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HYDROUSA

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Water in the context of circular economy

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Demonstration of water loops with innovative regenerative business models for the Mediterranean region

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Mangrove Still prototype installed and running

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Brief Description	Technologies foreseen at HYDRO 5 in Tinos set up and running for producing freshwater used to irrigate a greenhouse and salt, as a by-product. In particular, the Mangrove Still System - MSS), a pilot desalination system (Saltwater Evaporation Greenhouse - SEG) and a greenhouse (including irrigation system) have been set up. Initial tests conducted during October 2020 confirm potential for achieving KPI of 200 L/day of freshwater and 2 kg/day of salt.
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EXECUTIVE SUMMARY

The main objective of HYDROUSA project is to offer a set of innovative solutions for increasing the application of Circular Economy for Water and for reinforcing the water-energy-food nexus in the Mediterranean area. Solutions easily adaptable and replicable to other possible circumstances around the world are designed and implemented.

HYDROUSA implements 6 demonstration sites located in three Greek islands; HYDRO1 and HYDRO2, are located in the island of Lesvos, HYDRO3 and HYDRO4 are located in the island of Mykonos, and HYDRO5 and HYDRO6 are located in the island of Tinos.
Deliverable 2.4 "Mangrove Still prototype installed and running" includes a description of the HYDRO5 demonstration site, implemented within the Work Package (WP) 2 "Freshwater production, collection, storage and supply" and specifically through the implementation of the activities described in the Task T2.2 "Saltwater desalination system".

Under HYDRO5 the following specific objectives are accomplished:

- Demonstrate that circular nature-based technologies work for supplying fresh water from non-conventional water sources and
- Effectively deal with the demand side of unsustainable water consumption through the utilization of unconventional water resources for agricultural and domestic use

In particular, under the HYDRO5 the following technologies have been set up:

- A desalination system, (Mangrove Still System)
- An agricultural site composed by a greenhouse producing tropical fruits (Productive Greenhouse)
- A pilot nature-based (bio-assisted) desalination system (Saltwater Evaporation Greenhouse)

The integration of the above mentioned technologies is accomplished by i) an appropriate irrigation system for watering the tropical fruits inside the Productive Greenhouse and ii) a smart system of sensors that connects the above components so as to monitor the overall system and increase the efficiency of water production, irrigation and crop production. The latter activities are part of WP5 and are described in Deliverable 5.5: Design and Implementation of ICT infrastructure for data gathering and controlling.

Specifically, for HYDRO 5 the following key performance indicators (KPIs) are expected to be achieved:

i. production of 70 m^3/year of freshwater from saltwater/brine and rainwater,
ii. 700 kg/year recovered salt and
iii. 1.5 tons of tropical fruit

The HYDRO5 is located in Tinos and specifically within the private area of the local desalination (Reverse Osmosis RO) plant, owned by the Municipality of Tinos (TINOS), partner of the HYDROUSA project. The dedicated area was identified after on-site inspections. The available size of the area as well as the local weather conditions affected several aspects of the demo, in terms of materials and design, as well as the extension and configuration of the technologies.

The systems design was finalized, following the corresponding deliverable (D2.3: Design of the Mangrove Still Upgrade) and for a whole year was optimized before the actual installation of the technologies. However, it should be noted that their construction was scheduled to be completed by June 2020, but was postponed due to the COVID-19 pandemic, which impeded the normal continuation of the activities and travelling between countries. Therefore, the construction of HYDRO5 started in July 2020 and ended in September. Then, the

operation of the system started, while minor adjustments were made based on the evaluation of its operation. After a few days of operation, despite the unfavorable weather conditions (shortening of daily light and rains) the Mangrove Still System already showed the strong potential for achieving the KPI for freshwater production. However, longer operation time is required to confirm the achievement of the relevant KPIs, for both freshwater and salt production, the same applies to condensing plants in the greenhouse.

