quantities recovered

As described previously HYDRO4 is located in Mykonos. It consists of three separate but interrelated subsystems that have been designed, constructed, tested and optimized to collect and store rainwater for irrigation and aquifer recharge.

Regarding the water collection from the rooftops of the buildings (subsystem 1), the calculation for the collected and stored water is performed by summing the value of the Buffer Tank hydrometer which is connected to the manhole pump 1 and the surfaces that end up in Tank 1 with natural flow. For the period of the wet years the water that was collected from the roofs amounts to 153 m^3; 61 m^3 during the year 2021-2022 and 92 m^3 during the year 2022-2023. This rainwater was stored in Tank 1 and used in the residence for non-potable uses.

For subsystem 2, Slow Sand Filtration system, the rainwater that is collected and recovered is equal to 10 L/d.

For subsystem 3, during start-up, after the **Bioswale** was constructed, there were several major and minor rainfall events. In December 2020 the bioswale received about 160 m^3 of stormwater in 4 subsequent days (about 81 mm). A year later, in December 2021 another event occurred (about 34mm), which resulted in preventing the flooding of the lavender field but also in collecting about 65 m^3 of stormwater to be stored in the subsurface. Another event (about 46mm) took place in mid-January 2022, in which about 80 m^3 of stormwater was collected and sent to recharge the aquifer. In the same month (end of January and beginning of February 2022), a major rainfall event occurred (about 84mm), which resulted in collecting and storing about 165 m^3 of rainwater. Thus, in total, the stormwater collected from the bioswale system amounts to **470 m^3** for the three wet seasons.

The **surface runoff** was collected and stored in Tank 2 for irrigation use and in case of excess water for aquifer recharge. In total, for the irrigation needs about 80 m^3 were stored in Tank 2 for both the wet periods (2021-2022 and 2022-2023).

Based on the site monitoring on the rainfall events and the water level of Tank 2, shown in Figure 3.29, there is a quite good response rate of the surface runoff collected in Tank 2 after each event e.g., mid-October 2021, December 2021, mid-January 2022 and February 2022. Also, there are two periods of using the water of Tank 2 for irrigation: one in the planting phase of the lavender (November 2021) and a second in the start of the dry season (mid-April 2022).

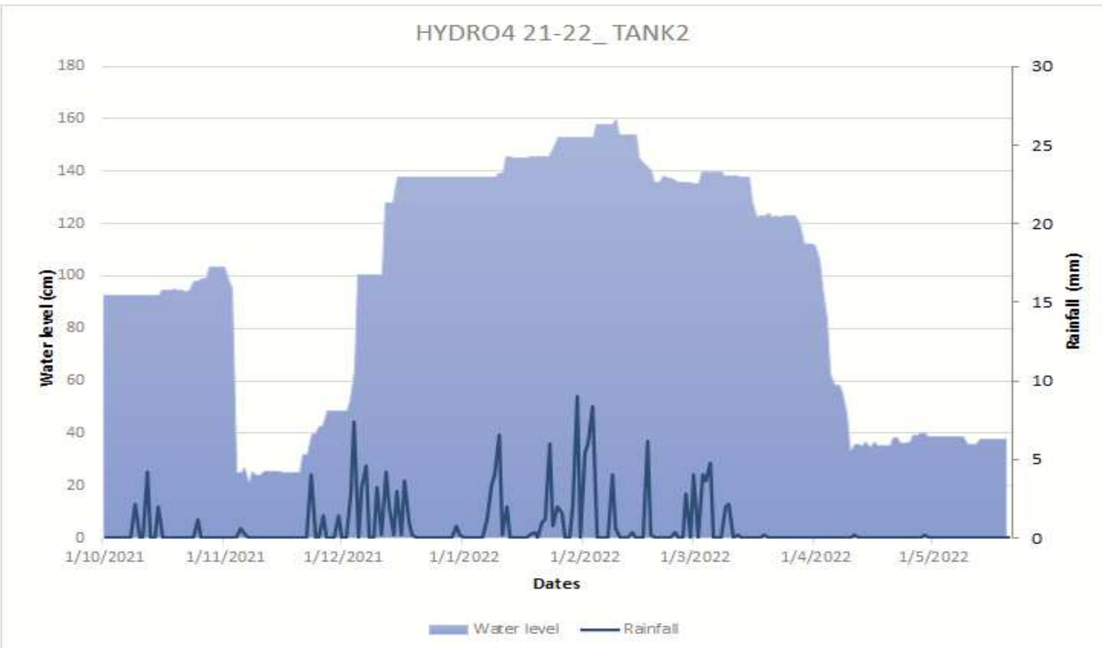
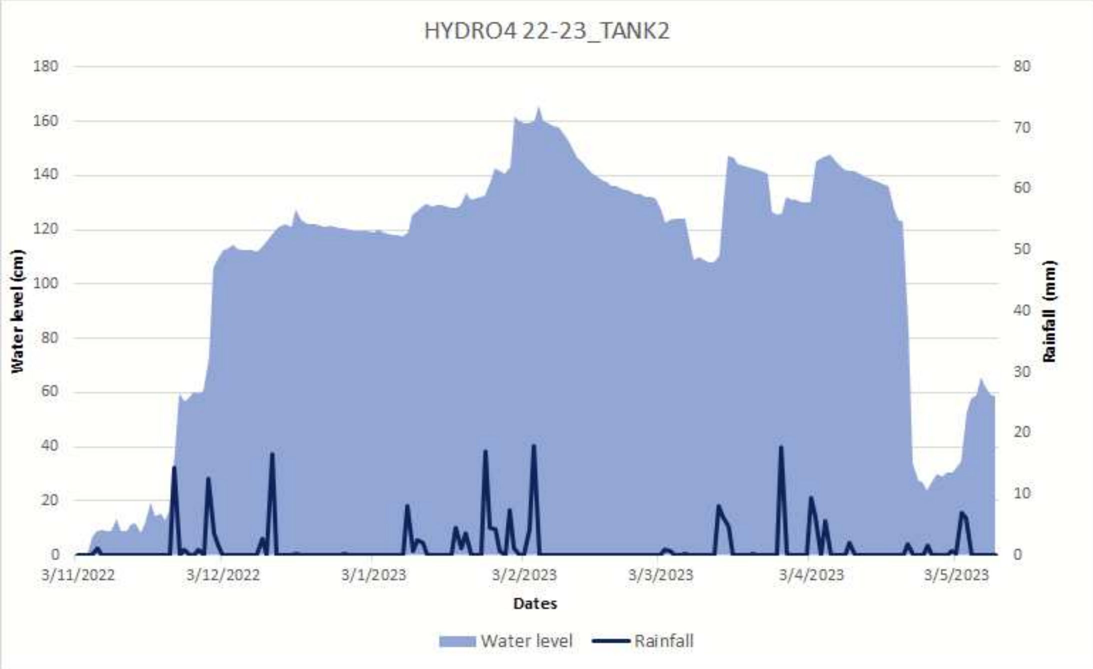


Figure 3.29. Daily Rainfall and Tank 2 Water Level response during the wet period of 2021 - 2022

With regard to the next wet period of 2022 - 2023, as shown in Figure 3.30 the water level responds quite well with the respective rainfall events e.g., December 2022, February 2023 and start of April 2023.

Figure 3.30. Daily Rainfall and Tank 2 Water Level response during the wet period of 2022 - 2023



In addition, it is apparent that at the start of the dry period (mid-April) part of the water of Tank 2 was used for irrigation. Also in March, the second phase of plantation of lavender was implemented, thus an amount of water from Tank 2 was used to irrigate the crop. This is also more apparent in Figure 3.31 where we can see the correlation of rainwater events and Tank 2 water level, at the end of the last wet period.

Figure 3.31. Daily Rainfall and Tank 2 Water Level response (last wet period - 2023)

During the first wet period of 2021-2022, 33 m^3 of excess water of Tank 2 was used to recharge the aquifer. In the next wet period of 2022 - 2023 the respective excess water that was sent to the AR area was 6 m^3. Thus, in total **39 m^3** of Tank 2 were used to recharge the aquifer during the two wet periods.

Regarding the **water used for irrigation** in the dry period of 2022, this is calculated from the water that has been measured to be stored in the open tank plus the water that was stored in Tank 2 and was measured to be used for irrigation.

Irrigation water = Open Tank + Tank 2 = 63 m^3+ 18 m^3 = **81 m^3**

The recovered water of the Open Tank from the aquifer is monitored by the water meter, which follows an increasing trend during the dry season due to the water needs of lavender. In practice it is the amount of water stored in the wet season in the recharge site and needed to be used in the dry months. This quantity is estimated by subtracting the water of the Open Tank at the end of the wet season (April 2023) to the value of 10m^3 which is the capacity of the Open Tank.

Recovery = Open Tank wet – 10 m^3 = 71 m^3- 10 m^3 = **61 m^3**

Modelling activities for assessing the performance of the aquifer

Beyond monitoring the systems and measuring the water collected, we have performed modelling work to simulate the artificial recharge well (W_{AR}) water level fluctuations, in combination with meteorological observations to provide optimized water management suggestions for the HYDRO4 site for the wet and dry seasons, respectively.

Initially, the partitioning between “wet” and “dry” seasons in HYDRO4 site, based on previous reports’ findings (D2.1: Design of rainwater management systems, D2.2: Rainwater management systems installed and running) that analysed a wide range of hydrological and geochemical data, was revised. These reports explored the forcing of air temperature to W_{AR} water level during the dry season, but also the respective role of rainfall to the HYDRO4 aquifer recharge mechanisms along with temporal variations and lags of the W_{AR} water level rise during successive wet seasons. It was previously stated that the wet season lasts from September to June (D2.2: Rainwater management systems installed and running), due to the spring rainfall period which in specific years can offer the system with high amounts of surface runoff. Subsequently the dry season included only the summer months (July and August). However, the continuous W_{AR} water level monitoring during the 2020-2021 and 2021-2022 hydrological seasons, validates that the partitioning between wet and dry seasons starts in March (Figure 3.32), due to the increasing forcing of daily air temperatures, irrespective of the spring (March – May) rainfall totals.

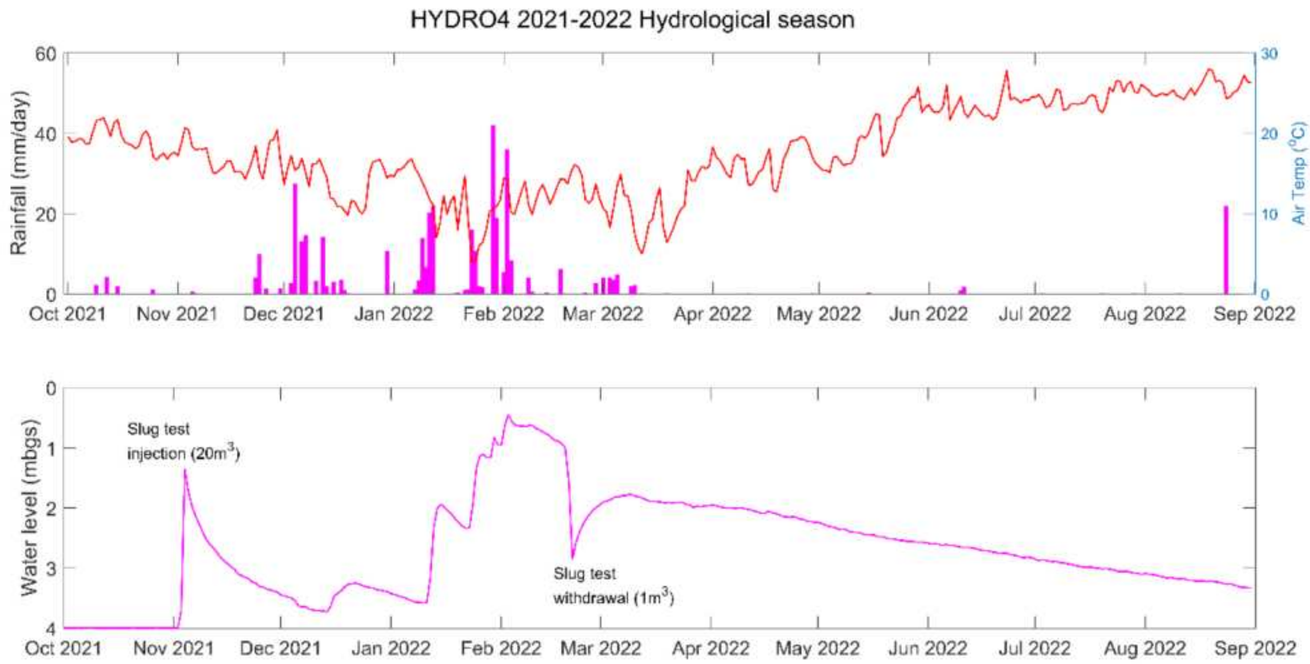


Figure 3.32. Air temperature and rainfall data[1] and WAR level during the 2021-2022 hydrological season.

Taken together, the dry season (March – September) field data from these two consecutive seasons point to an average daily air temperature threshold of 10°C that marks the linear decline of the W_{AR} water level (Figure 3.33).

Dry season aquifer simulation

The high linear correlation coefficients ($r > 0.9$, $p < 0.001$) between the dry season daily air temperatures (Temp) and W_{AR} water level (WL), suggest that simple linear regression models explain more than 80% of the observed variance and can efficiently describe the diel water level fluctuations during the dry season.

The difference in the regression slopes between the two hydrological years (see Table 3.17) is related to different initial boundary conditions at the end of the respective wet seasons. The total precipitation during the 2020-2021 wet season was 210 mm and resulted in lower W_{AR} water level at the beginning of the dry season (3.2 mbgl), compared to the 2021-2022 wet season, when the total wet season rainfall of 350 mm was above the annual average (D2.2: Rainwater management systems installed and running) and resulted to a higher W_{AR} level at 1.8 mbgl, despite the withdrawal of 1 m^3 of water (slug test) from the aquifer (Figure 3.34).

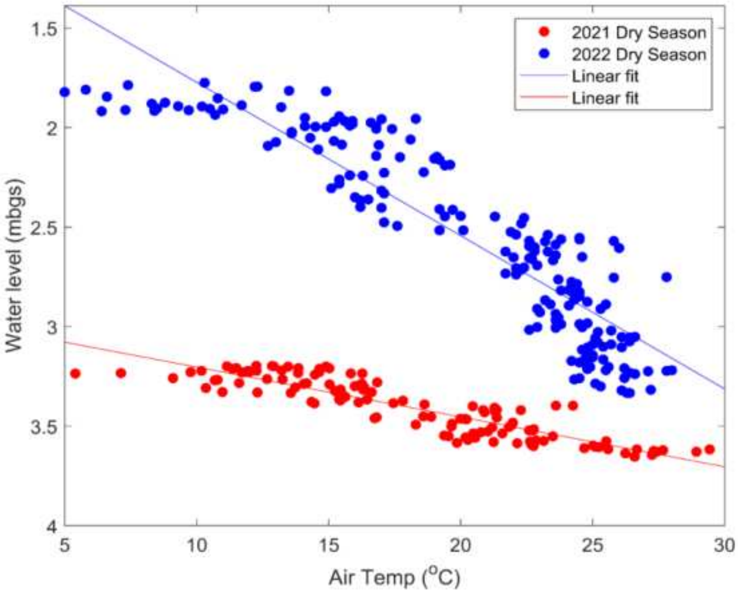


Figure 3.33. Linear relations between W_{AR} water level (WL) and dry season (March – September) air temperature (Temp)

Table 3.17. **Single and multiple linear regression parameters of HYDRO4 aquifer simulation models**

Model type	Parameters (season)	Correlation coefficient	Equation
Linear regression	WL – Temp (Dry 2021 / 2022)	r = 0.91 ($p < 0.001$)	*WL = 1.0031 + 0.077Temp*
Linear regression	WL – Temp (Dry 2020 / 2021)	r = 0.90 ($p < 0.001$)	*WL = 2.9529 + 0.0250Temp*
Segmented linear regression	WL – Temp (Dry 2021 / 2022)	r = 0.92 ($p < 0.001$)	*WL = 0.7209 + 0.0895Temp*
Segmented linear regression	WL – Temp (Dry 2020 / 2021)	r = 0.90 ($p < 0.001$)	*WL = 2.9231 + 0.0265Temp*
Multiple linear regression	WL - Temp – Rain (Wet 2021/2022)	r = 0.53 ($p < 0.001$)	*WL = -0.1197 - 0.0430Rain -0.1827Temp + 0.0035*
Multiple linear regression	WL – Temp* – Rain (Wet 2021/2022)	r = 0.59 ($p < 0.001$)	*WL = 0.4657 + 0.0626Rain - 0.2199Temp - 0.0056*

*Air temperature 10-day moving mean values were used to smooth the diel variations

The slope of the linear regression past the threshold air temperature value of 10°C, is more pronounced for the 2021-2022 dry season due to the higher WL at the end of the previous wet season and to subsequent more intense drop of W_{AR} water level (WL). The correlations between Temp and WL slightly improve through the application of segmented regression, with a breakpoint at 10^{o}C (Table 3.17). As such, the initial linear regressions are effective simulators of the dry season HYDRO4 aquifer simulation.

The low values of the linear regression slopes for both 2020-2021 and 2021-2022 dry seasons provide firm evidence of the retention capacity of the aquifer. Despite the spring (March-April) rainfalls during the 2020 - 2021 dry season W_{AR} water level continued its linear drop.

These observations suggest that all excess water stored in the other installations of the HYDRO4 site (rooftops, surface runoff, etc.) could be injected into W_{AR} before or during spring (March – May) rainfall events.

Wet season aquifer simulation

Wet season aquifer simulation shows a nonlinear response to the combined forcing of rainfall and precipitation. This is expected as the lagged response of W_{AR} water level (WL) can vary between 10 hours to 10 days depending on the aquifer recharge mechanism that is activated (D2.2: Rainwater management systems installed and running). Field data suggest that the longest lags of W_{AR} WL response to rainfall occur at the start of wet season when the relative humidity is still low and the soils in the recharge zone are undersaturated.

This is further evaluated through cross correlation of the 2021-2022 wet season WL and Rain data. The results suggest that the highest cross correlation between the two parameters, albeit low (r = 0.35) is reached after 25 days (Fig. 3.33). This large statistical lag is explained by the overall large variability of rainfall events which for the 2021-2022 wet season range between 2 and 10 days, but also from the different driving mechanisms of HYDRO4 aquifer recharge.

Wet season HYDRO4 aquifer simulation was achieved through Multiple linear regression (MLR) between rainfall (RAIN), air temperature (Temp) and W_{AR} water level (WL) for the 2021-2022 wet season. The results show a moderate correlation coefficient between measured and simulated values due to several nonlinearities discussed above. The MLR application with smoothed Temp (10-day moving mean) data improves the fit of the model (Table 3.17).

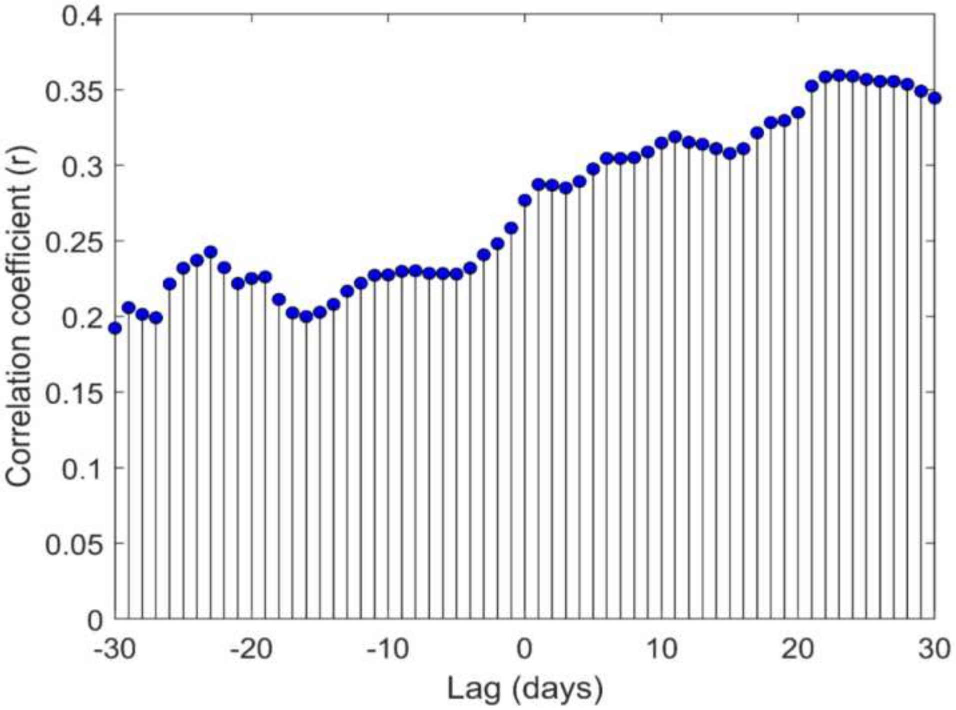


Figure 3.34. Cross correlation between W_{AR} water level and daily rainfall to depict the lagged response of HYDR4 aquifer to wet season rainfall events.

The MLR model simulation of HYDRO4 aquifer confirms that even in the wet season when air temperatures are above 20^{o}C the effect of rainfall on WL is substantially reduced. Visually this is evident from the lower edge of the MLR model fitted surface (blue colours), which corresponds to the lowest wet season water levels, even though daily rainfall values can exceed 10 mm (Fig. 3.33). The W_{AR} water level signal during the 2021-2022 wet season is also distorted by the two slug tests (Fig. 3.30), that introduce additional errors in the simulation (Figure 3.35). The diel air temperature variation introduces noises which are reduced through data smoothing, thus improving the model (Table 3.17).