The general scheme of HYDRO5 consist of a desalination system - owned by PLANET - named ‘’Mangrove Still System’’, developed according to the bio-inspired design approaches, capable to produce freshwater from seawater, utilizing a passive distillation process, triggered by sun irradiation. The produced freshwater is then collected and pumped to the Production Greenhouse, where tropical fruits are cultivated to meet the initial demand of the local tourist structures.

The project is complemented by a pilot nature-based (bio-assisted) desalination system, named Saltwater Evaporation Greenhouse, which produces freshwater leveraging on the condensation of the water vapour produced by selected salt-resistant plants via evapotranspiration. The feed stream of HYDRO5 technologies, more specifically seawater, which was selected as a non-conventional resource for freshwater production, comes from the local reverse osmosis (RO) plant. The discarded streams are also pumped back to the desalination plant, where then they are disposed 200 m far from the coast via a seabed pipe.

The engagement of the local community is crucial for the HYDROUSA project. More specifically, the involvement of the local community in the management of the system, as well as its awareness on emerging issues, such as water scarcity, was possible thanks to dedicated workshops organized in collaboration with and under the management of the HYDROUSA Communication team, specifically the Impact Hub Athens (IHA) partner.

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ABBREVIATIONS

BID	**Biologically Inspired Design**
EPDM	**Ethylene Propylene Diene Monomer**
IoT	**Internet of Things**
KPI	**Key Performance Indicator**
LDPE	**Low-density polyethylene**
MSS	**Mangrove Still System**
P&ID	**Pipe and Instrumentation Diagram**
PC	**Polycarbonate**
PE	**Polyethylene**
PGH	**Productive Greenhouse**
PMMA	**Poly(methyl methacrylate)**
PP	**Polypropylene**
RO	**Reverse Osmosis**
SEG	**Seawater Evaporation Greenhouse**
VFD	**Variable Frequency Device**
WP	**Work Package**
ZLD	**Zero Liquid Discharge**

1. INTRODUCTION

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 three technologies for the production of freshwater and tropical fruit, as follows:

- A desalination system, named Mangrove Still System (MSS)
- A pilot nature-based (bio-assisted) desalination system, named Saltwater Evaporation Greenhouse (SEG)
- An agricultural site composed by a greenhouse producing tropical fruits, named Productive Green House (PGH) and an appropriate irrigation system

The following sections aim to describe the three installed technologies.
Section 2 provides a detailed description of the systems highlighting their technical aspects and possible deviation from the design deliverable. Section 3 focuses on the equipment used and the operation process, through the description of the operation manuals. Finally, in section 4, the main steps carried out for the systems construction and start-up are presented.

This deliverable is divided based on the three technologies. Then, **Figure 1.1** shows the general layout of HYDRO5.

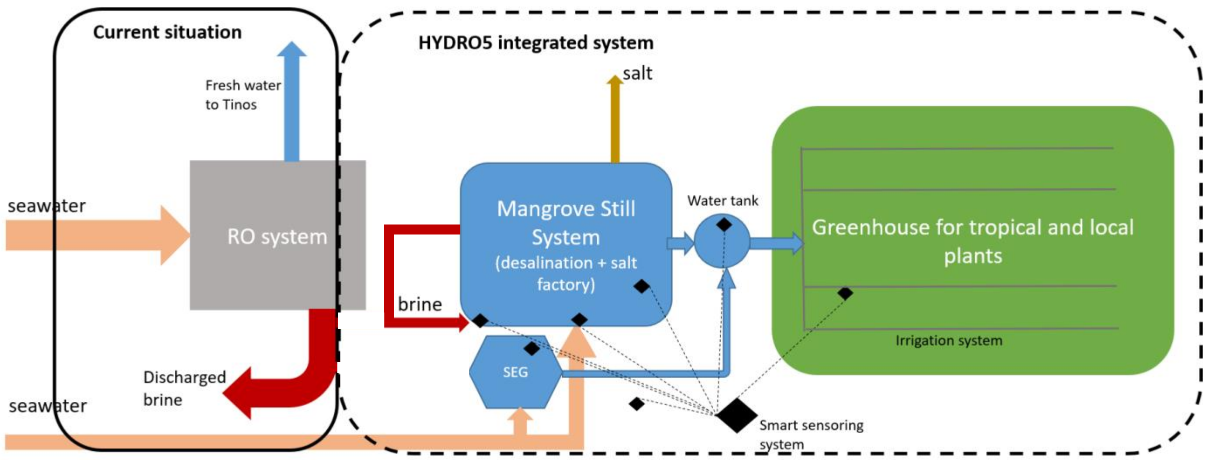


Figure 1.1 Scheme of the overall system

The overall system utilizes seawater, which is derived from the desalination plant as a non-conventional water resource for the production of freshwater, tropical fruits and salt, which will be used for local products or industrial use.

The **Mangrove Still System** is per-se an integrated system capable of desalinating seawater and brine, producing distilled water for agriculture and also capable of recovering salt through an evaporation and condensation process. The process runs by solar energy and gravity. The system has as input pre-treated seawater (by filtration) from the existing desalination plant of Tinos and is planned to produce at least 200 L/day of freshwater from seawater and 2 kg/day of salt. The system was designed following a biologically-inspired (BID) approach, and therefore already incorporates the principles of the circular economy (the same principles can actually be found in nature) and takes into account the water loop.

An appropriate **greenhouse (PGH)** and related **irrigation system** to grow tropical and local crops has been designed under Task 4.2. Its construction has been completed and occupies a total area of 200 m^2, which includes 100 m^2 for the actual plant cultivation and 30 m^2 for the SEG implementation, while the remaining space is dedicated to service paths for maintenance and management functions. The plants are fed through a dedicated irrigation system, using freshwater produced by the MSS and rainwater collected by ducts installed on its roof.

The **Saltwater Evaporation Greenhouse (SEG)** has been developed as a nature-based integrated system, which utilizes plants tolerant to saline water (halophytes) to extract fresh water from sea water, using the evapotranspiration process of the vegetated areas and a saltwater pond and subsequently condensing the so generated air dissolved water vapour in different condensation units installed in the SEG. The conceptual design has been developed within the HYDROUSA project and a first pilot test is set under the HYDRO5. The water produced by this pilot will be complementary to the one produced by the Mangrove Still System.

The main **benefit** of this integrated system is that it will provide the opportunity to produce food in water stressed areas, in which saline water is abundant. It opens up the opportunity to exploit land that previously would not have been used for the good of the community. The system is modular and can be sized according to the needs and restriction of the particular land plot, ensuring adequate scalability. One **limitation** is that the freshwater production units need extra space and depending on the cost of land, this solution may not be economically feasible.

2. SYSTEM DESCRIPTION

In this section a detailed technical description of the systems installed within the HYDRO5 at Tinos Island is reported. The chapter is divided according to the three installed systems: the Mangrove Still System (MSS), the Production Greenhouse (PGH) and the Seawater Evaporation Greenhouse (SEG). The technical description, the deviations from the deliverable D2.3, and diagrams representing their actual construction are described for each system.

2.1. Analytical technical description of the Mangrove Still System

The Mangrove Still System is a modular technology capable of desalinating seawater and brine, producing high quality distilled water for agriculture and also capable of recovering salt, via a process of evaporation and condensation.

The technology, designed by PLANET, was developed following the bio-inspired design (BID) approaches and tools, and its early development within the specific context of HYDRO5 together with first estimations and considerations, have been described in the previous deliverable D2.3 "Design of the Mangrove Still upgrade". During over a year, before the actual installation of the system, significant improvements have been accomplished, thanks to dedicated inspections at the site, and an early pilot test carried out during the summer 2019, within the outdoors areas of Neorurale, an innovation centre placed in the north part of Italy (Pavia). The pilot test allowed us to further review the system design and select the appropriate materials to meet the operational conditions, estimating potential outputs and defining the most optimal configuration for the specific context of HYDRO5.