Both MLR models overestimate by 1.2 m the W_{AR} water level rise and thus HYDRO4 recharge volume capacity during the first significant rainfall period in December 2021. This is likely attributed to the high air temperatures (Figure 3.32) and to the slow water percolation across the weathered bedrock-soil boundary and delayed saturation of the granitic fracture system that resulted in an overall lagged WL response. This mechanism cannot be captured by the linear regression models. On the contrary, the MLR model with the smoothed air temperature data performs well in simulating the W_{AR} WL during the February 2022 rainfall period. The simulated abrupt drop in WL is biased to the slug test.

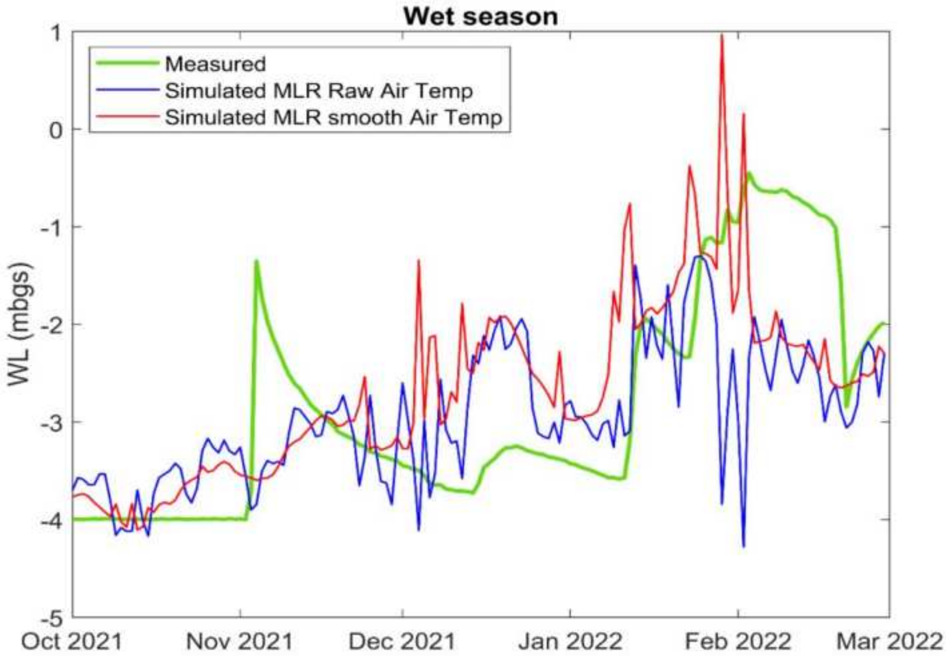


Figure 3.35. Wet season HYDRO4 simulation through MLR models, using raw and smoothed air temperature data.

The field observations and simulations agree with previous conclusions regarding the functioning of HYDRO4 aquifer. Early wet season rainfall shows a nonlinear and lagged response of aquifer recharge, whereas during the late wet season aquifer response becomes linear and more predictable.

Considering the field observations and the aquifer simulation results **for optimizing the HYDRO4 water management**, the following conclusions were drawn, and suggestions were made and implemented:

Hourly observations of meteorological parameters and W_{AR} water level show that HYDRO4 aquifer steady state is nearly never achieved due to diel variations of several parameters including water level (D2.2: Rainwater management systems installed and running).

- However, we consider the daily means shown in this report to represent quasi-steady state conditions of HYDRO4 aquifer.
- The partitioning between wet (October – February) and dry seasons (March – September) is driven by the air temperature annual and seasonal variations.
- Wet season high temperatures and low rainfall impact the HYDRO4 aquifer by pertaining dry season soil undersaturation and low aquifer water level, causing long recharge lags to antecedent rainfall events. This is validated from a slug test (November 2021) when 20 m^3 were injected in W_{AR} with subsequent drop of WL over the next 40 days due to overall “dry” conditions.
- **Suggestion:** As the response of HYDRO4 complementary water harvesting installations (bioswale, surface runoff, roof tops, etc.) will be faster than the observed and simulated subsurface aquifer recharge during early wet season rainfall events, the injection of (excess) water from the water harvesting installations into W_{AR} prior to forecasted rainfall events will precondition the aquifer to store more water during the wet season.
- **Suggestion**: Late wet season withdrawal of water volumes of ~1m^3 from the subsurface aquifer for domestic or agricultural use is possible and supported by both the simulation model and the slug test.
- Wet season cumulative rainfall and W_{AR} water level, define the regression slope of dry season W_{AR} water level drop and thus HYDRO4 aquifer retention capacity, which appears to be high.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

- Spring (March – May) rainfall is offset by the high seasonal air temperatures, resulting in an observed and simulated linear drop of aquifer water level.
- **Suggestion:** The injection of excess water from HYDRO4 complementary installations (bioswale, surface runoff, roof tops, etc.) before forecasted rainfall during the early dry season (March – May) will result in higher retention capacity and permit the use of small amounts of water during the dry season. This management practice has the additional advantage of reducing the conductivity and turbidity values, which increase during the dry season (D2.3) and hence improves the quality of the water stored in HYDRO4 aquifer.

3.2.2. Water Quality

Besides monitoring the quantity of water, the system also incorporates quality monitoring, as mentioned above. This monitoring approach covers the simultaneous collection of online data, in situ measurements, and laboratory analysis. This thorough methodology allows the operator to promptly identify any potential operational or sensors' failures. An illustrative example of this check is presented in Figures 3.36.-3.37, depicting the conductivity values reported by the online system, the operator in situ measurements, and the lab reports for both the AR and Tank 2 of the HYDRO4 collection systems. These graphs serve to demonstrate the consistency and accuracy of the conductivity measurements across the different monitoring methods. Notably, the measurements are in alignment, indicating the smooth progression of the monitoring process without any issues.

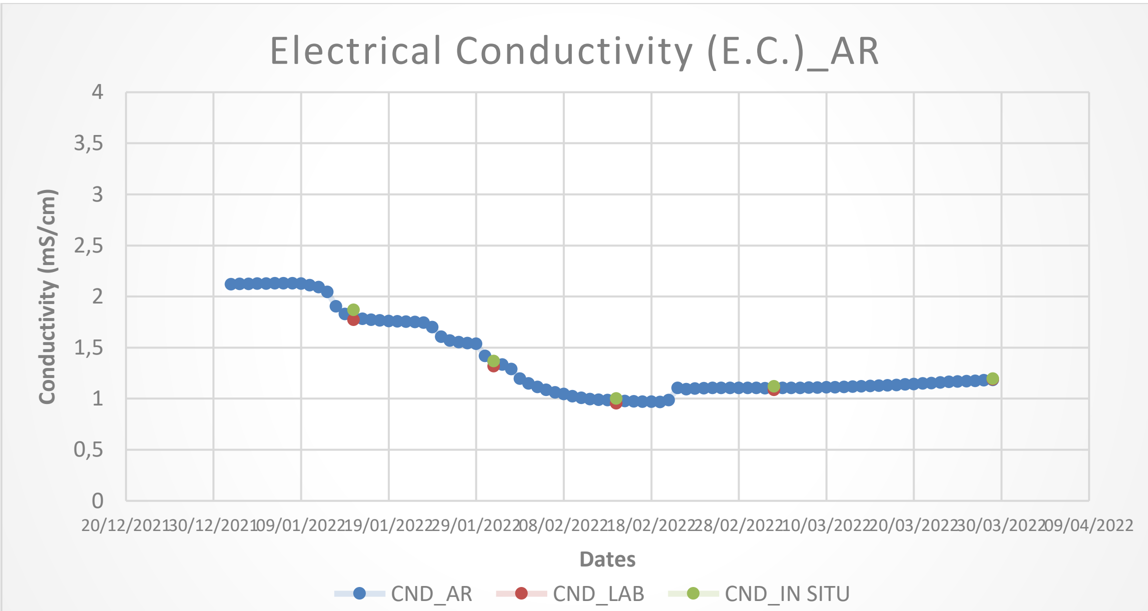


Figure 3.36. E.C. measurements in the AR well (online sensor, operator and lab measurements)

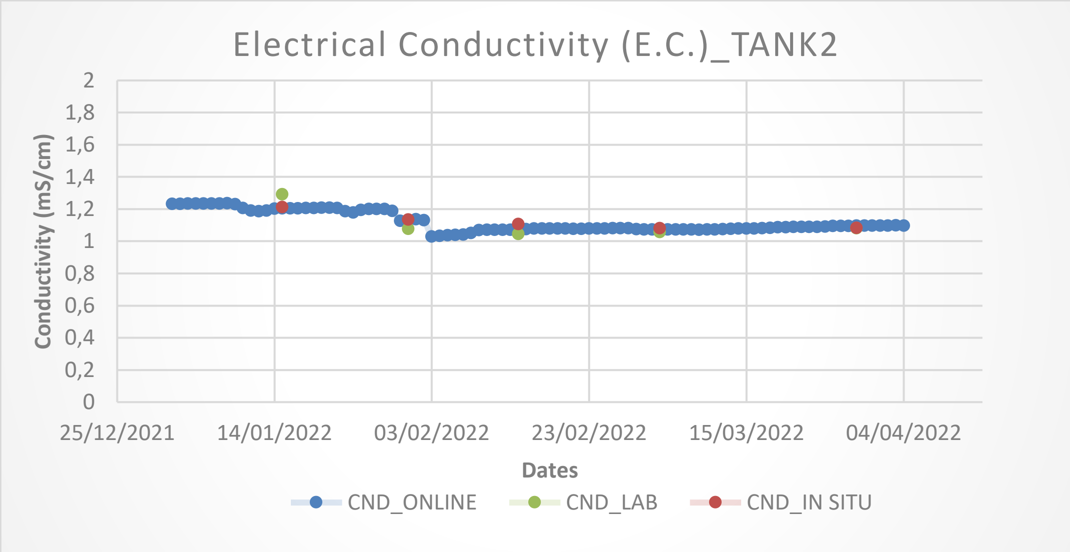


Figure 3.37. E.C. measurements in Tank2 (online sensor, operator and lab measurements)

The differences in the water quality of the various rainwater/stormwater streams of HYDRO4 subsystems are presented in Table 3.18. These are attributed to the different collections systems and collection surfaces but also in the first flush diversion applied in the rooftops' collection system, which washes out the large part of the solids that accumulate on the collection surface during the dry season.

Regarding the surface runoff collection system, high turbidity levels were reported, as expected, since rainwater washes out dust and suspended solids that had settled on the surface during the dry period. As reported by Zded et al (2019) the materials and the slope of the surface are related to the turbidity values. Surfaces with high roughness (such as concrete) and low slope tend to accumulate a higher percentage of particles on their surface. This is also confirmed by the high TSS and turbidity values reported for this system. The elevated chloride and sodium concentrations show the effects of the coastal environment and marine aerosols and explain the salt accumulation. The electrical conductivity (E.C.) values reported are high, surpassing 750 μS/cm, classifying the water in category C3-S1 in terms of salinity risk (Figure 3.38). It is important to note that these elevated EC values could not solely be attributed to the coastal environment. Another contributing factor was the return water flow from the AR system back to Tank 2, when it was essential. This introduced higher salinity levels into Tank 2, consequently influencing the overall salinity of the collected water.

The alkaline nature of the minerals in this part of the islands of Mykonos is indicated by the pH of the groundwater presented in the AR samples, which ranges from 7.5 to 7.9 (average value of 7.7). The electrical conductivity of the samples (~1445 μS/cm) is mainly due to slight penetration of seawater. This fact is also verified by the increased concentrations of chloride and sodium salts.

Concerning the 1st subsystem (harvested rainwater), the lower value of electrical conductivity (E.C.) indicates the low concentrations of chloride, sodium, calcium and other ions, which in all cases were found to be far below the limits of potable water (since domestic , non-potable water limits are not available). The study by Sazakli et al. (2007) carried out in rainwater collected from concrete roofs in Kefalonia shows E.C. values of 108 μS/cm and an alkalinity of 42 mg/L $CaCO_3$, which differs slightly from the samples of HYDRO4 due to the proximity of the site to the sea. The low turbidity value and the low concentration of suspended solids (less than 2 mg/L) can be attributed to the diversion of the first flush. The hardness of the water was analysed as 59 mg $CaCO_3$/L, which classifies it as soft.

The performance of the bioswale system is reported as highly satisfactory. Firstly, the system successfully prevented flooding incidents that occurred on the site in December 2020 and December 2021, as well as in January 2022. This not only safeguarded the lavender cultivation but also allowed for the collection of 470 m^3 of water for irrigation purposes through the system. Furthermore, despite the lower quality of stormwater due to debris, the bioswale system's collection and infiltration processes contributed to improving the final water quality in the Open Tank. This enhanced water quality met the requirements for lavender irrigation, as demonstrated in the Wilcox diagram (Figure 3.38). Sulphate ions (SO_4^{2-}) did not exceed the limit of 250 mg/L in any system. In terms of the microbiological results (Total Coliforms, *E. Coli, Enterococcus*) obtained during the monitoring period, bioswale showed mean values of 918 CFU/100 ml for Total Coliforms and 8 CFU/100 ml for *E. Coli*, groundwater-AR (8229 CFU/100 ml TC and 279 CFU/100 ml *E. Coli*) and surfaces runoffs (6956 CFU/100 ml TC and 456 CFU/100 ml *E. Coli*). It is worth noting that there are no specific regulations governing rainwater collection for irrigation purposes. However, these results fall within the expected range for natural surface water quality, as outlined, for instance, in Council Directive 75/440/EEC (1975) concerning the Quality Requirements for Surface Water Intended for Drinking Water Abstraction in Member States (Natural Surface Water Quality: Total Coliforms: 50-5000 CFU/100 ml, *E. Coli*: 20-2000 CFU/100 ml).

Table 3.18. Results of water quality analysis collected from rainwater/stormwater management system (Average value ± standard deviation)

HYDRO4	Groundwater from Artificial Recharge	Surface runoff for irrigation	Rainwater from Rooftops	Stormwater from bioswale
pH	7.73 (±0.22)	7.64(±0.25)	7.83 (±0.32)	7.65 (±0.5)
Conductivity (μS/cm)	1445 (±269)	1115 (±270)	390 (±182)	517 (±170)
Turbidity (NTU)	5.6 (±4.3)	7.9 (±3.1)	1.7 (±0.9)	6.5 (±2.5)
TSS (mg/L)	4.8 (±1.8)	8.9 (±6.1)	1.3 (±0.7)	9.5 (±3.7)
NO_3-N (mg/L)	8.7 (±3.4)	2.2 (±0.9)	1.8 (±0.9)	0.68 (±0.3)
SO_4^{2-} (mg/L)	96 (±18)	73 (±10)	26 (±12)	45 (±18)
Cl^- (mg/L)	344 (±95)	290(±89)	97 (±34)	175 (±42)
TN (mg/L)	8.8 (± 3.4)	2.3(±1.1)	2.1 (±0.9)	0.74 (±0.3)
TDS (mg/L)	717 (±135)	591(±98)	195(±92)	263(±80)
TP (mg/L)	<1	<1	<1	<1
Alkalinity ($mgCaCO_3$/L)	146 (±36)	133 (±25)	57 (±21)	98 (±50)
Total hardness ($mgCaCO_3$/L)	213 (±66)	243 (±32)	59 (±18)	107 (±63)
Sodium adsorption ratio (SAR)	6.67(±0.71)	3.48 (±0.33)	1.6 (±0.9)	2.3 (±0.68)
TC (as mean value)(CFU/100 ml)	**8229**	**6956**	**89**	**918**

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HYDRO4	Groundwater from Artificial Recharge	Surface runoff for irrigation	Rainwater from Rooftops	Stormwater from bioswale
***E. Coli* (as mean value) (CFU/100 ml)**	279	456	3	8
***Enterococci* (as mean value) (CFU/100 ml)**	101	354	51	69

Therefore, it can be concluded that the quality of water is quite stable and satisfactory in terms of electrical conductivity and sodium hazard. No significant variation is noticed and the irrigation water is of average quality fully complying with the needs for the irrigation of lavender.

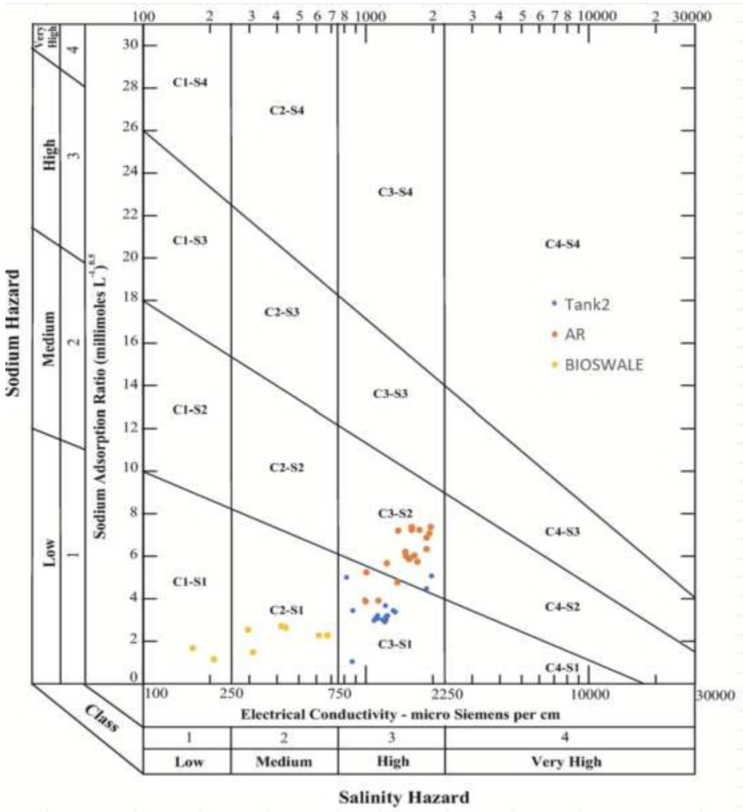

Figure 3.38. Wilcox diagram for the rainwater collected from the different systems to be used for irrigation purposes in HYDRO4.

Additionally, heavy metals have been analysed for the different water qualities recovered in HYDRO4, shown in Table 3.19 in comparison with the irrigation water quality guidelines of FAO and Greek Common Ministerial Decision of 08/03/2011, 145116/2011. The reported concentrations for all the analysed heavy metals are below the limits, causing no threat to the cultivation, based on both guidelines.

Table 3.19. Heavy Metals' and ions' concentration in the harvested water of HYDRO4 compared with the relevant guidelines

Parameter	Groundwater from Artificial Recharge	Surface runoff for irrigation	Rainwater from Rooftops	Stormwater from bioswale	*Greek Regulation Limits 145116/2011*	*FAO*
Cu (μg/L)	15 (±13)	18 (±11)	22 (±20)	33 (±20)	200	200
Cd (μg/L)	<0.25	<0.25	<0.25	<0.25	10	10
Cr (μg/L)	5.5 (±4.9)	3.2 (±0.95)	2.3 (±0.78)	3.1 (±1.5)	100	100
Pb (μg/L)	<3.0	<3.0	<3.0	<3.0	100	500
Ni (μg/L)	21 (±14)	<5.0	<5.0	5.1 (±1.5)	200	200
Mn (μg/L)	9.1 (±4.8)	15 (±7.7)	2.1 (±3.6)	4.6 (±2.9)	200	200
Zn (mg/L)	0.52 (±0.24)	0.22 (0,027)	<0.10	<0.10	2.0	2
Fe (μg/L)	50 (±23)	51 (±36)	<20	<20	3000	5000
Al (mg/L)	<0.020	0.020	<0.020	0.020	5	5
B (mg/L)	<0.05	<0.05	<0.05	<0.05	2	<0.7 no restriction 0.7-3, slight to moderate restriction >3.0 severe restriction in use

The outlet of SSF unit was analysed during the monitoring period and the results are presented in Table 3.20. This physical process was implemented in order to test if the treated water characteristics could fulfil the standards of human consumption. Thus, analysis of SSF samples is compared with the Drinking Water Directive limits. These show that the produced water is of acceptable quality, with low conductivity values (average of 377 μS/cm) and low total hardness (53 mg $CaCO_3$/L) and all the parameters are reported in values below the set limits from the legislation. However, it is important to note that while the system demonstrates a capability for microbiological removal, it does not achieve complete satisfaction in this regard, as the values for *E. Coli* (1 CFU/100 ml) and *Enterococci* (1 CFU/100 ml) are not zero, as specified by the Directive. Coupling it with a downstream disinfection process can result in easily reaching the required targets of 0 CFU/100 ml for both *E. Coli* and *Enterococci*.

Table 3.20. Physicochemical and metal analysis of the water produced from the Slow Sand Filtration system compared with the drinking water limits.

Parameter	SSF	Limits drinking water Directive EU 2020/2184	*Parameter*	SSF	Limits Drinking Water Directive EU 2020/2184
pH	7.92 (±0.24)	6,5 -9,5	**Al (μg/L)**	<20	200

Parameter	SSF	Limits drinking water Directive EU 2020/2184	*Parameter*	SSF	Limits Drinking Water Directive EU 2020/2184
Conductivity (μS/cm)	377 (±130)	2500	**Sb (μg/L)**	0.31	10
Turbidity (NTU)	1.1 (±0.5)	Acceptable to consumers and no abnormal change	**As (μg/L)**	0.20	10
TSS (mg/L)	<0.6		**B (mg/L)**	<0.05	1.5
NO_3-N (mg/L)	1.6 (±0.1)	11.3	**Cd (μg/L)**	<0.25	5.0
SO_4^{2-} (mg/L)	21 (±3.2)	250	**Co (μg/L)**	0.55	-
Cl- (mg/L)	92 (±22)	250	**Cu (μg/L)**	17 (±16)	2000
TP (mg/L)	<1	-	**CN (μg/L)**	<10	50
Alkalinity ($mgCaCO_3$/L)	54 (±12)	-	**Cr (μg/L)**	<2.1(±0.32)	25
Total hardness ($mgCaCO_3$/L)	53 (±9.1)	-	**F (mg/L)**	<0.1	1.5
Na^+(mg/L)	3.6	200	**Mn (μg/L)**	2.8 (±3.6)	50
phenols (mg/L)	0.034		**Mo (μg/L)**	0.38	-
TC (CFU/100 ml)	5	-	**Se (μg/L)**	<0.5	20
E. Coli (CFU/100 ml)	1	0	**Pb (μg/L)**	<3.0	10
Enterococci (CFU/100 ml)	1	0	**Ni (μg/L)**	<5.0	20
			Hg (μg/L)	<0.03	1.0
			Zn (mg/L)	<0.10	-
			Fe (μg/L)	<20	200

Further analysis on the organic compounds of the drinking quality water produced in the SSF system as conducted and the results are shown in the Table below compared with the regulation limits (2020/2184). For the majority of the compounds the concentration was below the detection limits and in no case, this exceeded the parametric value of the directive. Only Acenaphthene was quantified to be 0.017 μg/L from the PAH group (Polycyclic aromatic hydrocarbons), with no set limit for this.

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Table 3.21. Analysis of organic compounds in water produced in SSF system.

Parameters	Average values	Limits 2020/2184	Parameters	Average values	Limits 2020/2184
Total Petroleum Hydrocarbons (TPH) (mg/L)	<0.1		Quintozene	<0.003	0.1
Bromate (μgBrO_3/L)	<0.1	10	Tetrachlorvinphos	<0.003	0.1
Trihalomethanes (THM) (μg/L)			Tetradifon	<0.003	0.1
Chloroform	<0.5		Triadimefon	<0.003	0.1
Bromodichloromethane	<0.5		Trifluralin	<0.003	0.1
Dibromochloromethane	<0.5	100	Vinchlozoline	<0.003	0.1
Bromoform	<0.5		Organophosphate pesticides (OPPs) (μg/L)		
Total Trihalomethanes	<2.0	100	Azinphos-Et	<0.003	0.1
Acrylamide	<0.01	0.1	Azinphos-Me	<0.003	0.1
Epichlorohydrin	<0.01		Bromophos-Et	<0.003	0.1
Polycyclic aromatic hydrocarbons (PAH) (μg/L)		0.1	Bromophos-Me	<0.003	0.1
Naphthalene	<0.1		Chlorfenvinphos	<0.003	0.1
Acenaphthylene	<0.005		Cadusaphos	<0.003	0.1
Acenaphthene	0.017		Chlorpyrifos-Et	<0.003	0.1
Fluorene	<0.005		Chlorpyrifos-Me	<0.003	0.1
Phenanthrene	<0.005		Diazinon	<0.003	0.1
Anthracene	<0.01		Ethion	<0.003	0.1
Fluoranthene	<0.01		Ethoprophos	<0.003	0.1
Pyrene	<0.005		Etrimfos	<0.003	0.1
Benzo[a]anthracene	<0.005		Fenamiphos	<0.003	0.1
Chrysene	<0.005		Fenthion	<0.003	0.1
Benzo[b]fluoranthene	<0.002		Heptenophos	<0.003	0.1
Benzo[k]fluoranthene	<0.002	0.1	Malathion	<0.003	0.1
Benzo[g,h,i]perylene	<0.002		Methidathion	<0.003	0.1
Indeno(1,2,3-cd) pyrene	<0.002		Parathion-Et	<0.003	0.1
Benzo[a]pyrene	<0.001	0.01	Paraoxon-Me	<0.003	0.1
Dibenzo[a,h]anthracene	<0.002		Phorate	<0.003	0.1
Halogenated pesticides (μg/L)			Phosalone	<0.003	0.1
Aldrin & Dieldrin	<0.003	0.03	Phosmet	<0.003	0.1
Bromopropylate	<0.003	0.1	Phosphamidon	<0.003	0.1
Chlordane cis & trans	<0.003	0.1	Pirimiphos-Et	<0.003	0.1
Chlorothalonil	<0.003	0.1	Pirimiphos-Me	<0.003	0.1
Cyfluthrin	<0.003	0.1	Prothiophos	<0.003	0.1
Cyhalothrin-λ	<0.003	0.1	Pyrazophos	<0.003	0.1
Cypermethrin	<0.003	0.1	Quinalphos	<0.003	0.1
DDT/DDD/DDE	<0.003	0.1	Triazophos	<0.003	0.1
Deltamethrin	<0.003	0.1	Organonitrogen Pesticide (μg/L)		
Dinitramine	<0.003	0.1	Atrazine	<0.01	0.1
Diniconazole	<0.003	0.1	Bitertanol	<0.01	0.1
Endosulfan (sum of isomers α-, β- & sulfate)	<0.003	0.1	Benfuracarb	<0.01	0.1
Endrin	<0.003	0.1	Carbaryl	<0.01	0.1
Ethalfluralin	<0.003	0.1	Carbofuran	<0.01	0.1
Fenarimol	<0.003	0.1	Cyanazine	<0.01	0.1
HCH -α	<0.003	0.1	Cyproconazole	<0.01	0.1
HCH -β	<0.003	0.1	Cyprodinil	<0.01	0.1
HCH -γ (lindane)	<0.003	0.1	Fenoxycarb	<0.01	0.1
Heptachlor	<0.003	0.03	Fludioxonil	<0.01	0.1
Heptachlor epoxide endo	<0.003	0.03	Metalaxyl	<0.01	0.1
Hexachlorobenzene (HCB)	<0.003	0.1	Metribuzin	<0.01	0.1
Iprodione	<0.003	0.1	Myclobutanil	<0.01	0.1
Penconazole	<0.003	0.1	Pirimicarb	<0.01	0.1

Parameters	Average values	Limits 2020/2184	Parameters	Average values	Limits 2020/2184
Profenofos	<0.003	0.1	Prometryn	<0.01	0.1
Procymidone	<0.003	0.1	Simazine	<0.01	0.1
Pyrifenox	<0.003	0.1	Terbuthylazine	<0.01	0.1
Quinoxyfen	<0.003	0.1	Tebuconazole	<0.01	0.1

3.3.3. Crop yield

Due to the highly touristic nature of Mykonos Island, the hotels and resorts situated on the island are high consumers of the freshwater resources with a high amount of water being imported to the island, it deems the use of fresh water in agriculture a challenge. Therefore, HYDRO4 depends on rainwater harvesting and collecting systems and reuse of these reserves for the cultivation of plants, providing an added value to the island.
HYDRO4 covers about 0.2 ha of land area. The lavender plant that was selected for this site grows slowly during the first years and needs about 1.5 to 2 years for essential oil production. In 2022 17.5 kg of lavender was collected. After harvesting, plants were dried in the shade. Natural drying is a common procedure recommended to be performed at 30-35°C for commercial scale production. In 2023 105 kg of lavender was collected, dried and distilled.

3.3.4. KPIs status

Table 3.22 presents the KPIs achieved throughout the operation of HYDRO4. As evidenced, KPIs achieved are very satisfactory and almost all above the expected values that have originally being set.

Table 3.22. Key Performance indicators for HYDRO4

Performance indicator	Expected	Achieved
HYDRO4 –rainwater and surface runoff collected per year	> 250 m^3/year	Average 272 m^3/year Max 411 m^3/year
Fresh water stored in aquifer	500 m^3	509 m^3
Rain converted to freshwater HYDRO4	10 L/d	10 L/d
Cultivation	0.2 ha of lavender	0.2 ha irrigated
Production	1000 kg Lavender /year/ha 200 kg/year for 0.2 ha	105 kg /year for 0.2 ha

3.4 HYDRO5 Performance

3.4.1. Water Quantities recovered

As described in the previous chapter, HYDRO5 is located in Tinos Island in an area next to the local RO plant. It consists of two different technologies: i) a desalination system, named Mangrove Still System (MSS) and ii) an agricultural site composed by a greenhouse producing tropical fruits and an appropriate irrigation system.

At the first operation period, based on collected data by IoT water level sensors installed by PLANET, the system produced in average 210 L/d of fresh water, in line with the estimations already reported in Deliverable D2.3.
Currently the produced FW quantities are monitored and recorded online, through the FW tank's flux-meter. Minimum water quantities (refers to FW production during fall & winter 2022), are in line with the expected

yield. The data reports a FW average production at about 161 L/d, as presented in the Table below. It must be noted that the FW production is highly dependent on the weather conditions (incoming solar radiation and the cloud covering), resulting in a high variation between the seasons. The respective recovered quantities during the spring and summer periods are noticeably higher, reaching even a maximum value of 300 L/d. Finally, it must also be considered that 76 out of 80 units are currently functioning (which means an average loss of 8-10 L/day).

Table 3.23. Average freshwater production from the MS System

Average Daily FW recovery (L/day)	Maximum Daily FW recovery (L/day)	Average Annual FW recovery (m^3/year)	Average Annual FW recovery in full operation (m^3/year)
161	**300**	**58.7**	**61.8**

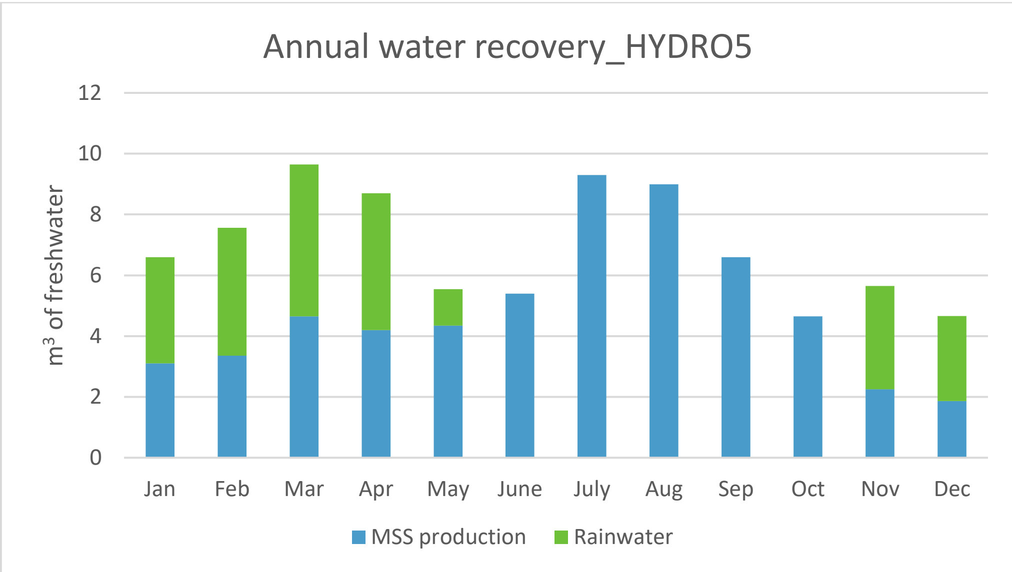

Figure 3.39. Monthly distribution of recovered water in HYDRO5

Figure 3.39 shows the yearly water recovery in the HYDRO5 site presented by month. As described above it is clear by the graph that that the MS System is more effective within the summer months when production increased up to 300 L/d. The design of the system allows the user to also collect the rainwater during the winter months, which compensates for the decreased production of the freshwater during these months. Taking into account the yearly operation of the system the collected water reached 83 m^3.

Salt Quantities recovered

The Mangrove Still System includes salt factories that aim to achieve the KPI of 2 kg of salt per day. The salt factory is integrated into the Mangrove Still System with the perspective of having a zero liquid discharge (ZLD) system in which part of the brine is treated and its discharged quantity is reduced. The ***salt factory*** is implemented into the supporting structure, beneath the Mangrove Still Unit, and is composed of: (i) aluminium trays and (ii) fans (Figure 3.40).

The aluminium tray has an area of 0.8 m^2 and is able to contain ca. 20 L of brine. To accelerate the salt production process, fans are installed to increase the evaporation rate by forced convection. Unlike the first installed version, which included 4 fans mounted horizontally and blowing air into a longitudinal direction, the actual/final version, integrated after some laboratory and on-field tests, has just 1 vertical fan, which results in lower energy consumption and a more efficient evaporation process.

The overall size of the salt factory has been then re-scaled as follow:
Brine plate capacity = 20 L
Average brine concentration = 45 g/L
Fans air speed = 2 m/s
Evaporation time = 5 days
Based on that, 17 trays have been arranged in the system, which was enough to achieve the related KPI, even considering some salt losses during the process (i.e., because of collection). Below is a series of pictures regarding the new salt factory configuration (Figure 3.40). The salt factory system was operated by demonstration leaders for several consecutive months, yielding approximately 2 kg of salt daily, as calculated according to the introduced KPIs. However, due to its manual nature, this operation demanded significant effort from the operational team to maintain consistent production. While the transition to an automated system for the salt factory is feasible and easily attainable, a strategic decision was made to prioritize the optimization of the MSS system (freshwater production from seawater).

Figure 3.40. Representative pictures of the salt factory

3.4.2 Water Quality

The Mangrove Still System (MSS) configuration was installed at the site between July and September 2020. During September 2020 the system was running as a trial operation period and the evaluating operation period started at the end of May- beginning of June 2021. The monitoring equipment installed at the site (industrial and low-cost) has already been described.

The MSS sampling campaigns started at the end of June 2021 when the system was fully operational. The analysis conducted included typical physicochemical parameters, heavy metals and major ions and microbiological parameters (TC, *E. coli*, *Enterococcus*) of freshwater in order to ensure the high quality of the irrigation water, in accordance with the limits provided by the Greek and EU water reuse regulation (CMD No 145116, 2020/741). Physicochemical analysis is also conducted in the inlet and outlet of the system (seawater and brine, respectively) to monitor the desalination process. The sampling campaign stopped at the end of September 2021, as the system was going through a troubleshooting period. As described above the operators managed to resolve the troubleshoots and with its regular cleaning and maintenance, along with the implemented amendment, as they referred in Section 2.4.1., the system was back in continuous operation with no troubles during summer 2022. The sampling campaigns started again at the last days of September 2022 and continue until June 2023 (21 sampling campaigns).

The pH values of the freshwater tank reported through the industrial and low-cost sensors are shown in Figure 3.41, where a three-month period (07-11/2022) is outlined, during which modifications and optimisation activities were conducted. This shows that both sensors are constantly following the same pattern but with a gap of around 1 pH value. Troubleshooting activities took place, and the operation team managed to inline the two sensors in the right value of around 7. Figure 3.42 shows the pH data acquisition of the last period, showing the satisfactory alignment of the two monitoring pH systems (industrial and low-cost sensors).

Figure 3.41. pH values in the freshwater tank (industrial sensor and low-cost sensor)

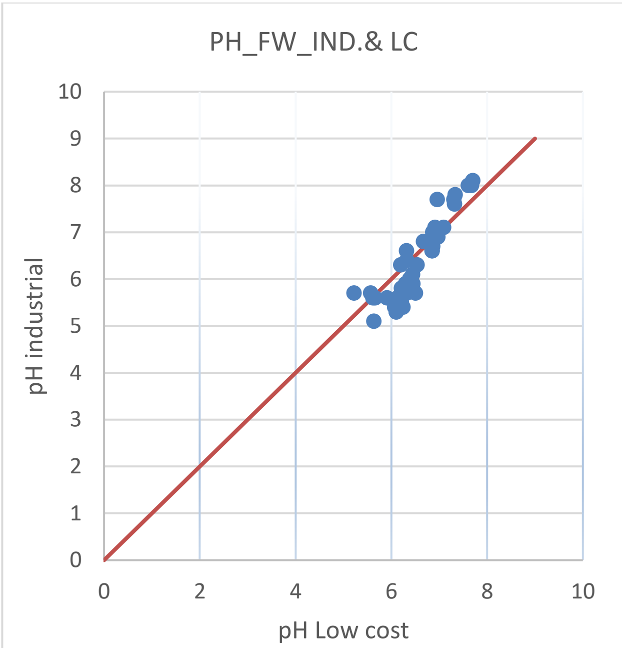

Figure 3.42. pH sensors correlation (industrial and low-cost) in the Freshwater Tank

Figure 3.43 shows the performance of the MSS based on the everyday conductivity values of the inlet and outlets. The low conductivity of the freshwater outlet (FW) suggests that the system is efficiently removing ions and salts from the water. The conductivity of the brine is higher than the seawater inlet, as expected.

The FW conductivity during the period July-September 2022 shows some peak values (around 10 mS/cm) correlating with the troubleshoot time of the system reported above. The conductivity of the freshwater outlet (FW) is decreasing over time; suggesting that the system was more effective at removing ions from the seawater. With the completion of all the maintenance and performance optimising activities the system was stabilised. As shown in Figure 3.43, from January 2023 the conductivity values of FW are constantly below 30 µS/cm and the performance of the system is stable.

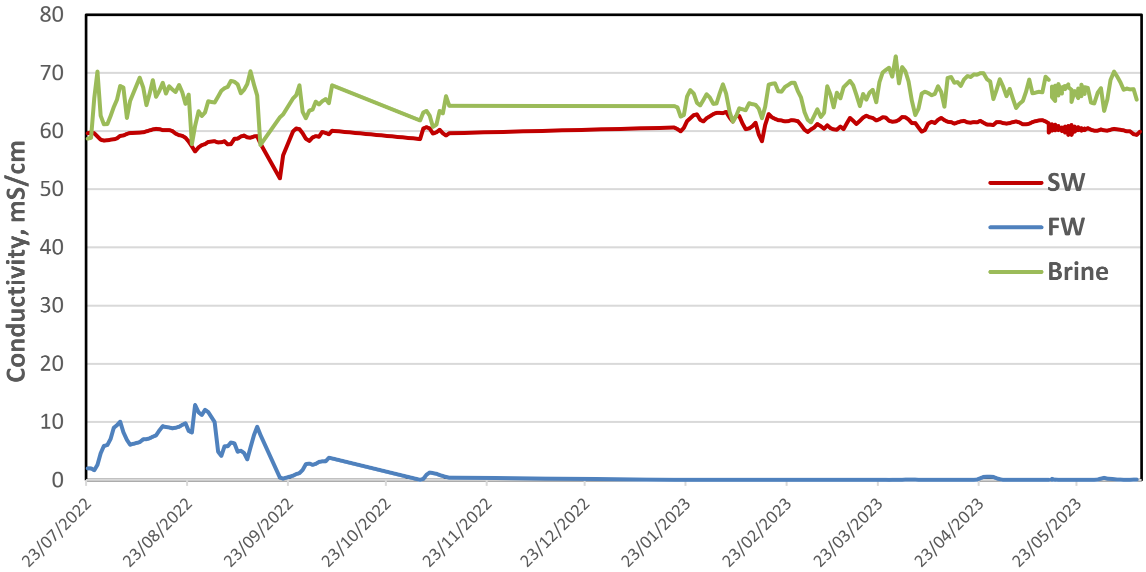

Figure 3.43. Conductivity values of the influent-Seawater (SW) and treated effluent-freshwater and brine (FW/ Brine) of the MS System in HYDRO showing the effectiveness of the desalination process.

Lab analysis was conducted in order to evaluate the salinity and the sodium hazard of the freshwater used for irrigation of the tropical greenhouse. The results are presented in Table 3.24 and the Wilcox diagram for the samples analysed is presented in Figure 3.44. The quality of the water for the first operating period (Jun-Sep 2021) was classified as C2S1-C3S1 satisfying the needs for the cultivation. There was a tendency though to higher salinity, due to the accumulation of salt in the system, affecting the final freshwater quality. This phenomenon is resolved with the regular cleaning of the MSS, some extra maintenance activities, and the careful monitoring, so it is almost diminished in the latest period of operation. This is profound from the latest results (conductivity values, SAR values) and since the conductivity values are below 100 µS/cm, the latest period is not reported in Wilcox diagram.

Table 3.24. Physicochemical analysis results (average values)

HYDRO5	Freshwater produced June 2021-Sep 2021	Freshwater produced Sep 2022 -Dec 2022	Freshwater produced Jan 2023-June 2023
pH	7.25 (±0.41)	7.1(±0.7)	7.32(±0.6)
Conductivity (mS/cm)	0.716 (±0.338)	1.236 (±0.731)	0.012 (±0.005)
Total hardness (mgCaCO$_3$/L)	63.5(±34)	75(±31)	1.9(±0.9)
Sodium adsorption ratio (SAR)	4.8(±1.3)	6.7(±1.8)	0.3 (±0.2)

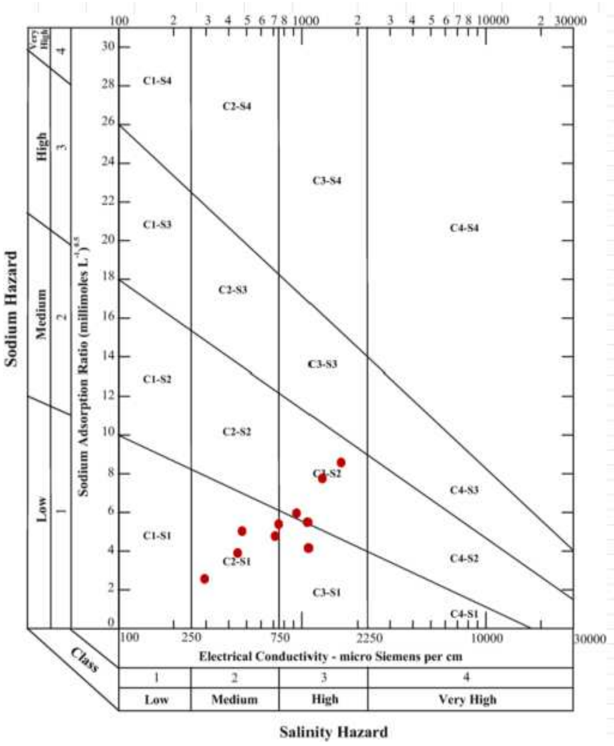

Figure 3.44. Electrical Conductivity plotted to SAR (Wilcox diagram) for the freshwater produced in HYDRO5.