The system configuration, emerged from the whole period of development, was installed at the site between July and September 2020, and is composed by the following sub-components:

- Mangrove Still Unit
- Supporting structure
- Salt factory
- Rainwater collection system
- Hydraulic circuit
- Electrical infrastructure (including sensing and controlling system)

The next sections are dedicated to the technical description of each of these elements; together with the main differences that emerged in comparison to the initial design concept.

2.1.1. The Mangrove Still System: plant description

Before having a deep insight on each single Mangrove Still System's sub-component, a general overview of the plant is presented. The design of the MSS and the overall HYDRO5 has been carried out considering the specificity of Tinos Island and the location, the Tinos Desalination Plant area, which was pre-determined. This imposed a number of technical and operational choices, which increased the challenges in the design for the achievement of the targeted KPIs, namely 200 L/day of freshwater and 2 kg/day of salt.

The area dedicated for the MSS, equal to Ca. 250 m^2, is represented in **Figure 2.1**, where the location of the other systems installed within the HYDRO5 are also reported. All around the system a buffer area has been identified of at least 2 m width, in order to facilitate installation activities, as well as the passage of equipment and technicians, decreasing the available area for the installation, to Ca. 160 m^2. According to the general layout described in section 2.4.1., the total number of units installed is 80, where 4 are dedicated to experimental purposes. Considering an average freshwater production of 2.2-2.3 L/day per each unit, the expected output is therefore 170 L/day, which is going to be compensated with the collection of rainwater, to reach the target goal of 200 L/day.

As mentioned, even though the limited available area has been a constraint in terms of number of installed units, the construction of the MS within the constraints has been significant for demonstrating the capability of the Mangrove Still System to be adaptable to the context specificities.

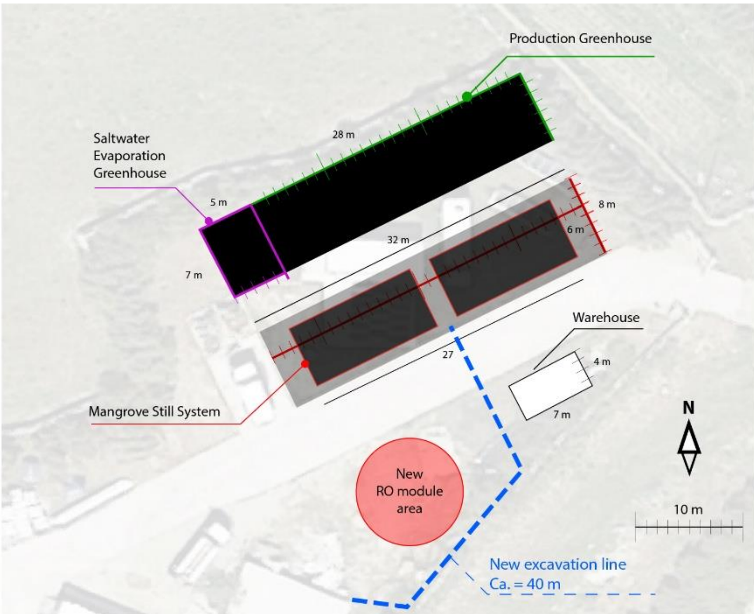


Figure 2.1 HYDRO5's systems allocation within the site

The system has as input pre-treated seawater coming from the Desalination Plant. The feeding flow entering into the units is subject to an evaporation/condensation process from which two different outputs emerge: freshwater and brine. The former is collected by gravity in dedicated buffer tanks to then be pumped into a main freshwater tank of 500 L. Considering that the objective yield (according to the KPI) is an average of 200 L/day, it will be enough for storing the freshwater for more than 2 days. The freshwater is then transferred to irrigate the Production Greenhouse. The second expected output of the distillation process is the brine; the portion of non-evaporated seawater with higher salt ion concentration. The brine flow is conveyed by gravity to a buffer tank, from where it can then follow three different paths:

i. It is pumped to collection point of the RO plant, to be discharged 200 m from the coast, via a seabed pipe. The additional volume of brine, ranging between 0.5 and 0.7 m^3/day, with a salt concentration of around 50 g/L that can be considered negligible with respect to the 5000 m^3/day, which are discharged only from the RO plant.
ii. Toward a Zero Liquid Discharge (ZLD) perspective, the brine from the buffer tank can be used as input for the distillation units, in order to undergo a second distillation process. Although, in this case, due to the higher amount of salt ions in the inlet flow, a lower productivity must be taken into account.
iii. Finally, within the ZLD concept, the brine can be collected in the Salt factory placed beneath the units, delivered to a further evaporation process and obtain salt as a by-product.

The whole system is supported by a dedicated hydraulic circuit, responsible for the management of inputs and outputs, powered by an electrical infrastructure.

2.1.1.1. Deviations from the design deliverable

Regarding the overall plant, the main deviation compared to the initial concept is the occurred configuration change. It emerged from the considerations raised after the missions at the HYDRO5 site, which allowed identifying the final installation spot of the system, as well as from the pilot test performed in Italy. Although, a multi-layer system (up to three levels with units connected in series) was initially considered, the complexity (both from a structural and legislative point of view) due to the high supporting structure and the risks arising from its installation and management, steered us toward a more simple and flexible configuration, which includes a single-layer system with all the units connected in parallel (**Figure 2.2**).

Figure 2.2 Mangrove Still System installed in Tinos

2.1.2. Mangrove Still Unit

The Mangrove Still Unit is a passive, cascade-wick, single-slope solar distiller, which leverages on:

- solar irradiation: to trigger on the evaporation/condensation process
- gravity: to collect freshwater and brine

The unit, with an approximate size of 1 m^2, is constituted by a main body obtained by a thermoformed sheet of black polycarbonate (PC), which forms the basin plate, specifically, a stepped-cascade basin plate. The unit is fixed at the supporting structure, with a tilt angle of 32°, according to the local latitude, in order to optimize the solar irradiation incidence. Moreover, being black, solar irradiance absorption is promoted, in favour of a more efficient heat accumulation in the flowing seawater.

The seawater is continuously fed with a constant input flow rate of 2 L/h via the dedicated hydraulic circuit, and flowing down within the unit, thanks to its specific design, following a side-by-side path in the different steps, which increases the seawater residual time. At the end of the cascade path, the seawater becomes brine as a result of the evaporation process, to then leave the unit from a bottom right exit, where a brine collection channel stores it in a buffer tank.

The water vapour produced during the evaporation condenses on the inclined cover and runs to the collection point at the lower end. The unit cover is made of tempered extra-clear glass, in a single sheet with a thickness of 5 mm. The selection of these design parameters aims at maximizing the cover transmittance, while ensuring the structural robustness required for outdoor applications in possible harsh environments. The droplets are harvested in the dedicated channel, with a suitable inclination, to have them flowing by gravity towards the freshwater outlet point.

The rear of the unit is closed by a flat panel of the same material, and the space between the two is filled with glass-wool, so as to minimize the heat losses to the environment. In addition, to efficiently seal to top glass cover, the edges were covered with ethylene propylene diene monomer (EPDM) rubber gaskets, and four slotted metal bars were screwed to securely close the distillation unit. Threaded rivets inserted along the frame of the stepped basin were mounted to accommodate the complementary screws, so as to minimize as much as possible the losses from the evaporation chamber.

2.1.2.1. Deviations from the design deliverable

The final design of the unit and consequently its construction, from a geometric point of view, is the same as presented in the deliverable D.2.3, with minor changes. It was indeed based on features which emerged from literature, above all regarding key characteristics as water level depth within steps, optimal unit inclination, or ergonomic considerations. Minor changes regard overall unit dimensions, inlet/outlet exit positions or the configuration of the compartment for the distribution of the condensation surface.