Further physicochemical parameters were defined through consistent lab analysis in order to test the water quality for irrigation needs but also for drinking purposes. Thus, in Table 3.24 a more detailed analysis is reported compared with Food and Agriculture Organization (FAO) standards in order to interpret the water quality for irrigation. The conductivity values as reported for the first period are slightly higher than 0.7 mS/cm and in the final period <0.1 mS/cm. The nitrate values are for all the periods below <0.23 and the Cl^- concentration for the last period is low (<12 mg/L), classifying the produced water as irrigation water with no limitations whereas the freshwater produced in the first operation period was classified according to FAO to irrigation water with slight to moderate restriction based on Cl^-> 140 mg/L and SAR, EC values (SAR >3- E.C.: 0.3-1.2 mS/cm). Regarding the microbiological parameters, there are no regulatory limits established on the seawater treated for irrigation purposes. However, the analysis conducted during the two periods when the system operated efficiently (June 2021 -September 2021 and January 2022 - June 2023), indicated a consistently low microbiological load in the samples. This suggests that the irrigation process poses no risk in terms of microbiological contamination.

Regarding the use of the desalinated water produced as potable water, comparing the reported analysis of the latest period, when the system was operating efficiently in steady conditions, with the drinking water limits of the Directive (EU) 2020/2184 there is no limitation observed as all the physicochemical parameters are below the set limits. The previous operational periods were not complying with the drinking water quality standards as the microbiological results were above 0 and the Cl^- exceeded the parametric value of 250 mg/L.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No 776643

Table 3.25. Physicochemical and microbiological analysis of the recovered water in HYDRO4.

HYDRO5	Freshwater produced June 2021 - Sep 2021	Freshwater produced Sep 2022 - Dec 2022	Freshwater produced Jan 2022 - June 2023	Limits 2020/2184 (drinking water)	Irrigation water FAO & 145116/2011		
					No limitations	Slight to moderate restriction	Severe restrictions
pH	7.25 (±0.41)	7.1(±0.7)	7.32(±0.6)	≥ 6,5 and ≤ 9,5	6.5-8.5		
Conductivity (mS/cm)	0.716 (±0.338)	1.236 (±0.731)	0.012 (±0.005)	2.5	< 0.7	0.7 -3.0	> 3.0
Turbidity (NTU)	0.61 (±0.14)	0.65 (±0.21)	0.42 (±0.17)	Acceptable to consumers and no abnormal change			
NO_3-N (mg/L)	<0.23	<0.23	<0.23	11.3	<5	5-30	>30
Cl (mg/L)	268 (±159)	362 (±213)	12(±9)	250	<140	140-350	>350
SO_4^- (mg/L)	17 (±12)	23 (±12)	<4	250			
Alkalinity ($mgCaCO_3$/L)	18 (±7)	15 (±6)	<5.0				
TSS (mg/L)	<0.5	<0.5	<0.5				
Phenols (mg/L)	0.12(±0.04)	0.14(±0.01)	0.09(±0.01)				
Na^+(mg/L)	72 (±30)	138 (±65.8)	1.1 (± 0.7)	200			
TC (CFU/100ml)	152	2720	324	-			
***E. Coli* (CFU/100ml)**	2	207	0	0			
***Enterococci* (CFU/100ml)**	1	0	0	0			

Inorganic micropollutants analysis (heavy metals) was also conducted in the inlet and the two outlets. Freshwater samples from 4 different operating periods were tested giving similar results showing that the quality of the freshwater regarding the heavy metals is constant. The results of seawater and brine outlets are from one sampling campaign on 07/12/2022. The concentration of the heavy metals reported is at low levels, indicating that there is no concern for the use of the freshwater produced as irrigation water. The Fe concentration of the water seems to increase during the process implying that Fe is extracted from some parts of the system. However, this is in low levels < 3 mg/L, so this cannot affect the final quality of the outlets. The quality of freshwater produced by this method is compared in Table 3.26 with the guidelines of FAO and Greek Common Ministerial Decision of 08/03/2011, 145116/2011 (Determination of measures, conditions and procedures for the reuse of treated wastewater and other provisions). The reported concentrations for all the trace elements are below the limits, causing no threat to the cultivation, based on both guidelines.

The freshwater produced also complies with the limits set for the drinking water of EU Directive 2020/2184 of the European Parliament and the council of 16 December 2020 on the quality of water intended for human consumption regarding the metal concentrations reported. However, as the specific treatment removes a significant amount of minerals the freshwater produced is characterised by low concentration of Ca^{2+} and Mg^{2+} and low electrical conductivity values, which increase water corrosiveness; so, it can cause health effects in case of human consumption. Thus, as practised in the desalinated water of most RO units, it will be necessary to add calcium and magnesium salts to enhance the water quality, resolve potential negative effects and enhance taste.

Table 3.26: Freshwater metal analysis results

HYDRO5	Freshwater produced	Greek Water Reuse Regulation 145116/2011	FAO	EU Drinking Water Directive 2020/2184
Cd (μg/l)	<0.25	10	10	5
Mn (μg/l)	3.9 (±3.1)	200	200	50
Pb(μg/l)	<3.0	100	500	5
Ni(μg/l)	<5.0	200	200	20
Fe(μg/l)	<20	3000	5000	200
Cu (μg/l)	2.5 (±2.1)	200	200	2000
Cr (μg/l)	<1.6	100	100	50
Zn (μg/l)	<0.10	2	2	
Sb (μg/l)	<0.03			10
As (μg/l)	<0.1			10
Co (μg/l)	<0.03			
Mo(μg/l)	<0.03			
Hg (μg/l)	<0.03	2		1
Al (mg/L)	<0.07	5	5	0.20
F (mg/L)	<0.06	1	1	1.5
CN (μg/L)	<3			50
B (mg/L)	0.21 (±0.03)	2	<0.7 no restriction 0.7-3, slight to moderate restriction >3.0 severe restriction in use	1.5

Further analysis on the organic compounds of the freshwater produced was conducted and the results are shown in Table 3.27 compared with the relevant regulation limits of the EU Drinking Water Directive (2020/2184). For the majority of the compounds the concentration was below the detection limits. However, some compounds from the PAH group (Polycyclic aromatic hydrocarbons) were quantified, namely Benzo[b]fluoranthene-Benzo[g,h,i]perylene -Indeno(1,2,3-cd) pyrene; but in no case this exceeded the parametric value of the Directive.

Table 3.27: Organic compounds' analysis in freshwater produced.

Parameters	Average values	Limits 2020/2184	Parameters	Average values	Limits 2020/2184
Total Petroleum Hydrocarbons (TPH) (mg/L)	0.18		Quintozene	<0.003	0.1
Bromate (μgBrO_3/L)	<0.1	10	Tetrachlorvinphos	<0.003	0.1
Trihalomethanes (THM) (μg/L)			Tetradifon	<0.003	0.1
Chloroform	<0.5		Triadimefon	<0.003	0.1
Bromodichloromethane	<0.5		Trifluralin	<0.003	0.1
Dibromochloromethane	<0.5	100	Vinchlozoline	<0.003	0.1
Bromoform	<0.5		Organophosphate pesticides (OPPs) (μg/L)		
Total Trihalomethanes	<2.0	100	Azinphos-Et	<0.003	0.1
Acrylamide	<0.01	0.1	Azinphos-Me	<0.003	0.1
Epichlorohydrin	<0.01		Bromophos-Et	<0.003	0.1
Polycyclic aromatic hydrocarbons (PAH) (μg/L)		0.1	Bromophos-Me	<0.003	0.1
Naphthalene	<0.05		Chlorfenvinphos	<0.003	0.1
Acenaphthylene	<0.005		Cadusaphos	<0.003	0.1
Acenaphthene	<0.005		Chlorpyrifos-Et	<0.003	0.1
Fluorene	<0.01		Chlorpyrifos-Me	<0.003	0.1
Phenanthrene	<0.005		Diazinon	<0.003	0.1
Anthracene	<0.01		Ethion	<0.003	0.1
Fluoranthene	0.084		Ethoprophos	<0.003	0.1
Pyrene	<0.005		Etrimfos	<0.003	0.1
Benzo[a]anthracene	0.04		Fenamiphos	<0.003	0.1
Chrysene	0.035		Fenthion	<0.003	0.1
Benzo[b]fluoranthene	0.046		Heptenophos	<0.003	0.1
Benzo[k]fluoranthene	<0.002	0.1	Malathion	<0.003	0.1
Benzo[g,h,i]perylene	0.013		Methidathion	<0.003	0.1
Indeno(1,2,3-cd) pyrene	0.014		Parathion-Et	<0.003	0.1
Benzo[a]pyrene	<0.001	0.01	Paraoxon-Me	<0.003	0.1
Dibenzo[a,h]anthracene	<0.005		Phorate	<0.003	0.1
Halogenated pesticides (μg/L)			Phosalone	<0.003	0.1
Aldrin & Dieldrin	<0.003	0.03	Phosmet	<0.003	0.1
Bromopropylate	<0.003	0.1	Phosphamidon	<0.003	0.1
Chlordane cis & trans	<0.003	0.1	Pirimiphos-Et	<0.003	0.1
Chlorothalonil	<0.003	0.1	Pirimiphos-Me	<0.003	0.1
Cyfluthrin	<0.003	0.1	Prothiophos	<0.003	0.1
Cyhalothrin-λ	<0.003	0.1	Pyrazophos	<0.003	0.1
Cypermethrin	<0.003	0.1	Quinalphos	<0.003	0.1
DDT/DDD/DDE	<0.003	0.1	Triazophos	<0.003	0.1
Deltamethrin	<0.003	0.1	Organonitrogen Pesticide (μg/L)		
Dinitramine	<0.003	0.1	Atrazine	<0.01	0.1
Diniconazole	<0.003	0.1	Bitertanol	<0.01	0.1
Endosulfan (sum of isomers α-, β- & sulfate)	<0.003	0.1	Benfuracarb	<0.01	0.1
Endrin	<0.003	0.1	Carbaryl	<0.01	0.1
Ethalfluralin	<0.003	0.1	Carbofuran	<0.01	0.1
Fenarimol	<0.003	0.1	Cyanazine	<0.01	0.1
HCH -α	<0.003	0.1	Cyproconazole	<0.01	0.1
HCH -β	<0.003	0.1	Cyprodinil	<0.01	0.1
HCH -γ (lindane)	<0.003	0.1	Fenoxycarb	<0.01	0.1
Heptachlor	<0.003	0.03	Fludioxonil	<0.01	0.1

Parameters	Average values	Limits 2020/2184	Parameters	Average values	Limits 2020/2184
Heptachlor epoxide endo	<0.003	0.03	Metalaxyl	<0.01	0.1
Hexachlorobenzene (HCB)	<0.003	0.1	Metribuzin	<0.01	0.1
Iprodione	<0.003	0.1	Myclobutanil	<0.01	0.1
Penconazole	<0.003	0.1	Pirimicarb	<0.01	0.1
Profenofos	<0.003	0.1	Prometryn	<0.01	0.1
Procymidone	<0.003	0.1	Simazine	<0.01	0.1
Pyrifenox	<0.003	0.1	Terbuthylazine	<0.01	0.1
Quinoxyfen	<0.003	0.1	Tebuconazole	<0.01	0.1

Salt production

Analysis was conducted also for the salt produced in the MSS system. The results are presented in Table 3.28, reporting that no constraint was detected. Specifically, the produced salt complies with the Regulation (EU) 2023/915 of 25 April 2023 on maximum levels for certain contaminants in food and repealing.

Table 3.28: Results of salt analysis produced in the salt factory of MS System compared with the relevant regulations' limits.

	Results	Regulation (EU) 2023/915 of 25 April 2023	CODEX STAN 150-1985 Standard for Food Grade Salt Rev. 1-1997 Amend. 1-1999, Amend. 2-2001 1
Al (mg/KgDS)	187		
Ca (mg/KgDS)	2150		
Mg (mg/KgDS)	6620		
K (mg/KgDS)	6529		
SO_4 (mg/KgDS)	11500		
Cl (g/100gDS)	58.8		
Na (g/100gDS)	38,4		
NaCl (gNaCl/100gDS)	97.2		97
Iodine (mg/KgDS)	2.2		
Cd (mg/KgDS)	<0.1	0.5	0.5
Pb (mg/KgDS)	<0.2	1	1
Hg (mg/KgDS)	<0.05	0.1	0.1
Ni (mg/KgDS)	<0.5		
Cu (mg/KgDS)	<1.0		2
As (mg/KgDS)	<0.1	0.5	0.5
Bisphenol A (mg/KgDS)	<0.02		

The full monitoring of MSS system included the monitoring of the seawater (influent of the system) and brine as the effluent of the system in order to assess the overall performance. The characteristics (physical and heavy metals) for the two streams are presented in Table 3.29.

Table 3.29. Seawater and brine water analysis of HYDRO5 demo site

HYDRO5	Seawater June 2021 – Sep 2021	Seawater Sep 2022 – June 2023	Brine June 2021 - Sep 2021	Brine Sep 2022 – June 2023
pH	7.93 (±0.03)	8.0 (±0.07)	7.81 (±0.06)	8.14 (±0.01)
Conductivity (mS/cm)	59.36 (±0.49)	58.78 (±1)	71.78 (±3.75)	63.25 (±4.0)
Turbidity (NTU)	0.77 (±0.49)	0.97 (±0.6)	1.05(±0.54)	1.2 (±0.6)
Cl (mg/L)	23780 (±1111)	24975 (±248)	28840 (±844)	25400 (±950)
SO_4 - (mg/L)	2766 (±189)	2820 (±170)	3900 (±1039)	4100 (±700)
Alkalinity ($mgCaCO_3/L$)	145 (±4)	142 (±3)	145 (±46)	170 (±56)
Cd (μg/l)	-	<0.3	-	<0.3
Mn (μg/l)	-	2.0	-	2.4
Pb(μg/l)	-	<1	-	2.1
Ni(μg/l)	-	<0.3	-	<0.3
Fe(μg/l)	-	<50	-	170
Cu (μg/l)	-	34	-	46
Cr (μg/l)	-	<1	-	<1
Zn (μg/l)	-	<50	-	63
Sb (μg/l)	-	<1	-	<1
As (μg/l)	-	1.7	-	1.6
Co (μg/l)	-	<0.3	-	<0.3
Mo(μg/l)	-	11	-	12
Hg (μg/l)	-	<0.3	-	<0.3

3.4.3. Crop yield

The yield data on each tropical fruit harvested is presented in Table 3.30. This represents the harvest of tropical fruits of the PGH specifying the number of harvested Bananas, Ananas and Papayas, *Aloe leaves* mass etc.

Table 3.30. Tropical fruits harvest up to June 2023

Tropical fruit	Number of Harvested Products	Total harvest - June 2023 (kg)
Ananas	32	16
Passiflora	46	1.61
Papaya	142	45.44
Physalis	214	2.14
Musa fruits	17	138.38

Tropical fruit	Number of Harvested Products	Total harvest - June 2023 (kg)
(Banana Bunches)		
Aloe Vera (leaves)	1.109 (144 Plants)	250.1
Aloe Arborescens (leaves)	494 (13 Plants)	35.48
Elettaria cardamomum (leaves)	50	27.41
Ginger	6	0.63
Total		**517.19**

**Harvested Products: Refers to fruits, leaves roots or bulbs for each harvested plant unit*

3.4.4. KPIs status

Table 3.31 present the KPIs achieved throughout the operation of HYDRO5. As evidenced, all KPIs achieved are very satisfactory and well above the expected values that have originally being set.

Table 3.31. Key Performance Indicators for HYDRO5

Performance indicator (KPI)	Expected	Achieved
HYDRO5 - freshwater production from saltwater/brine	>200 L/d	300 L/d
HYDRO5 - recovered salt	> 2 kg/d	> 2 kg/d
HYDRO 5 – Production of tropical fruits	> 1.5 tons tropical fruits per ha > 30 kg for 0.02 ha	517 kg /200 m^2

3.5 HYDRO6 Performance

3.5.1. Energy System Monitoring and Performance

ELT has the peculiarity of operating an off-grid electricity system and exclusively relying on renewable energy production and storage on site. This makes the system a key component of operating HYDRO6 and is designed, maintained and monitored accordingly. The upgrade of the system that was necessary within the project in order to supply the increased electricity demand and was described in detail in "D3.5: Upgrade of the decentralised ecotourism wastewater management". The upgraded system is operational from June 2020 and is performing as designed with only three down time events lasting less than three hours.

The different components were selected for interoperability, implemented open industry standards and a company policy supporting open-source software. These criteria made it possible to design an overall system that is very adaptable and can be monitored down to a very low level within the hardware giving access to a high number of parameters. A central embedded computer interacts with all components logging all parameters in a redundant way. The log files are kept on two storage media on site and are sent to a cloud service where they can be accessed remotely. The same feature provides control over the installation for purposes of tele-maintenance and controlling of active components such as relays used for switching on and off devices.

The data show an overall increase in the power consumption as it was foreseen within the modelling for the system upgrade. The daily consumption has increased from 2019 with 3.1 kWh, to 3.5 kWh in 2020-21, to 4.4 kWh in 2022. The monthly consumptions are shown in Figure 3.45 below. While the increase is significant it was possible to stay below the foreseen consumption of 6.7 kWh.

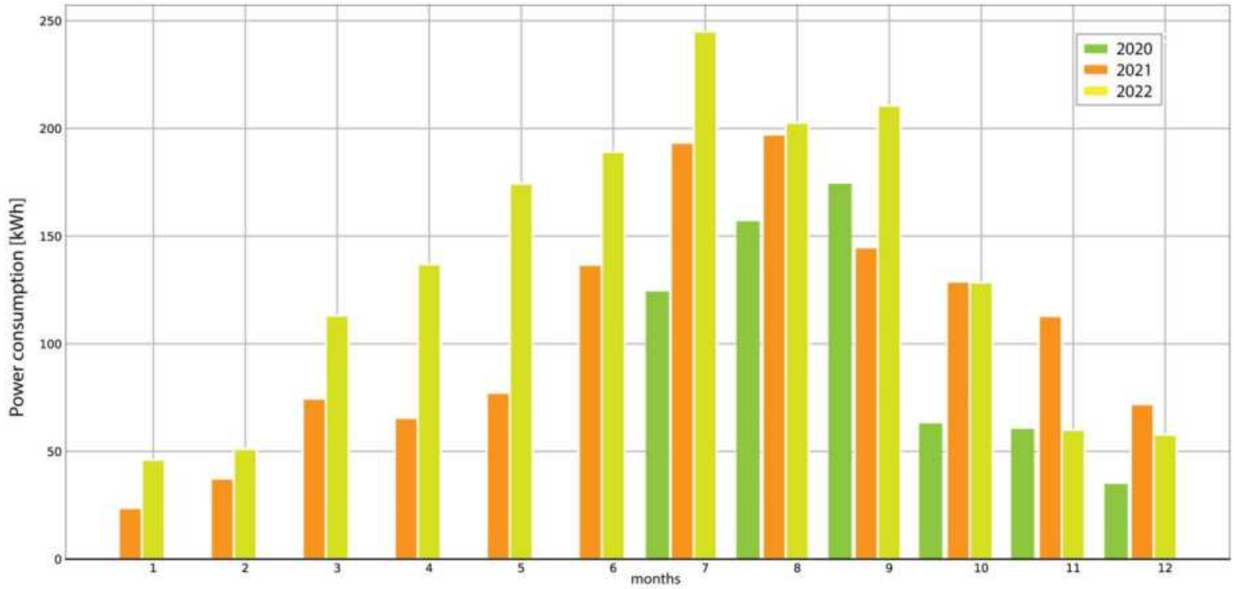

Figure 3.46.Yearly energy consumption by month

The monitoring data of the three main parameters being electric consumption, PV-production and the state of charge (SOC) of the battery plotted over the time period of two and a half years give certain key insides regarding the performance of HYDRO6 (see Figure 3.46). The main parameter of concern is the SOC in an off-grid system because it determines if the system is running or not and how well the batteries are maintained. The achieved target was to maintain a SOC of above 60% at over 90% of the time. Only at several days in a row with heavy cloud cover the system drops below this threshold which rarely occurs at the location. Three events could be tracked over the whole operational period where the system actually shut down due to

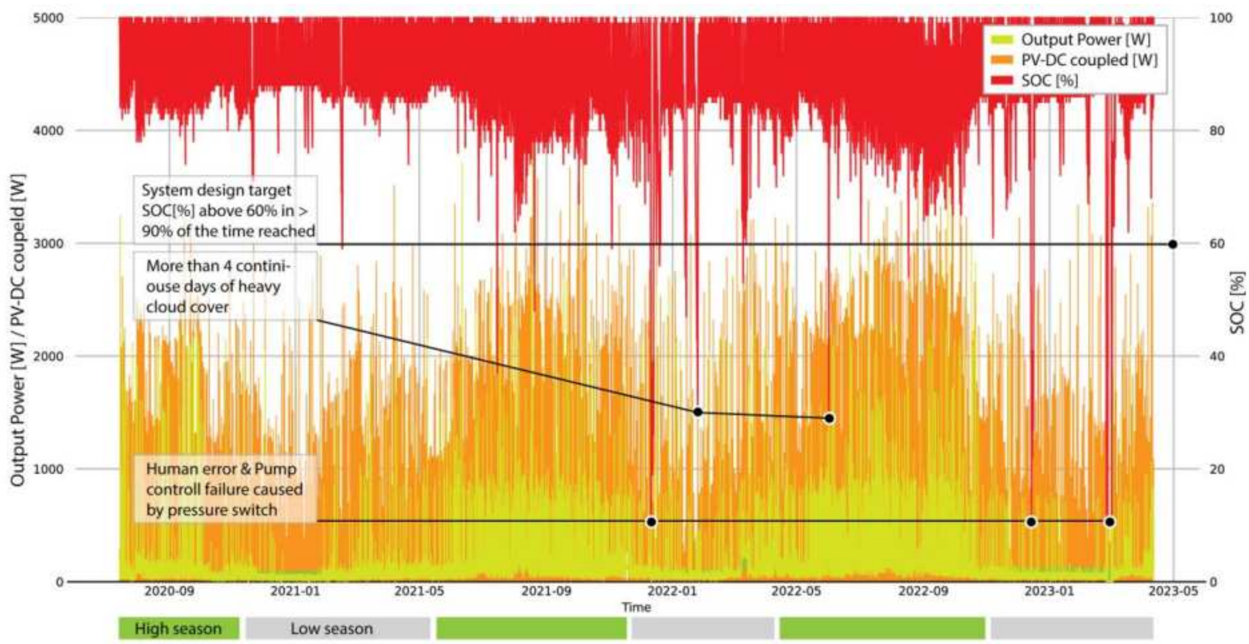

Figure 3.45. Energy monitoring and failure analysis

dropping below the battery protection threshold of 10% SOC. These events where caused by a malfunctioning pressure switch controlling a pump and human error forgetting to close an irrigation valve. In all three cases the shutdown was actually beneficial due to the reduction of lost water.
Even in this error events the system is self-restarting when the PV-arrays start to produce energy in the morning. Only in combination with heavy cloud cover it can take several days to fully recover the SOC to target values while the system is running (see right part of Figure 3.47).

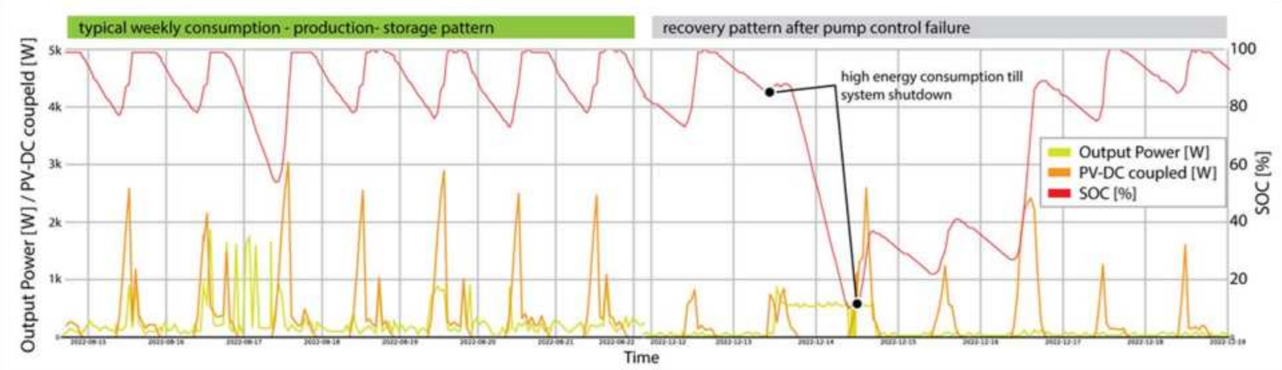

Figure 3.47. Recovery after failure

The graph above also illustrates the fluctuation of the energy demand depending on high and low touristic season. For the customers of ELT a live view of the energy system was implemented within the website which provides the customers with the opportunity to observe also their own power consumption while being at the lodge (energy-live-monitoring).

3.5.2 Water quantities recovered

Monitoring with Level Sensors

The monitoring strategy for measuring the volume flows of rainwater and reclaimed water is currently based on the utilization of low-cost ultrasonic distance sensors, which have been developed specifically for this project. In the HYDRO6 demonstration site, three of these sensors were strategically positioned, with the first sensor commencing data recording in July 2021. The initial setup phase was successful, and minor errors were promptly rectified. However, some issues have been observed over time, including the misalignment of the sensor holder caused by strong winds, the presence of insects constructing nests on or in front of the sensor, the accumulation of water droplets due to condensation and weak mobile network coverage resulting in inaccurate distance measurements. Furthermore, it has become evident that solely measuring the level of the water presents a limitation, as it fails to capture simultaneous inflow and outflow events. Considering the prevailing conditions at HYDRO6, it is imperative to enhance the monitoring strategy by incorporating flow meters alongside the ultrasonic level measurement technology. This integration will enable more accurate and reliable capture of both inflow and outflow events.

Reclaimed water production

The reclaimed water production originates from two sources:

1. The preexisting vertical flow constructed wetland treating up to 8 PE with a collection tank volume for treated water of 6.1 m^3. The calculated input of raw sewage is approx. 85.4 m^3 per year and the theorical volume reclaimed (taking into account the evapotranspiration losses) is approx. 60 m^3 per year.

2. The vertical flow constructed wetland build within the project treating dark grey water from the new lodge, has a treatment capacity of 3 PE with a cistern volume for treated water of 0.6 m^3. The

calculated input of raw sewage is approx. 19 m^3 per year and the calculated reclamation volume is approx. 13 m^3 per year.

The two treatment units are fully operational without problems from the start up till now producing reclaimed water for irrigation. The project aimed at monitoring the level within the reclaimed water with ultra sonic low-cost distance sensors. The monitoring data from the collection Tank 1 within a fully operational year are presented in Figure 3.48. The yearly water volume reclaimed in this tank is recorded to 57.6 m^3.

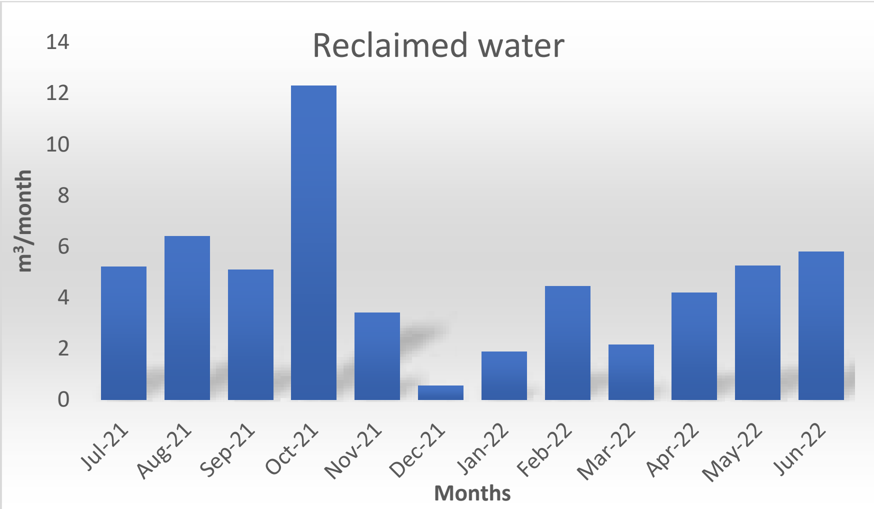

Figure 3.48: Reclaimed water production for the preexisting system over 12 months, derived from level sensor

During the period from July 2021 to June 2022, the sensor data indicates a reclaimed water production of 57.62 m^3, as illustrated in the accompanying graph. The recorded values are closed to the calculated and observed values and the overall distribution of quantities aligns reasonably well with the operational and occupancy patterns of the lodges. Upon analysing the data over an extended time frame, a small disparity becomes apparent between the occupancy pattern of the lodges and the captured data. Typically, between June and October, the lodges consistently maintain an occupancy rate exceeding 80%. However, October 2021 depicts higher quantities than the rest of the touristic months. This could be due to the accumulation in the wetland or some rain events that could have an influence in the outflow volume.

Rainwater harvest

The rainwater harvesting system consists of two sub systems:

1. The preexisting one with a capture area of 297 m^2 with the harvesting surface material consisting of concrete. The storage cistern of 100 m^3 is closed and placed underground.

2. Within the project a second system was built with a capture area of 204m^2 with mixed material surfaces. The storage cistern of 80 m^3 is underground but open to the surrounding.

The whole system is operational from 2020 onwards collecting rainwater and storing it for the dry summer months. In autumn 2021 the cistern of the old system had to be maintained by reapplication of a waterproof cement slurry layer to ensure water tightness. Otherwise, the system is running without problems and maintenance is composed out of visual inspections, every two-year removal of sediment material and cleaning out gutters before the raining season. The sensor-based monitoring shows similar noise and bias as already described above. Additionally, to the level sensor also the rain gauge data show a certain amount of noise. However, the quantity monitoring was achieved with minor problems. Figure 3.49 shows the recorded values for the two systems. The microclimate of HYDRO6 increases the rainfall events at about 15% compared with the Chora of Tinos meteorological stations' records. The performance of the system was assumed in the design process of 90% harvesting efficiency with a runoff coefficient of 0.9 for the old system and 0.85 for the new system due to the different materials of the surfaces. These assumptions are in line with onsite observations and the monitoring data. Figure 3.49 shows that every year the KPI of 50m^3 of rainwater harvest was achieved and, in most years, over performed. The data set for 2023 is not complete as it includes precipitation data until May.

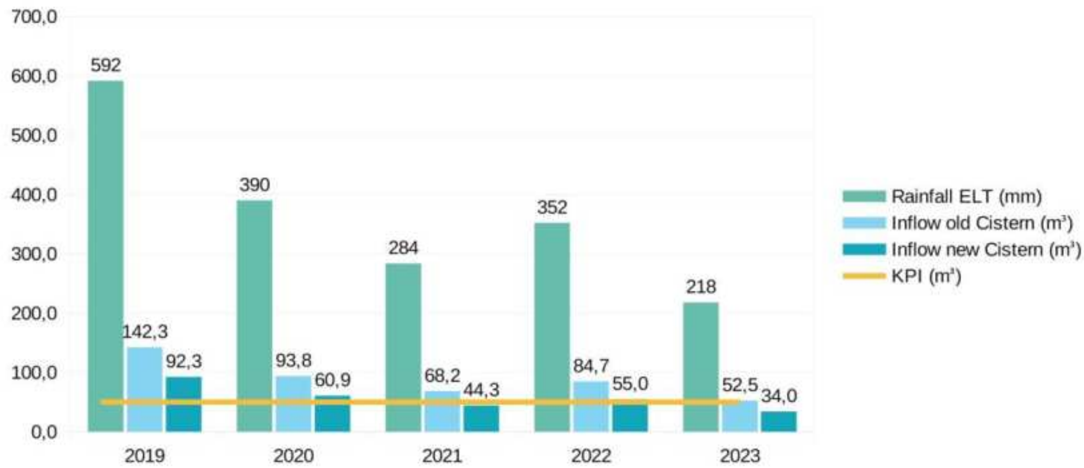

Figure 3.49: Rainfall and according rain water harvest of both systems compared to KPI

Vapour Condensation Systems

The tested vapour condensation systems consist of the Water Flower (WF), the MultiFunctional Roof (MuFu) and the Zero Mass System. Regarding the prototype vapour condensation systems, the water collection happens in separate storage tanks with water meters interposed between outlet and collection tank in order to quantify the water output automatically. The assessment of water yield is realised by self-developed tipping counters for each unit. For further correlation, the surface temperature of all three units is measured constantly and logged every 10 minutes coupled with natural conditions such as air temperature, relative humidity, absolute pressure, and illuminance. As back-up, a weather station was mounted in the middle of the set-up logging additionally wind speed and wind direction.

The frequency of water quality probes should be based on the local environmental conditions for dew occurrence. Rain events can alter the quality of the water collected and may not be representative of the quality of water collected from dew harvesting. For example, in areas with high levels of pollution or during the rainy season, more frequent testing may be required. It is recommended to collect and analyse water samples under consistent environmental conditions and to ensure that the water has not been altered by rain. It is also important that the water is tested frequently so the microbiome does not contaminate the water in the small sized collection tank.

The analysis of the water quantities recovered from the Water Flower and the MuFu systems is crucial for evaluating their practical application as alternative water sources. The comparison of the surface temperature and the dew point plays a key role in determining the occurrence of dew formation during the monitoring period. The data collected for two months in 30-minute intervals provides insights into the correlation between the measured temperature drops and local environmental conditions, including wind speed and dew point. Of particular interest is the correlation of wind speed to surface temperature, which can impact the water recovery rate. The sub-dew temperatures of the condenser, which are directly related to dew formation on the surface, are analysed during different periods in autumn 2021. While the exact relation of the measured parameters water recovery is difficult to quantify, especially given the erratic availability of quantity measurements; this analysis provides a valuable overview of the distribution of dew formation over a continuous period. The longer this sub-dew temperature is reached the higher the probability of dew harvesting and the lower below the dew point, the more intense is the dew formation happening. The dataset gives detailed insight in 52 days of analysis and several learnings were found. The following figures (3.50-3.51) illustrate the relation of surface temperature to dew point and indicate whether a sub-dew temperature was reached or not. The timely distribution here is of importance and shows the dew occurrence from 00 – 24 hours.

Table 3.32. Overview on logged parameters around the condensation prototypes

Parameter	Sensors	weather station
Water output	tipping counter - in-house development resolution: 3ml accuracy: ±20ml	
Surface temperature	LM35DT/NOPB resolution: 10mV/°C accuracy: ±1,5°C	
Air temperature	HTS221 accuracy: ± 0,5°C range: -40°C to +120°C	Bresser 5 in 1 no data
Relative humidity	HTS221 accuracy: ± 3,5% rH range: 20 – 100%	Bresser 5 in 1 no data
Absolute pressure	LPS22HB range: 260 to 1260 hPa	Bresser 5 in 1 no data
Illuminance	TEMT6000X01 no data	Bresser 5 in 1 no data
Wind		Bresser 5 in 1 no data

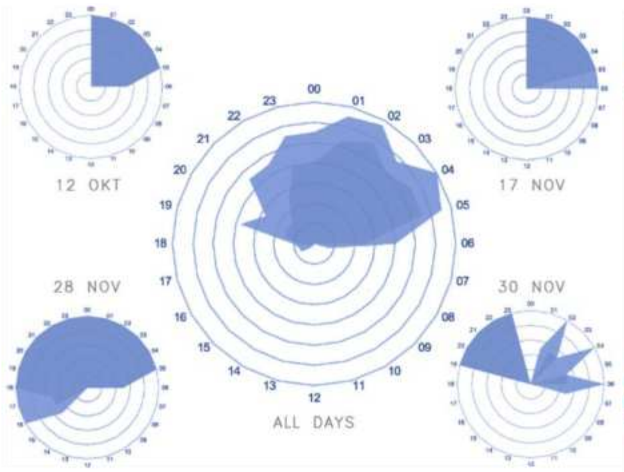

Figure 3.50: Active WF

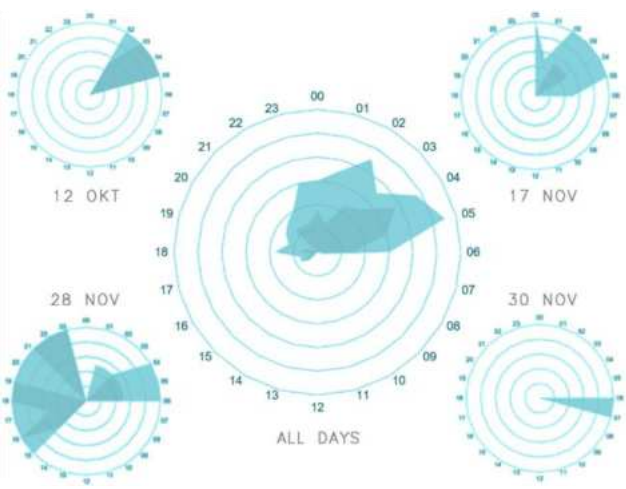

Figure 3.51: Passive WF

The difference between actively cooled and passively cooled can be noted very well where the active Water Flower (WF) has a more intensive and longer period of dew occurrence than the passive WF. Sub-dew temperatures on active WF and passive WF were observed on 27 and 19 days respectively. Of these days of dew occurrence, a condenser surface temperature of -1°C sub-dew and lower was reached during 20 days at a WF and 14 days at pWF. The lowest sub-dew surface temperatures were -4,3°C and -2,3°C with an average of -1,1°C and -0,7°C for the active WF and passive WF respectively.

On the MuFu no surface temperatures were measured, but it can be assumed that the surface temperatures are similar to the passive WF. The MuFu worked in the sense that it was operating in nominal mode. Yet, due to the nature of the system (PV panels not being optimised for condensation) and the difficult local conditions (low relative humidity, strong winds), even when condensation occurred, it never was enough to produce significant runoff.

Two solar driven vapor condensation units ***(Zero Mass system)*** were installed in order to compare their operation with the afore mentioned systems and the vapour condensation units installed in HYDRO3. The units operated from November 2020 to April 2022, with some operational gaps due to malfunctions. The two graphs below show, as an example, part of the production data of the system (referring to one of the two panels). It was observed that the average production volume is 6.4 L/day/panel, which remains relatively stable on a monthly basis but is mostly influenced by the humidity percentage. The decrease in production during August can be attributed to the high wind speed experienced in Tinos during that month. The total production per year is reported to be 4.45 m^3 for both panels.
Since April 2022, the panels have been malfunctioning, and no service or guidance has been provided by the supplier nor the manufacturer. Additionally, the quality of the water that was recovered was unsatisfactory (pH= 4, E.C=30μS/cm, total hardness =17 $mgCaCO_3/L$), as indicated by the results from the conducted sampling campaigns, which consistently showed unacceptable quality according to drinking water standards. These factors have led to the conclusion that the system is not fulfilling its intended purpose.

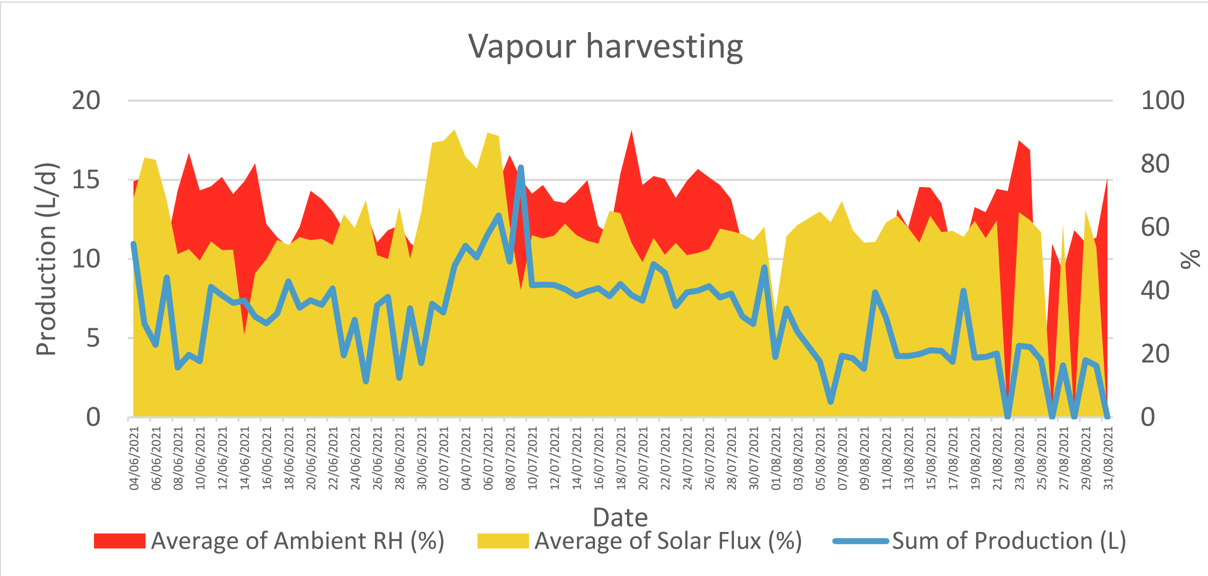

Figure 3.52. Vapour harvesting per day in the one of the panels installed in HYDRO6, illustrated with the percentage of solar flux and relative humidity.

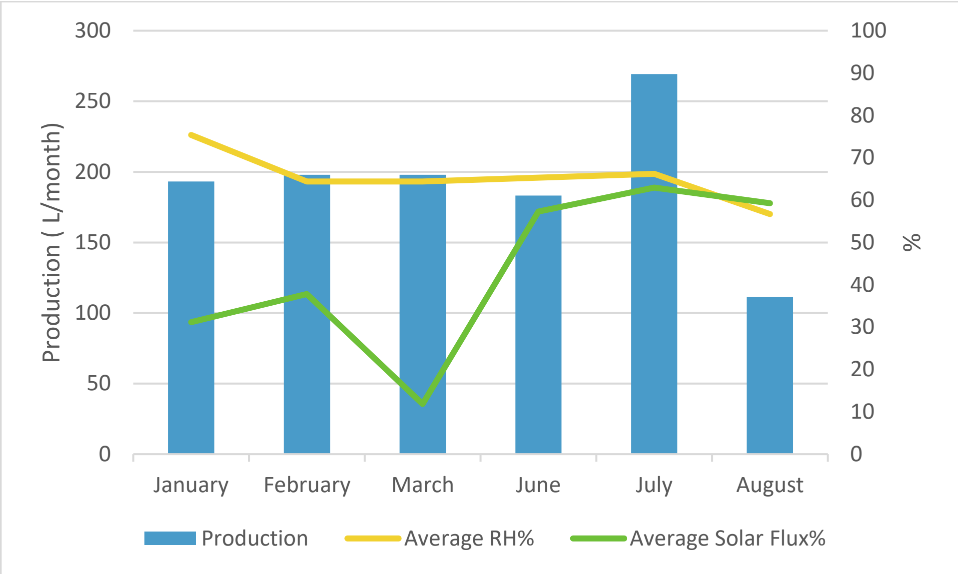

Figure 3.53. Illustration of relative humidity and solar flux impact on vapour water volume harvested.

3.5.2. Water Quality

The HYDRO6 demo site is fully operational from August 2020. Regarding the rainwater collection systems, as described above (section 2), two separate rainwater collection systems have been designed and are operating, collecting rainwater from structured surfaces such as roofs, sidewalks and terraces. The rainwater is then led through gutters to 2 storage tanks, the open cistern of 80 m^3 and the closed sub surface cistern of 100 m^3. The results of the quality analysis for the rainwater collected are presented in the following Tables (Table 3.33, 3.34).

Table 3.33: Physicochemical characteristics of rainwater harvested in the two cisterns of HYDRO6

HYDRO6	Open cistern	Closed cistern
pH	8.0 (±0.49)	7.07(±0.41)
Conductivity (μS/cm)	708 (±98)	427 (±92)
Turbidity (NTU)	4.6 (±2.3)	1.9 (±1.1)
Cl^- (mg/L)	115 (±27)	49 (±14)
NO_3-N (mg/L)	0.14 (±0.09)	0.41 (±0.4)
TN (mg/L)	0.17 (±0.1)	0.49 (±0.4)
SO_4 (mg/L)	33 (±8)	24 (±7)
TSS (mg/L)	6.5 (±2)	2.3 (±0.95)
TDS (mg/L)	323 (±65)	203 (±57)
PO_4^{3-}(mg/L)	<0.1	<0.1
Alkalinity (mg$CaCO_3$/L)	126 (±22)	106(±25)
Total hardness (mg$CaCO_3$/L)	181(±44)	100 (±43)
Sodium adsorption ratio (SAR)	1.9 (±0.77)	1.27 (±0.3)
TC (as mean value) (CFU/100 ml)	770	377
E. Coli (as mean value) (CFU/100 ml)	17	14
Enterococci (as mean value) (CFU/100 ml)	22	4

It must be noted that although the rainwater is collected from similar surfaces and the location is the same, the final quality differs due to the type of the tanks (closed and open). Closed storage tanks provide several benefits for maintaining water quality. By sealing the tank, they prevent external contaminants, such as dirt, debris, and pests, from entering the water, thus reducing the risk of contamination, and helping to maintain the purity of the rainwater. Closed tanks also minimize exposure to sunlight, which can inhibit the growth of algae and other microorganisms that may negatively impact water quality. Open storage tanks, on the other hand, are more susceptible to external influences. Without proper precautions, they are prone to contamination from various sources, including airborne particles, leaves, insects, and animal waste. These contaminants can degrade the quality of the collected. The higher of organic and inorganic contaminants in open systems compared to closed systems has been widely reported (Schutte et al., 2016, Kew et al., 2018, Oyarzun et al., 2012, Lye et al., 2014).

Thus, the storage type effect to the final quality of collected water is reflected in the value differences in conductivity and total dissolved solids. In the open tank, the EC average value was 708 μS/cm, while in the closed one it ranged at significantly lower levels with an average of 427 μS/cm. The TDS in both cases had a correlation coefficient with the value of EC 0.45, with an average concentration of 323 mg/L and 203 mg/L for the open and closed tank respectively. The lower values of electrical conductivity are in line with research on rainwater collected from roofs. In the report of Sazakli et al., 2009 for rainwater collection system from roofs in Kefalonia, the maximum value of conductivity was recorded to 210 μS/cm. However, the design and practices followed in each case should be taken into consideration as techniques such as first flush diversion, water filtration and collection surface maintenance can significantly improve the quality of water that ends up in rainwater tanks.

An important role to the final quality of the collected rainwater also plays the material, inclination and roughness of the collection surfaces and even the orientation according to several studies. Regarding the concentrations of the main ions content of the rainwater collected, the chloride in the case of the open tank had an average value of 115 mg /L while in the closed one 49 mg/L. Similarly, the sodium concentration was higher in the open cistern with an average value of 33 mg/L compared to 24 mg/Lin the closed one. The presence of Cl^- and Na^+ in the rainwater of the HYDRO6 system is mainly due to the influence of marine aerosols (Zdeb et al., 2019). The sodium adsorption ratio (SAR) was recorded to average values less than 10 for both sampling points classifying the collected water in category S1. Fitting the SAR and conductivity values to the Wilcox diagram (Figure 3.54), classified the rainwater in the closed tank to the category C2-S1, while the open cistern samples are classified between categories C2-S1 and C3-S1 proving the influence of storage type to the quality of collected water. Thus, we can conclude that the storage tank type is an important design parameter that should be considered depending on the final use e.g., in this case the cultivation needs and the soil characteristics (salinization, drainage, etc.). The turbidity of the samples was in averaged of 4.6 and 1.9 NTU for open and closed tank respectively. The concentrations of the nutrients NH_4-N, NO_3-N, NO_2-N, TP and PO_4^{3-} are in low levels and in no case, these could be a limiting factor for the water reuse.

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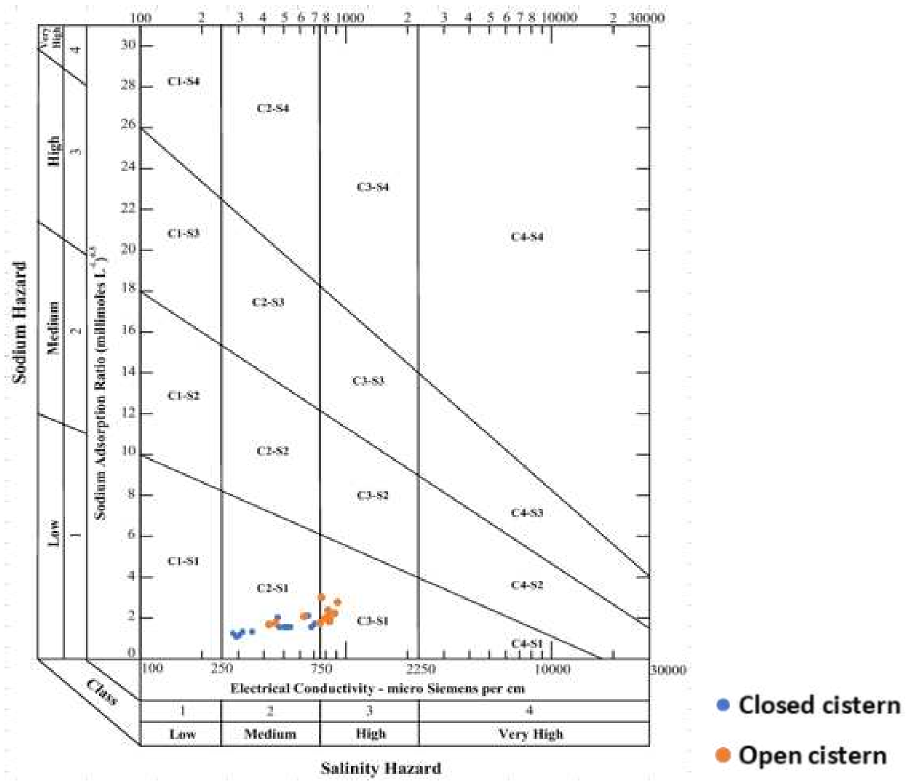

Figure 3.54: Wilcox diagram (salinity to sodium hazard) for the rainwater collected in the closed and open cistern of HYDRO6.

Regarding the microbiological results (TC, *E. Coli, Enterococcus*) that were obtained during the monitoring period, the mean values is of 370 and 770 CFU/100 ml for Total Coliforms and 14 and 17 CFU/100 ml *E. Coli* for the closed and open cistern respectively. While there is no regulation relating to rainwater collection implying limits for irrigation use, the above results range within expected values for natural surface water as reported for example in Council Directive 75/440/EEC (1975) Concerning the Quality Required of Surface Water Intended for the Abstraction of Drinking Water in the Member States (Natural surface Water quality _TC: 50-5000 CFU/100 ml, E.Coli: 20-2000 CFU/100 ml).

Additionally, heavy metals have been analysed for the rainwater collected in the two cisterns of HYDRO6, shown in Table 3.34 in comparison with the irrigation water quality guidelines of FAO and Greek Common Ministerial Decision of 08/03/2011, 145116/2011. The reported concentrations for all the analysed metals are below the limits, causing no threat to the cultivation, based on both guidelines.

Table 3.34. Metal and other ions' concentration of harvested water in two collection cisterns compared with the respective legistlation

Parameter	Open cistern	Closed cistern	*Greek Regulation Limits 145116/2011*	*FAO*
Cu (µg/L)	2.3 (±1.1)	10 (±5.7)	200	200
Cd (µg/L)	<0.25	<0.25 ()	10	10
Cr (µg/L)	<1.6	<1.6 ()	100	100
Pb (µg/L)	<3.0	<3.0 ()	100	500
Ni (µg/L)	5.2 (±4.1)	33 (±21)	200	200
Mn (µg/L)	2.2 (±1.6)	21 (±12)	200	200
Zn (mg/L)	0.11 (±0.059)	0.35 (±0.27)	2.0	2

Parameter	Open cistern	Closed cistern	*Greek Regulation Limits 145116/2011*	*FAO*
Fe (µg/L)	<20	<20	3000	5000
Al (mg/L)	<0.020	<0.020	5	5
B (mg/L)	<0.050	<0.050	2	<0.7 no restriction 0.7-3, slight to moderate restriction >3.0 severe restriction in use
F (mg/L)	0.024	0.3	1	1
CN (mg/L)	<0.030	<0.030	-	-
Phenols (mg/L)	0.17	0.18	-	-

Another non-conventional source that is valorised in HYDRO6 is the treated wastewater from the lodges. As described above the constructed toilets in the old loop is using rainwater for flushing and a segregating system by centrifuge of blackwater and faeces is implemented. The faeces are used in one of the composting systems of HYDRO6 and the black water is treated by a reedbed system with a water tank of 6.1 m^3. The new sanitation loop only treats grey water due to the implementation of a composting toilet (with no flushing) within the new lodge. Therefore, the new reedbed treats the greywater from showers, kitchen and also urine with a tank volume for treated water of 0.6 m^3. The treated wastewater is used for the irrigation of herbs and ornamentals which are plants that belong to category that can be irrigated with reclaimed water of minimum water quality of Class C (based on the EU Regulation 2020/741).

In this context the performance of both reedbed systems installed in HYDRO6 site was satisfactory as the reclaimed water can be categorised in Class B (COD ≤ 125mg/L, BOD_5 ≤ 25 mg/L, TSS ≤ 35 mg/L, *E. Coli* ≤ 100 for 90% of the samples), while complete nitrification and partial denitrification is also achieved. The detailed performance is reported in Table 3.35 & 3.36 and in Figure 3.55.

Table 3.35 Performance of the constructed wetland of the old loop in HYDRO6.

Parameter	Inlet	Outlet	After UV	Removal (%)
TSS (mg/L)	223 (±180)	13 (±6)		97%
COD (mg/L)	650 (±423)	67 (±14)		95%
NH_4^+-N	28 (±8)	0.66 (±0.52)		93%
NO_3^--N		15 (±4)		
Turbidity (NTU)		5.31 (±2.5)		
pH	7.1 (±0.4)	7.8 (±0.3)		
SO_4 (mg/L)	30.4 (±18.1)	105.7 (±25.3)		
***E. Coli* (CFU/100mL)**	1.39×10^5 ($\pm 0.57 \times 10^5$)	753 (±224)	87 (±23)	2.3 log (outlet), 0.94 log (UV)
TC (CFU/100mL)	2.85×10^6 ($\pm 0.62 \times 10^6$)	12328 (±5637)	1532 (±353)	2.4 log (outlet), 0.91 log (UV)
***Enterococci* (CFU/100mL)**	2558 (±467)	156 (±87)	54 (±21)	1.2 log (outlet), 0.46 log (UV)

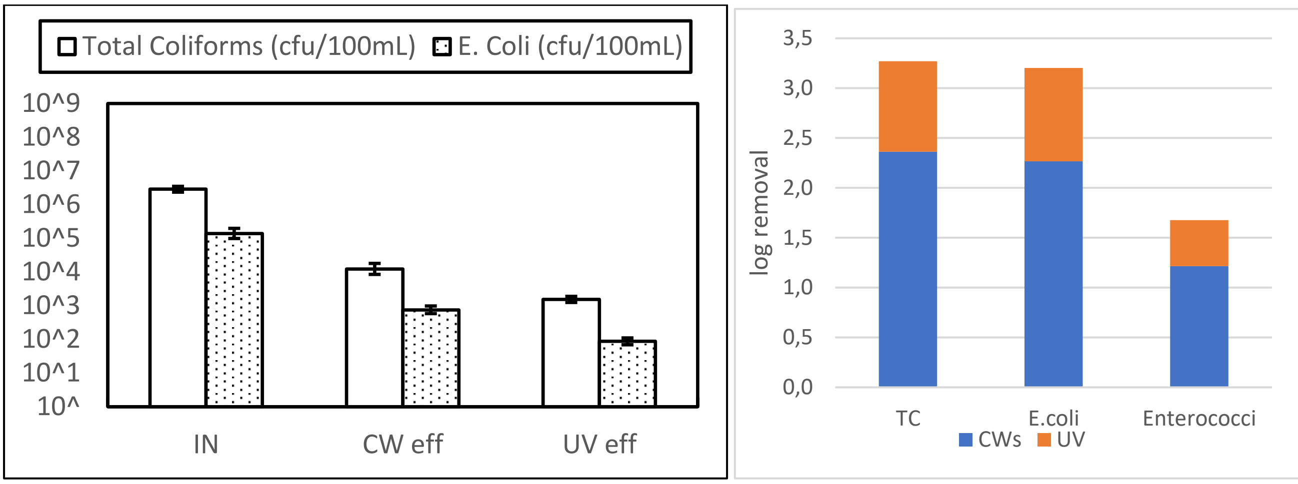

Figure 3.55. Microbiological reduction in the old loop of HYDRO6

Table 3.36. Performance of the constructed wetland of the new loop in HYDRO6.

Parameter	INLET	OUTLET	After UV	%Removal
TSS (mg/L)	97(±21)	2.25 (±0.35)		97%
COD (mg/L)	484 (±43)	27 (±11)		95%
NH_4^+-N (mg/L)	44 (±11)	3 (±1)		93%
NO_3^-N (mg/L)		35 (±8)		
Turbidity (NTU)		2.33 (±1)		
pH	7.4 (±0.4)	7.7 (±0.2)		
SO_4 (mg/L)	25.6 (±16)	76.4 (±6.2)		
***E. Coli* (CFU/100 mL)**	26463 (±1753)	247 (±74)	22(±8)	2log (outlet), 1.1 log (UV)
TC (CFU/100 mL)	5.4×10^6 ($\pm1.2\times10^6$)	2006 (±934)	800 (±78)	3.4 log (outlet), O.4 log (UV)
Enterococci (CFU/100 mL)	37136 (±4875)	19 (±6)	8 (±1)	3.3 log (outlet), 0.37 log (UV)

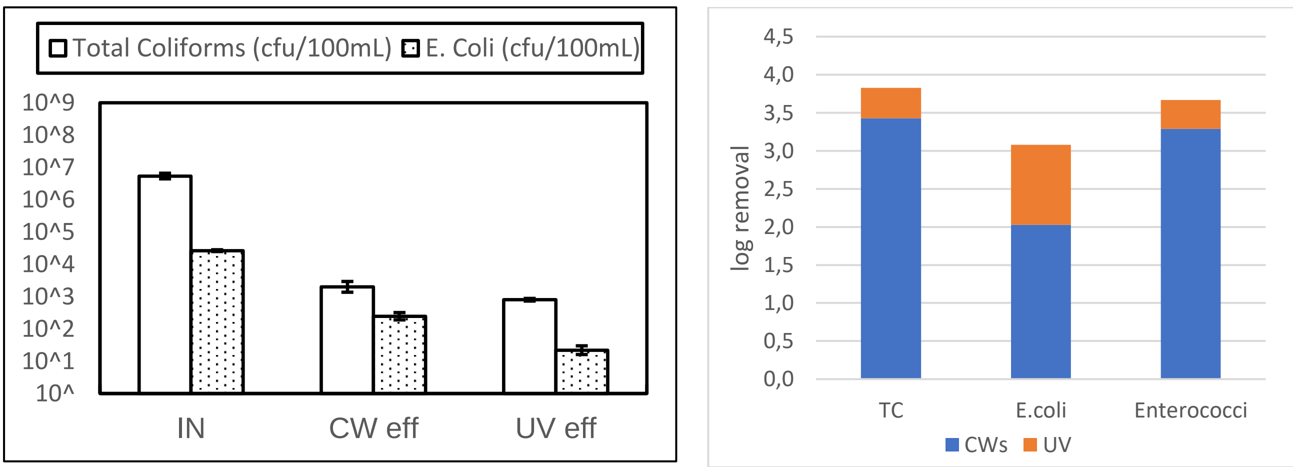

Figure 3.56. Microbiological reduction in the new loop of HYDRO6.

The contribution of reedbed system in pathogens removal was profound but as expected the contribution of the UV system was necessary in order to decrease the *E. Coli* values below 100 cfu/100 mL in both systems Based on the results it is anticipated that HYDRO6 can efficiently conform with the requirements of the EU regulation for herb and ornamental irrigation.

Since the reclaimed water is used for irrigation the Wilcox diagram (Figure 3.57) was also illustrated showing the salinity hazard for the respective cultivations. The results depicts that most of the samples fall in (*C3 – S1*) quality with high *salinity* hazard and low sodium hazard.

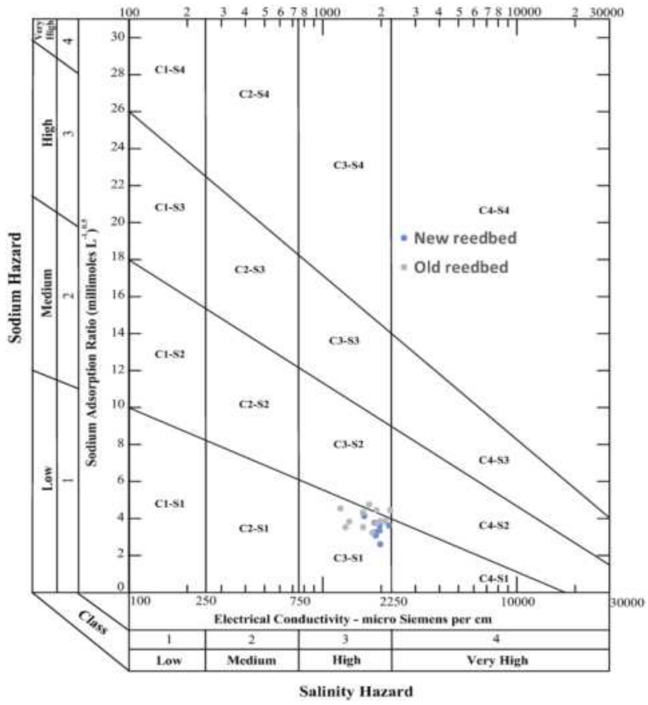

Figure 3.57. Wilcox diagram for the reclaimed water of HYDRO6.

Additionally, heavy metals have been analysed for the treated effluent of the reedbed systems, shown in Table 3.37 in comparison with the irrigation water quality guidelines of FAO and Greek Common Ministerial Decision 145116/2011. The reported concentrations for all the analysed metals and ions are below the limits, causing no threat to the cultivation, based on both guidelines.

Table 3.37. Heavy metals and ions' concentrations in the inlet and outlets of the two CWs in HYDRO6

Parameter	New reedbed system	Old reedbed system	Greek Law 145116/2011	FAO
Cu (μg/L)	39 (±21)	14 (±7.9)	200	200
Cd (μg/L)	0.71 (±0.48)	2.6 (±1.9)	10	10
Cr (μg/L)	2.5 (±2)	2.1 (±1.4)	100	100
Pb (μg/L)	<3.0	<3.0	100	500
Ni (μg/L)	37 (±25)	9.4 (±4.4)	200	200
Mn (μg/L)	160 (±73)	92 (±67)	200	200
Zn (mg/L)	0.46 (±0.26)	0.12 (±0.075)	2	2
Al (mg/L)	<0.07	<0.07	5	5
F (mg/L)	1.01	0.625	1	1
CN (μg/L)	<10	<10	-	-

Parameter	New reedbed system	Old reedbed system	Greek Law 145116/2011	FAO
B (mg/L)	0.094	0.154	2	<0.7 no restriction 0.7-3, slight to moderate restriction >3.0 severe restriction in use
Phenols (mg/L)	0.096	0.576	-	-

3.5.3. Crop yield

Crop yields and agricultural system

The intensive agricultural system of HYDRO6 has evolved throughout the project and consists at the time being of a poly cropping approach with a high number of different species and cultivars in a densely cultivated manner and a high crop rotation per plant bed. Also, it follows a no till approach to propagate a healthy living soil. This system was evaluated through the experience gained from season to season. The extensive agricultural systems consist out of the grape, herb, prickly pear, artichoke, and caper production. These cultivations are well suited for the environmental conditions on the island and need less inputs.

In the first Season in 2019 ELT tested a high variety of different crops and cultivars in order to analyse the suitability of every species for the specific conditions within HYDRO6 and its market potential within the restaurant and private customer range HYDRO 6 is targeting. Also, the variety composition of the overall production was tested. This initial test setup was refined from season to season according to yield, quality, workload and suitability within an organic growing setup.

The overall yields could be increased in every growing season from 2019-22 as shown in the graph below. The two main cultivation practices, consisting out of open field and green house production, are monitored independently. Also, some crops are measured in gram and others in pieces or bunches (Figure 3.58) depending on the common local market unit.

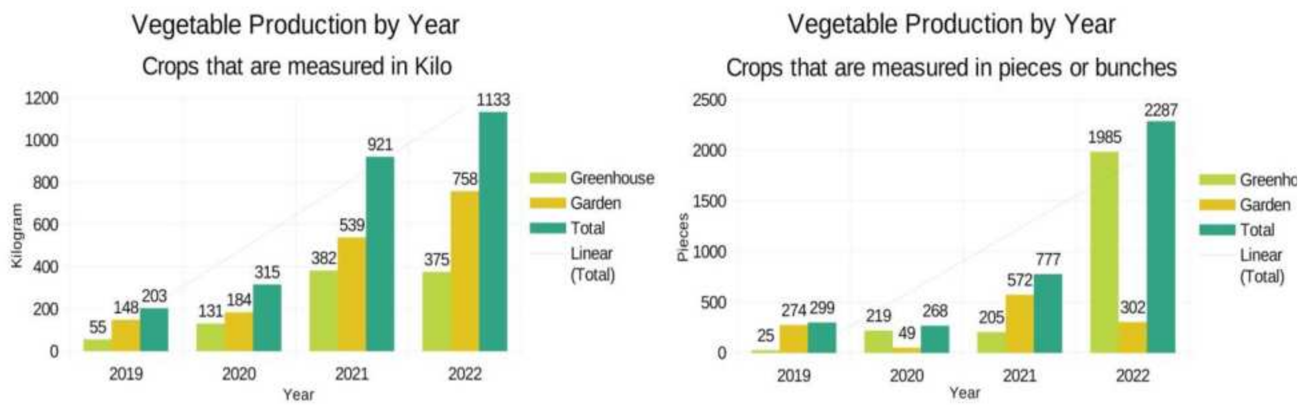

Figure 3.58: Yields per year

Most crops that are recorded in pieces or bunches are grown outside and consist mainly out of salad heads and fresh kitchen spices like parsley, chives, dill etc. and Mediterranean herbs like oregano, thyme etc. Within HYDRO6 it was possible to increase the production by a factor of 5.5 compared to the initial overall production from 2019 to 2022. This shows that the gain of knowledge, the right crop type and cultivar together with the slow process of improving the overall conditions like soil, crop rotation, irrigation etc. led to an overall increase in production and plant health.

Figure 3.59: Market Garden production summer

Crop yields development

As described above a targeted production according to certain production goals is very difficult to achieve over a complete growing season especially with the high variety of different crops cultivated in HYDRO6. Furthermore, the needs of the two different main market outlets further complicate the production. The restaurants need a constant supply of certain crops in high volumes. Fresh leafy salads and colourful rare varieties are in highest demand by this group. The boxes on the other hand need a high variety of different crops in smaller quantities, but the overall composition has to create a cooking friendly unity.

Figure 3.60 shows the total production over the entire growing season for the years 2019 to 2023. Looking at the first season the production started late in May with a fast rise and peaked in June for a short period, then flattens out through July to mid-August and afterwards declines heavily from September to December.

Figure 3.60: Market Garden production autumn

In both cases, the lack of knowledge about production timing, time to harvest, harvesting time span and actual capacity lead to an unbalanced and insufficient timed production. In 2021 as described above ELT managed to establish a crop plan based on the collected data and experiences from the previous seasons. The curve shows a nice steady increase from March to mid-June, peaking in July, decreasing fast in August and picking up again from September to the end of the season. The decrease in August was caused by the heavy focus on the spring period with still inadequate experience of harvest time spans for certain crops declining faster than anticipated and a beginning exhaustion of the crew after 5 months of constant hard work in the field. The positive part was that the declining production was realized early on and new plants and seedlings could be established for a high autumn yield.

Figure 3.61: Market Garden production spring

2022 shows the best growing season so far with a slow increase from January on meeting the first high production target for Greek Easter around April, lowering slowly till the start of the touristic season and picking up till July. Through August the production could not be maintained at this high level and decreased as in any previous season but not as dramatically. A fairly positive September high was managed with a slow decrease as the tourist season ends and the Vegetable Boxes maintain the market outlet. In every season we see that August is the most problematic month. In our analyses there come several factors into play such as difficult environmental conditions with high sun radiation, high water stress, low water availability, strong north winds and peaking pest pressure. Also, the crew fatigue on the physical level as well as the psychological exhaustion from constant trouble shooting, failing crops and pressure form set goals come into play. Nevertheless, for the first time the planned production could be achieved over wide periods of the growing season and real progress in the overall management where made. The Black curve shows an optimal production as anticipated by ELT taking into account its current knowledge, market and available resources.

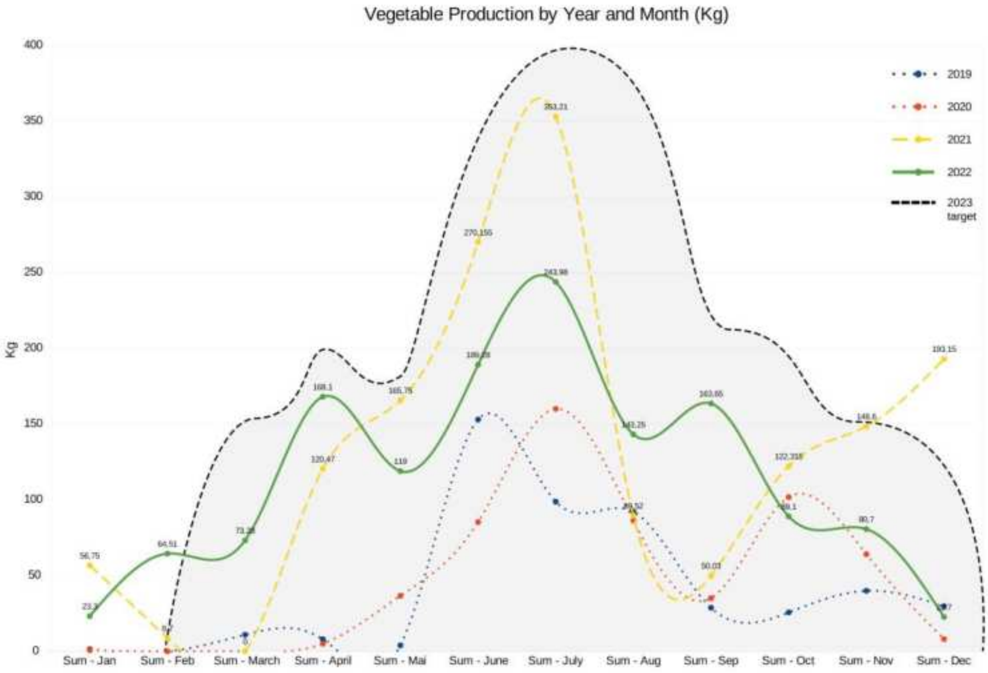

Figure 3.62: Yields per year and month

3.5.4. KPIs status

Table 3.38 displays the Key Performance Indicators (KPIs) attained during the operation of HYDRO6. It is evident that all the achieved KPIs not only meet but also surpass the initially established expected values, demonstrating a highly satisfactory performance.

Table 3.38. Key Performance indicators for HYDRO6

Performance indicator (KPI)	Expected	Achieved
HYDRO6 - rainwater harvested	> 50 m^3/year	~180 m^3/year
HYDRO6 - reclaimed water production	20-30 m^3/year	approx. 73 m^3/year
HYDRO3&6 – water recovered from atmospheric vapour	>20 m^3/year	28.4 m^3/year HYDRO3 4.45 m^3/year HYDRO6

4. OPERATING PROBLEMS

4.1 HYDRO1&2

4.1.1. Encountered Problems

Various operational problems were experienced during the 30 months operation of HYDRO1 that were caused either by internal failures of the treatment system or by external factors, as described below:

- Frequent clogging of the feeding system located either to pump impeller or to non-return valves, feeding nozzles. Residue found was mostly hairball and inert materials that people dump in toilet before flushing. Mitigation measure is only the detailed monitoring of the feeding system pressure. An extra microfilter could also be installed before the UASB feeding pumps to protect it from clogging. This problem could be considered as permanent with the need for proper and frequent maintenance.
- Electrical issues related to power shut down caused by the electrical supply company that could be observed throughout the year, but mostly during winter and storm weather and were due to the poor electricity network of Lesvos Island. Yet, no electrical failure occurred to equipment such as pumps, motors, electro-valves etc. No other mitigation measure could be applied offering a permanent solution, rather than visiting the site for inspection after severe weather conditions.
- Wear of equipment was not extended considering the harsh weather conditions during winter period or extended sunlight in summer, but minor problems like cable wear was observed mainly due to rats. Since this is a common issue faced in most decentralized plants like solar parks etc., a frequent inspection should be considered to detect and replace damaged cables.
- Out of the five species of reeds or ornamental plants that were planted in the CW beds, two were outcompeted by aggressive local weeds in the bed’s microenvironment. The only way to mitigate weed invasion is the temporary flooding of the bed to promote the aquatic plants growth. However, this change in vegetation did not adversely affect the performance of the CWs.
- The reclaimed water storage tank was initially exposed to sunlight and during the first months of operation algae formed. Tank was covered to avoid algal presence and possible negative effect on the drip irrigation system of HYDRO2. Algal formation also induced false TSS measurements.
- Biogas temporary storage tank (before the biogas upgrade) had been attached to its slab in a loose way and methane leaked out of the gasholder. Yet, after proper screwing of the attachment bolts seal was tight. It was possible that bolts had become loose in the meantime among installation and start-up. No further problems followed.

Figure 4.1 Stream cleaning for on-site flood prevention

Pilot line

Some problems were encountered during the monitoring of the pilot line. These include the clogging of the feeding system, and the solution was the cleaning once per weak. Also, a major problem was the poor plant growth and the short percolation time in unsaturated beds. The solution was the increase of pulses that improved the above but also improved the performance of conventional pollutants in the pilot line.

HYDRO2

The main problems encountered during the monitoring of HYDRO2 are summarized to the following:

- The wide diversity of plants requires a daily inspection and different approaches in terms of plants management.
- The presence of a variety of invading weeds could negatively affect the plants growth and transmit plant infestations.
- The size of the field required significant human resources in order to apply the appropriate manual interventions.
- The weather conditions were quite stressful for some plant species. For example, the heavy rainfalls during winter and the poor drainage of some parts of the fields affected the lavender and barley growth and were responsible for the presence of mycological issues.
- During the two years of the agroforestry system operation, various infestations were encountered in almost all the plant species from fungi, bacteria, viruses, insects, and soil nutrient deficiencies, as well as consequences from extreme temperatures like frost and intense heat. All these issues were managed with the application of only biological preparations like vegetable oil and extracts.

4.1.2. Maintenance activities

HYDRO1

Regular maintenance activities included the following:

- Cleaning of the UASB feeding system. Manual cleaning of crucial parts on the piping system (pump impeller, non-return valve ports) and pressurized water pumping to solve feeding nozzles clogging using external freshwater pump.
- Weeds removal from the CW beds during spring to avoid the expansion of tree-like species development, mostly.
- Frequent cleaning and calibration of the online sensor probes according to the manufacturer's maintenance manual to obtain accurate measurements. Replacement with new spare probes if required.
- Cleaning of the cartridge filter that captures impurities found in the piping system of the CW effluent before the tertiary treatment – disinfection. Cleaning was necessary to maintain an effective treatment flowrate in the disinfection unit.
- Refilling the MEA solution container when needed in the biogas upgrade unit, since complete regeneration cannot be performed.
- UASB biogas line compartments need regular inspection. Overpressure safe relief works with variable water level; thus, water needs to be added in the tank, mostly during summer when evaporation is high. In addition, condensation trap needs to be emptied but only at a low frequency.

Figure 4.2 Various snapshots from regular or emergency maintenance activities

HYDRO2

- Manual weed removal interventions were constantly applied 3-4 times per week depending on the season.
- Planting of annual crops, pruning and harvesting of plants.
- Manual carving close to the plants' roots.
- Biological interventions with appropriate spraying apparatus (pressure sprayer) to deal with the plant infestations.
- Weekly monitoring of the irrigation system proper operation and maintenance of the irrigation pumps and irrigation piping.

4.2 HYDRO3

4.2.1. Encountered problems and Maintenance activities

To ensure the system's smooth operation, regular checks and maintenance are carried out, particularly on the sensors and the meteorological station. The first sensors were installed in June 2020. Their measurements are checked and cross-referenced with laboratory results as well as with a portable device once per month. If calibration is required, it is performed immediately. Before the start of the wet season, the sensors measuring quality parameters are removed and cleaned in a mild soap solution with a sponge, and only the pH sensor is cleaned with deionized water.

Frequent replacement of solar collectors in autonomous monitoring and recording systems is required due to wind and the accumulation of dust.

The pump used for irrigation is a dry type, not submersible, and therefore requires less frequent maintenance. However, it needs to be lubricated with silicone grease.

The electrovalves, which are connected to the pumping station, require regular inspection and maintenance. Any leaks in the network result in a drop in pressure, triggering the pump to start. It is recommended to replace the membranes of the electrovalves twice a year, during both the wet and dry periods. The installation of nine electrovalves in the HYDRO3 system, connected to the irrigation network, allows for water distribution to the different sections of the cultivation based on soil moisture sensors, thus conserving energy and water.

At the end of each dry period, the two storage tanks are cleaned using high-pressure water jetting. Algae growth on the walls is cleared, and sediment and debris are removed from the bottom of the tanks (Figure 4.3).

Figure 4.3. Snapshots of the tanks' cleaning process.

The water generator has been optimized to maximize the water production and minimize the energy cost per litre of produced water, as well as extend the system operating range to extreme temperature and extreme humidity conditions. The generator operation diagram is the following:

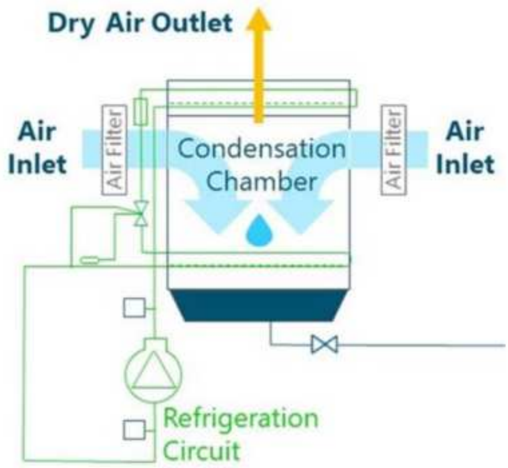

Figure 4.4. Atmospheric Water Generator working diagram

This generator requires two kinds of maintenances:

- Basic Maintenance, to be carried out by the user.
- Professional Maintenance, to be done by a refrigeration professional qualified for this generator.

The Basic Maintenance Tasks are described below:

✓ External Cleaning

To keep the generator free of dust and dirt, the housing surface is wiped with a damp cloth. Detergents or solvents are not used.

✓ Air Filters

By the generator use, dust and dirt will be deposited on the air filters, hindering the air flow. This requires a periodic filter replacement.

✓ Hydraulic Circuit

The hydraulic circuit is composed of several elements that require supervision, cleaning and replacement maintenance.

✓ Leakage Check

Checking periodically and after any cleaning or replacement operation the absence of leaks in the hydraulic circuit.

✓ Replacement of the Filters

The water filters are used to trap particles that have penetrated through the main air filters, to avoid microbiological and chemical contamination risk, to avoid any smell or flavour in the water, and to enrich the water with minerals such as calcium, magnesium or potassium.

✓ Cleaning the Water Tank

With the use of the generator, the water tank will accumulate sediments. It is important to keep it clean and inspect it periodically.

4.3 HYDRO4

4.3.1. Encountered Problems

With regard to the operational problems that have been recorded since the start-up and throughout the entire operation of HYDRO4, these mainly involve the expected operating issues emerging from pumps, valves, piping, manhole and filter clogging as well as more case specific matters related to power supply shutdowns. Indicatively, some of the more common issues and the actions taken to solve them are summarized below.

- Failure of the pumps due to clogging originating from rainfall and flood deposits. The pumps have been removed, repaired and properly maintained before being placed back.
- Failure of electrovalves due to clogging issues; subsequent extraction and repair.

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- Failure of non-return valves; replacement.
- Failure of UPS components; repair or replacement.
- Failure of solar panels for recording and monitoring water quality characteristics, due to winds and dust causes; cleaning or replacement when needed.
- Desynchronization of the central control system of the sensors due to frequent power shutdowns, resulting in a date change and loss of data monitoring in terms of water quality.
- Cracks in the Open Tank due to high temperatures and exposure to solar radiation during the dry season. Coating with insulating material was performed to avoid losses.
- Clogging of the leaf and debris retention filter in the surface runoff, resulting in overflow and loss of water that would have been collected in Tank 2. Cleaning of the filter.
- Incompatibility of PLC fuses with the amber of the pump operation or long-term use; replacement of fuses.
- Damages in wiring from rodents; Replacing the wires and taking measures to remove rodents.

Figure 4.5. Restoration activities in the open tank of HYDRO4

Several of the failures mentioned above can affect the proper operation of the system and are also quite costly for a decentralized system. The principal aim is to protect the system components by recording the frequency of these failures and by preventing them from being caused through regular and targeted maintenance. The maintenance of equipment must be carried out at scheduled intervals, taking into account the requirements of the production process.

Figure 4.6. Installation of filter before Tank 2 collection because of reported blockages resulting in overflow

4.3.2. Maintenance activities

With regard to the maintenance activities of HYDRO4, there are three types that were followed to ensure the smooth operation of the systems.

- **Preventative maintenance**, which is carried out at regular time intervals, according to specific criteria and aims to reduce the probability of failures.
- **Optimization maintenance** carried out in order to modify and upgrade the operation of equipment and installations through calibrations or replacement of equipment.
- **Emergency maintenance** due to failure, which is also the reason for extracting and repairing the equipment, and therefore maintaining these components.

The scheduling of maintenance is performed on an operational and economic basis, so as to minimize maintenance costs, to avoid affecting the quantity of water collected and reducing the recording of qualitative and quantitative data by the monitoring systems due to failures.

In addition to the above types, maintenance is also divided into periods due to the particular design of the system and its dual role. In particular, during the wet season (November - April) HYDRO4 rainwater is collected, stored and recharged into the aquifer, while during the dry season (May - October) water is used to irrigate the crops both from the tanks and from the subsurface. Thus, the maintenance of the particular components each season is the reverse of the HYDRO4 system's period of operation. For example: In the dry season the pumps in the water collection wells are maintained, while in the wet season the irrigation pumps are maintained.

The key control points in HYDRO4 that are to be checked and repaired, when necessary or as appropriate, are summarized below:

In the **water collection and storage systems**:

- During the wet season, controls are performed in the pumps at the bottom of Tank 2, Open Tank and at the well of the aquifer recharge.
- During the dry season, controls are performed in the pumps of Manhole 1 and Bioswale Manhole 3, the rainwater harvesting wells and in Tank 2 at the overflow.
- In the wet season, controls are performed in the lavender irrigation electrovalves and in the dry season on the water distribution electrovalves and in the flushing of the network.
- At the end of the dry season cleaning and disinfection of all tanks and wells is carried out.
- Controls of the collection piping network.
- Controls of the distribution piping network
- Controls and cleaning of grids at the rainwater collection points. The stormwater inlet grids are usually located within gutters, which are primarily used for stormwater flows and protect pumps from debris and leaves carried with stormwater flows.

In the **electrical parts of the system**, preventive controls are performed on a monthly basis as follows:

- In the central control unit - PLC, controls of electrical contacts, terminals, switches are carried out.
- Controls and cleaning of the quality parameter sensors in the tanks and calibration if there is a discrepancy with the portable instruments or the results of the analyses.
- Controls of the pump float are performed.
- Lubrication of the electrovalve shafts and cleaning of the pump plate is carried out.
- Controls of the UPS are done.
- Controls of the level measuring instruments and calibration with a portable instrument are performed.
- Controls of the flow meters - hydrometers for proper monitoring. Checking wiring and taking measures against rodents.

The Slow Sand Filter (SSF) relies on the biological growth on the filter media to achieve higher quality effluent. However, this growth also leads to the clogging of the filter, especially at the upper surface of the bed. Consequently, regular cleaning of the filter is imperative. The following actions are undertaken for maintenance:

- **Periodic Removal of Top Layer:** Regularly removing the top layer of sand through manual or mechanical 'skimming' is essential to sustain efficient filter function. The decision to skim is prompted by an increase in head loss, indicative of clogging at the sand's surface. Each skimming operation involves the removal of a thin layer of the sand bed, typically ranging from 1-3cm.
- **Addition of Clean Sand:** Simultaneously, to maintain the designed sand depth, a new layer of clean sand is added. This process requires a 'ripening period' before the treated water meets the required quality standards. The ripening period is essential because water treatment by the filter relies heavily on the biological community established in the sand bed. Operational procedures such as skimming can disturb this community, and a recovery period is needed to restore optimal filter performance."

In the **crop irrigation system**:

- Controls of the soil moisture monitoring system are carried out
- Membranes on irrigation electrodes are replaced
- Checking the drip irrigation system so that it does not become clogged and opening new hloes if required

Figure 4.7. Maintenance activities for the probes In HYDRO4

4.4 HYDRO5

4.4.1 Encountered Problems

The main operating problems encountered since the start-up of the HYDRO5, as well as the actions taken and potential mitigation measure for the future, are listed below:

<u>**MSS**</u>

<u>-Pumps blockage</u>

Causes due to the automation failures and a low sensible pump timing control due to PLC constraints

Solution: Filling manually the pumps with water before re- activating

<u>- Unit leakages due to an inadequate adhesion between the parts</u>

Solution: De-assembling the units and replacing or tighten up the internal hydraulic connections and components

<u>- Non-Return Valve malfunctioning</u>

Solution: Replacement with a new high-quality Non-Return Valve

- Micro-dripper blockage:
Solution: Replacement with a new micro-dripper

- Internal brine pipe exit blockage due to salt microfilm formation causing brine overflow to FW channel and rising of MSS FW conductivity.
Solution: (i) Regular manual interior cleaning of panels and brine exit unblocking, followed by general flushing of the hydraulic circuit with tap water feed; (ii) day-to-day by-pass application to disintegrate and avoid film formation; (iii) weekly sample campaigns.

- SW and brine pumps corrosion due to high salinity water flow and their long-term operation.
Solution: Replacement with brand new pumps and anti-corrosion coating.

- Rust incidents occasionally presented in FW samples and on the interior channels of the panels.
Solution: (i) Regular manual interior cleaning of panels and brine exit unblocking, following by general flushing of MSS system; (ii) weekly sample campaigns.

- Electrical malfunctions of salt factory's fan.
Solution: Salt factory periodic operation (non-continuous)

- SW pump (RO plant) failures due to air inflow causing emptying of SW pump every night and weakness of activation next day
Solution: (i) Replacement its non-Return Valve with a brand new high-quality one; (ii) "Rakor" (Hydraulic hose fitting) replacement; (iii) pump's suction pipe adjustments; (iv) modification of pump's suction pipe and instalment of a 2nd non-return valve directly above the water inflow of the SW pump.

PGH

- Aphids presence in some aloes causing plant failure
Solution: Cycles of soap water, smoke water solutions or organic pesticides such as paraffin oil and Potassium salts application.

- Brown spots and holes were presented to some bananas probably due to "anthracnose" infection
Solution: Careful removal of infected units and application of copper-based spray or organic agents such as *Olligoactiv impulse* and *Serenade Aso* fungicides.

- Failure of some small bananas in two non-ripe bunches due to the wide range of temperature fluctuation between day (up to 40°C) and night (< 10-15°C) into the PGH.
Solution: Foliar fertilization and shading of the bunches during extremely warm and shiny days.

- Significant chlorosis mainly to banana leaves after a period of extremely low temperatures during winter.
Solution: Preventive fertilization using potassium and free amino agents, and soil mulching.

-Occasional PGH irrigation electrovalves' microleakages were caused continuous unexpected activation of the pressure booster pump
Solution: The electrovalves were unleashed and re-implemented after their insulation and tightening.

4.4.2 Maintenance activities

The main maintenance activities are listed below:

MSS

- Check of the tanks level (both buffer and main tanks)
- Check of the pressure gauge to see if the pressure level is appropriately set (>0.8 bar) and proper adjustment using the SW hydraulic return valve
- One by one inspection of the units and tubes to check their integrity (absence of leakages)

- Inspection of the pump operational status
- Inspection of sensing system adequate response and its connectivity to PLC (and AGENSO nodes' restarting if necessary)
- Basic cleaning of the units using the bypass flow (day after day to avoid internal salt crystallization and microfilm formation)
- Wi-Fi network function check (and router restarting if necessary)
- Keep water balance records and data export
- Overall HYDRO5 site cleaning

The system ordinary maintenance is conducted every ≈ 15 - 30 days and includes:

- Inspection of the micro-drippers for adequate water flow (and replacement if necessary)
- Check of the glazing surface integrity and cleanliness (replacement and cleaning if necessary)
- Thorough cleaning of the units using a tap water hose, following by hydraulic circuit flushing
- Weekly FW, SW and sample campaigns

PGH

Daily maintenance plan:

- Overall PGH status and cultivation condition audit (and application of plant protection measures if necessary)
- Monitoring of pest or disease incidence. In case of necessity apply corrective measures like spraying bio-inhibitors or insecticides
- Monitoring of proper functioning of the irrigation system and window ventilation / GH temperature regulation. Emergency water supply if necessary
- Inspection of irrigation system standard operation and their response via Ardeusis app
- Pressure booster pump audit and maintenance for potential unexpected activation, attributed to irrigation circuit micro-leakages
- Manual removal of weeds is a constant activity
- Evaluation of plant growth
- Keep records

Monthly maintenance activities:

- Application of fertilizers on the soil, in the irrigation water as fertigation or foliar sprays. Application of pH amendments
- Application of mulch layer
- Sporadic harvest of fruits or tubers
- Application of shading paint material on the PGH roof and walls once (check if repaint is needed)
- Cutting back of wilted leaves of banana, cut back of Passiflora branches and tying new shoots up
- Aloe and Banana offshoots replanting to enhance new future plant growth

4.5 HYDRO6

4.5.1. Encountered Problems

Due to the experience of operating a touristic facility and its different components at a remote location on a Greek island it was possible to avoid many problems by considering them in the initial designs or mitigate them by foreseeing and identifying potentially weak components so that only very short down times of the core systems would occur. ELT has managed to operate and maintain HYDRO6 with no down times or down times in the hour to maximum one-day range at all core systems like rain water catchment and storage systems, electricity system, wastewater treatment and reclaimed water storage systems and agricultural production systems. In the field of the water, meteorological and real time soil parameter monitoring systems ELT did not have any previous experience. This rather complex, sensitive and proprietary systems are difficult to maintain by unspecialized personnel. In case of malfunction the communication path and troubleshooting approach is difficult and reaction times until specialized technicians arrive is long.

A general problem faced by ELT was to find people interested in the versatile job description reaching from agricultural production over building activities to organizational skills. Also training periods are long until a new employee is familiar with the many different aspects of HYDRO6 and has a firm understanding enabling him/her to feel confidence.

The specific issues encountered are described below:

- Pressure switches are sensitive to malfunctions. At HYDRO6 two kinds are operated, the mechanical ones that actuate over a preloaded spring and inverter types that measure pressure, flow and control the pump frequency accordingly to maintain a constant flow rate. The mechanical ones are very simple devices and in case of malfunction can be repaired usually on site or with spare parts found on the island. The inverter types cannot be repaired on the island and have to be shipped. This is why an additional spare is stocked on site in order to be able to solve the problem fast and maintain operation. A malfunctioning pressure switch usually causes a cascade of problems one is high energy consumption draining the battery system, high wear on the pump that potentially works against a high pressurized network or the loss of significant amount of water or the malfunction of pipe connections not able to handle the high pressure over prolonged time intervals. According to our experience, every one to two years one of the three used switches will malfunction. In order to identify this condition fast a daily routine of monitoring the energy consumption has been established.
- Sewage pumps show a much shorter service interval due to the corrosive environment they are placed and the heterogeneous characteristics of pumped liquid.
- Irrigation controllers have failed in the Greenhouse due to the high temperature and high humidity and had to be replaced. A special cabinet was constructed lowering the direct sun exposure on the device. Electronic irrigation valves can clog due to particles in the water and rubber seals show leakages. The filter size was reduced from 250 microns to 150. This also showed positive effects on the emitters in the drip lines.
- In the beginning mesh filters of medium build size were used to filter the irrigation water and different locations. This filters were clogging fast and were difficult to clean. Also, the mesh filter cartridges broke every 6-12 months and the different locations made maintenance even more time consuming. The solution was to install one oversized disk filter at a central location with a more ergonomic design making its maintenance simpler and faster.
- The UV-disinfection units show a precipitation of certain minerals that create a coating on the glass cylinder protecting the UV lamp, reducing the transparency and subsequently the disinfection rate. The solution is inspecting and accordingly cleaning the glass cylinder.
- The retention stone walls forming the terraces have to be regularly maintained. Within the time span of the project four different wall sections collapsed and had to be repaired.
- In 2021 the existing underground concrete cistern showed leakage and after inspection a root intrusion was found and repaired.
- The low-cost monitoring equipment has shown different problems and malfunctions especially at its early development state. Different logger units and sensors were replaced, and performance was improved. The medium to low GSM network coverage at HYDRO6 is still a challenge that is difficult to mitigate.
- The MuFu and Water Flower: One of the main challenges is the variability of dew formation due to environmental factors such as wind and cloud coverage. This can lead to fluctuations in the amount of water produced, making it difficult to rely on a consistent source of water. Maintenance of both systems is also necessary to prevent soiling on the surface (which can affect the efficiency of the condensation process) and clogging of water collection systems. During the test and operation of the

MuFu and the Water Flower, several problems were encountered. Severe weather conditions, particularly strong winds up to 25m/s, required heavy anchorage to protect the lightweight WF against lift-off. Debris and leaves accumulating on the surfaces and water collection points led to maintenance issues. Insects were also found to disturb the measuring and monitoring equipment. Another issue was the reliable Internet connection, which was necessary for remote monitoring and data collection. To address these problems, various actions were taken, including implementing a sturdy anchorage system, performing regular maintenance work to remove debris and clean the collection points. The monitoring of water quantity was expected to have a high resolution of 3ml to ensure concise data correlation possibilities with the weather station parameters. This implied that the water meter must register miniscule volumes of water, making it difficult to implement in the harsh weather conditions outside. Clogging, insects and the sensitivity of the water meter began to abate after a few days already. This made the data unusable and we needed to rely on physical correlation between surface temperature and dew point to determine whether and when condensation was occurring or not.

4.5.2. Maintenance activities

The maintenance activities described below are the overall outline focusing on the important components of the systems. There are many other minor tasks that are just in cooperated into the day-to-day workload at HYDRO6 and would be too detailed for the below description. In the operating experience gained throughout the project it can be stated that on average around 10% of the daily effort is connected to maintenance activities in some broader way.

- The wetlands at HYDRO6 are maintained on a regular basis. Visual inspections are carried out for the sedimentation tanks, the wetlands and the reclaimed water tanks for blockage, leakage and any other unusual occurrences. Pumps and floating switches are checked, and the according time switches are controlled to ensure proper function. The biomass produced by the wetlands is harvested twice a year and used as organic material for the composting process or as mulching material.
- The Greenhouse and its peripherals are maintained on a regular basis. Especially the irrigation system has to be checked for leakages and readjusted regularly to the different crop varieties. Also, minor rust points have to be sanded down and re-coated. All moving parts as the windows and motors must be cleaned and greased to maintain good operation. Also, the elevated plant beds which were constructed out of wood have to be treated with oil every two years. The polycarbonate sheets must be washed down once a year with a pressure cleaner in order to maintain high transparency.
- The rainwater cisterns must be cleaned out of debris and sediment every two years. The waterproofed cement slurry has to be inspected for cracks and possible leakages and a new coating has to be applied every 3-5 years. The pumps must be checked and lifted out of the water once a year to inspect their condition and connections. The inflow gutters must be cleaned before the start of the rainy season in order to prevent clogging and unnecessary debris intake. Also, all roof surfaces have to be inspected for accumulation of leaves and foreign materials.
- Within the gardens all irrigation equipment is maintained, readjusted, and cleaned as needed. Especially the filtering devices need a lot of attention to maintain good flow, and weekly cleaning is necessary. Also, the different wooden constructions in the gardens as tool sheds, doors and fences must be maintained yearly. The pathways need mulching with wood ships every second year. All tools with blades must sharpened depending on their usage and most tools with moving parts must be serviced at least once a year. Also wheelbarrows need regular tire changes and repair of flat tires.
- The irrigation system overall needs a fair amount of attention because the UV-radiation, the high temperature differences and the changing pressure put a lot of stress on the equipment. Water leakages from a slow drip to fast dripping and even total failures with higher water losses occur. It is fairly time consuming to check the hundreds of connections that are weak points and usually are the

source of leakage. Also, the electronic valves need some attention to assure their proper operation. All drip lines must be controlled at least once per season for clogged emitters and washed out.
- In general, it can be stated that due to the harsh weather conditions and the high salt concentration in the air all metal structure despite their different coating technologies need regular maintenance. The only exception here is marine grade stainless steel and anodized aluminium used at the photovoltaic installation.
- The touristic infrastructure needs constant maintenance from broken things by customers over normal wear and tear that must be maintained in order to provide the appropriate standard for the targeted customer group.
- The compost toilets have a higher maintenance effort than water-based systems due to the need of changing or emptying out the compost barrel in order to have a cleaner look and feel experience for the next customer. This is mainly caused by the social acceptance boarder to new or alternative sanitation approaches.
- Photovoltaic panels collect a lot of dust especially during the dry season which should be cleaned once a year. Also, cable connections and wear on the panels have to be visually controlled and this is usually combined with the cleaning. The state of charge of the batteries and potential error logs are controlled on a nearly daily basis.

The Table below, outline the required actions and their respective time intervals for monitoring and maintenance of the Water Flower and MuFu. These actions include checking the system for debris, cleaning the collection point, and replacing the Peltier element if necessary. Regular maintenance is required to ensure the device operates at optimal efficiency and to prevent issues such as clogging or electrical failure.

Table 4.1. Maintenance activities for the Water Flower

Action for Water Flower	Time Interval
Clean the collection point and condenser surface from debris and dirt	Daily
Check the paint and surface of the condenser for damage and corrosion	Monthly
Check the TECU (thermoelectric cooling unit) for proper functioning	Monthly
Check and adjust the inclination of the condenser	Bi-annually
Check the system for leaks and repair as necessary	Weekly
Replace the Peltier elements	Yearly
Action for Multifunctional roof	**Time Interval**
Inspect the PV panels for dirt (soiling)	Weekly
Check the wiring and connections for any damage or loose connections	Monthly
Clean the heat exchanger and water tank	Bi-annually
Check the Peltier elements and TEC (thermoelectric cooling unit) for proper functioning	Monthly
Check the system for leaks and repair if necessary	Bi-annually
Replace the Peltier elements	Yearly

5. CONCLUSIONS

The main objective of HYDROUSA project was to setup, demonstrate and optimise on-site, innovative nature-based solutions (NBS) for the management of alternative non-conventional water streams, including wastewater, rainwater, groundwater, atmospheric vapour water and seawater to produce valuable resources, which can then be treated to enrich the domestic water supply and valorised to increase agricultural production and boost the economic activities of water-scarce Mediterranean areas. HYDROUSA aimed to close all water loops at local level, taking advantage of local resources, promoting the concept of decentralised on-site water, materials and energy conservation, treatment and reuse. The HYDROUSA concept was materialised by implementing six demonstration sites (HYDROs 1-6) at full scale in three Mediterranean islands (Lesvos, Mykonos and Tinos).

The extended operation period of more than two years of all HYDROs clearly demonstrates at full scale the feasibility and sustainability of innovative, low-cost water treatment and management technologies to recover freshwater, nutrients and energy from wastewater, salt and freshwater from seawater, and freshwater from atmospheric water vapour. Water conservation solutions including aquifer storage and sustainable agricultural practices such as fertigation and agroforestry were applied and provided sound evidence of success. The integration of modern and low-cost smart automation systems in all demo sites clearly supported the efficient monitoring and hence the optimization of all systems.

HYDRO1 is a novel wastewater treatment system appropriate for decentralized areas with high seasonal loads, consisting of anaerobic treatment in the form of upflow anaerobic sludge blanket (UASB) reactors followed by a system of vertical flow constructed wetlands (CW) in series (saturated and unsaturated). The UASB-CW effluent undergoes UV disinfection in order to achieve reclaimed water appropriate for unrestricted irrigation. During the 2.5 years of operation, more than 34,400 m^3 of raw wastewater have been treated in HYDRO1 and more than 32,600 m^3 of reclaimed water have been produced. The extensive monitoring program implemented through online industrial and low-cost probes and lab-scale analyses, provided clear evidence for the classification of reclaimed water at Class A, as well as for the low carbon footprint of HYDRO1 which accounts for the one fifth of the carbon footprint of conventional wastewater treatment plants with comparable treatment capacity. The biogas produced in the anaerobic reactors is collected and being treated in order to produce pure methane which is used as a fuel for one vehicle (waste collection truck) of the Municipality of Westen Lesvos. More than 10 m^3/d of biogas was produced on average, with maximum summer values as high as 16 m^3/d. The excess sludge of the UASB reactors is treated in sludge drying reed beds (i.e. sludge treatment wetlands) and a composting system in series to produce compost. More than a tonne of compost (1,250 kg) was produced during the third period of operation of HYDRO1 with quality characteristics within the limits that have been set in Greek legislation for the agricultural use of sludge.

In parallel four prototype pilot scale CWs with a treatment capacity of up to 1 m^3/d were set up and optimized: (i) three electroactive CWs and (ii) an aerated CW combined with a sand filter with UV to demonstrate the possible conversion of wastewater to fresh water. All pilot systems provided strong evidence of high treatment performance, thus highlighting the potential of future applications of low footprint constructed wetlands systems.

Part of the treated water in HYDRO1, depending on the irrigation needs, was used to fertigate a 1 ha agroforestry system (HYDRO2) consisting of a wide diversity of trees, shrubs, aromatic plants and annual crops. The main field of HYDRO2 has an area of about 0.8 ha and includes more than 60 different plant species, while the second field includes a seasonal plantation of maize/barley accompanied with some aromatic plants and trees. More than 6,500 m^3 were annually used to fertigate both fields. HYDRO2 was very successful in terms of crops production since more than 14.5 tons of crops were harvested and donated to local farmers and families in Antissa village during the 2 years of operation.

HYDRO3 is located in Ano Mera, Mykonos Island and it is an innovative, nature-inspired rainwater harvesting system perfectly harmonised with the landscape architecture. This prototype system consists of a shallow, sub-surface rainwater collector with a surface area of 280 m^2 and two cylindrical light structure storage tanks with a total water storage capacity of 60 m^3. The harvested water is utilized for irrigating 0.4 ha of oregano cultivation. For the implementation of HYDRO3, traditional construction techniques were used; stone works were implemented for the construction of the main entrance, while the rubble walls around the site were rebuilt. Additionally, an old warehouse in the southern part of HYDRO3 has been restored and repurposed as storage facilities for agricultural tools, and the place of the installation of the oil distillation unit, along with the two dehumidifiers. The prototype rainwater harvesting system has consistently operated for four consecutive years, collecting 60 m^3 of rainwater (at an average recovery rate of more than 80%) for the irrigation of the 0.4 ha oregano field planted next to the collection system (more than 825 kg of oregano/year/ha were harvested from the plot). To increase water recovery, two vapour recovery system were installed, producing 28 m^3/year of condensed water vapour. Based on the results of the intense monitoring performed, both the rainwater collected, and the water produced by the two dehumidifiers, present high-quality characteristics fully satisfying the needs for irrigation use.

The aim of HYDRO4 is to design, implement and optimize a residential-scale prototype decentralized, flexible and autonomous rainwater harvesting, storage and recovery system in the highly touristic Mediterranean island of Mykonos. The system demonstrates how a residential rainwater collection system can be upgraded to optimize the low-cost rainwater harvesting infrastructure and the natural services provided by the subsurface geological conditions, with a positive impact on the environment. The principal concept is to store excess water during the winter months to use it in the summer, that is to maximize the existence of the subsurface natural resource throughout the year and to increase the water management efficiency in water scarce areas. To achieve this, three separate but interrelated subsystems have been designed, constructed, tested and optimized; a) a rainwater harvesting system collecting water from the residential rooftops of the site property, to be used for domestic non-potable purposes in the local residences (e.g. washing, flushing toilets, etc.), b) a slow sand filtration system to convert raw water such as rainwater into a potable product and c) an aquifer storage and recovery system, where rainwater is collected, stored and used when needed (by collecting the surface runoff of the impermeable surfaces of the residences and stormwater through a bioswale system). Based on more than two years of continuous operation more than 270 m^3 of rainwater and surface runoff has been recovered for domestic use and aquifer recharge on an annual basis, while more than 500 m^3 of water has been stored into the aquifer. The water stored into the aquifer has been used to irrigate the nearby land of 0.2 ha of lavender. Based on the continuous monitoring plan, the collected water presents very satisfactory quality characteristics fully complying with the needs for the irrigation of the lavender plot.

A prototype system, the Mangrove Still system was developed in Tinos Island (HYDRO5) which has reached a steady state smooth operation. Its proper operation was evidenced through the required daily maintenance of both MSS and PGH sites for more than 2 years. The outcome of its performance indicates that the system is capable of delivering the expected results, achieving the targeted KPIs goals regarding the daily desalinated irrigation water, the produced salt and the cultivation yield. More specifically, this prototype, solar-driven water desalination system can evidently generate more than 200 L/d of fresh water from seawater, brine and rainwater, while producing more than 2 kg/d of salt. The aforementioned achievements highlight the environmental, economic and social efficiency of HYDRO5, as it constitutes a low-cost and low-energy footprint biomimicry system without harmful outputs. The system leverages on unconventional but abundant renewable natural resources: sun and saline water; producing fresh water through a passive evaporation/condensation process which demands negligible amounts of energy and materials. The produced water is appropriate for the delivery of high value tropical fruits and Aloe (more than 500 kg have been produced) by precision agriculture techniques utilizing effectively smart low-cost online probes and tools. It is evidently a sustainable non-conventional system skilled to enhance the local market by increasing at the same time social, economic and environmental welfare. Finally, regarding the system's upscaling and optimization, a dedicated plan of interventions has been conducted and will be tested in 2023, aiming to further upgrade its capacity at more than 400 L/d fresh water and maximize its cost/benefit ratio, in the context of water-energy-food-ecosystems (WEFE) and sustainability approach.

In HYDRO6 the innovative combination of water management cycles with agricultural and touristic activities have been demonstrated for approximately 3 years through water and wastewater loops in a small eco-friendly tourist lodge located at Tinos Island. The facilities have been upgraded to improve the efficiency of the existing water conservation systems (e.g., rainwater harvesting), and utilized to boost local production and consumption of organically grown vegetables and crops. Existing buildings have been renovated to enlarge the water conservation structure, maintaining the traditional structure and integration within the local context. In addition, several atmospheric water harvesting technologies have been implemented on site to increase water capture, without stressing the withdrawal of groundwater. Water is first collected and then reclaimed after usage within a system of loops that are interconnected and allow increased business diversification where eco-tourism is integrated with agricultural production. About 180 m^3 of rainwater have been harvested and 73 m^3 of reclaimed water have been produced on an annual basis. The business model developed within HYDRO6 is less vulnerable to fluctuations within the tourism sectors, as it generates income diversification, reduces costs, and increases biodiversification of the natural environment. To reduce the overall water withdrawal from the aquifer, the water used in the facility derives from: a) surface water from rain captured through a rainwater harvesting-storage system and a stream, b) vapour condensation unit for direct water production, c) reclaimed water produced by the treatment of domestic wastewater through CWs. These technologies are nature-based and rely on minimal use of energy that is provided through solar panels. The anthropogenic cultural landscape of the locality where HYDRO6 is being demonstrated (Tinos) and the natural habitat are carefully integrated and valorised into the design of the technology through technical measures (i.e., usage of local materials, building techniques, and traditional craftsmanship) and social adaptation (i.e., behavioural and cultural integration of changes toward alternative sanitation concepts).

In view of the above it is anticipated that the promotion of the application of circular economy for water and the reinforcement of the water-energy-food nexus in the Mediterranean area, which are the main objectives of HYDROUSA project, have been evidently supported through the design, implementation, and optimization of a set of innovative nature-based solutions in six demonstration sites in Greece. These solutions are low-cost, energy efficient, and environmentally sound and as such, are easily adaptable and replicable to locations around the world with similar water scarcity issues as in the Mediterranean area. It is worth noting that the all the solutions demonstrated in the six HYDROs can be applied interconnectedly as a whole in a specific area thus creating a circular supply chain by providing fresh water, reclaimed water, service water and drinking water originating from non-conventional sources and promoting the on-site production of several goods.

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