The key improvements from the initial design are mainly related to the selected materials and the glass closing system. Both of them emerged during the pilot performed the summer of 2019 at the Neorurale innovation centre (Pavia, Italy), when different options, in terms of materials and design were tested and monitored with a dedicated Internet of Things (IoT) System. This provided the opportunity to the PLANET team to better understand the operative conditions, to estimate/evaluate the productions and simulate them according to the conditions expected at the Tinos Island.

During the testing period, glass was identified as the optimal material for the condensation surface (polymethyl methacrylate (PMMA) and polyethylene (PE) were also tested) and a more appropriate closing system was designed, including seals and frames, in order to avoid heat and water vapour leaks as much as possible.

Finally, the material of the basin plate has changed. According to the tests, the internal temperature reaches peaks, up to about 110 ° C. Based on this and taking into account the average higher solar radiation that exists on the island of Tinos, a new material selection process was required, which had to be a trade-off between the monitored data and the manufacturing process. Polycarbonate emerged as the most suitable material.

2.1.3. Supporting Structure

The supporting structure is composed by commercially available, galvanized metal slotted L-profiles, joined together by stainless steel bolts. The structure sees the use of profiles in only three different lengths for its whole construction.

The supporting structure can be considered as the main skeleton, and other than hosting the units, it is also functional for the implementation of the salt factory and the rain collector. Thanks to its characteristics indeed, additional functional modules can be added to the structure, creating a configurable design. Furthermore, the slots along the profiles allow to adjust the position of the functional modules and to slightly modify their inclination in order to set the most appropriate tilt angle and compensate small hollows possibly present on the ground.

The structure, in the specific context of HYDRO5, characterized by strong wind with gusts up to 40 knots, is then completed by three extra-systems, creating an integral wind-resistant frame:

i. The structure is posed and secured at the ground by the mean of a 6-meter-long, aluminium squared-tube, upon, which it is fixed via screws being accommodated on the corresponding threaded rivets mounted on the squared-pipe.
ii. The metal poles are fixed at the ground and connected to the structures by bolts.
iii. Supporting structures are connected to each other by bolts.

2.1.3.1. Deviations from the design deliverable

During the development process, the differences regarding the supporting structure are due to the change of configuration. Switching from a multi-layer system to a mono-layer system has allowed the PLANET team to reconsider the structure both in terms of materials and design. Although initially wood with resistance class C24 was considered, step by step, attention was shifted to plastic to then focus on metal profiles (various solutions were also tested). The selection of slotted profiles was significant to build up a structure able to host not only the units, but also the other functional modules.

2.1.4. Salt factory

The salt factory aims to produce salt in order to achieve the KPI within the HYDROUSA project, which foresee the production of 2 kg of salt per day. As previously mentioned the salt factory is integrated into the system with the perspective to having a ZLD system in which part of the brine is treated and its discharged quantity is reduced. The salt factory (see detail in Figure 2.3.) is implemented into the supporting structure, beneath the Mangrove Still Unit, and is composed by: i) aluminium tray, ii) fans and iii) protecting panels.

The aluminum tray has an area of 0.8 m^2 and is able to contain ca. 20 L of brine. Because of its position, the plate is barely hit by direct sun irradiation, and therefore, to accelerate the salt production process, 4 fans have been installed so as to increase the evaporation rate by forced convection. Finally, to avoid dispersion of the blowing air from the fans and protect the tray from dirt, plastic panels have been installed all around the salt factory.

The overall size of the salt factory has been then estimated considering:
Brine plate capacity = 20 L
Average brine concentration = 45 g/L
Fans air speed = 2 m/s
Evaporation time = 10 days (as reported in D2.3 and also emerged from previous tests at Neorurale)

Based on that, 30 trays have been arranged in the system, which we expect being enough to achieve the related KPI.

2.1.4.1. Deviations from the design deliverable

The main design improvement resulting from the development process is the integration of the salt factory directly into the support structure. Initially, a dedicated movable structure was considered to be placed under the system (**Figure 2.3**). However, moving from a multi-layer structure to a single level configuration reduced the available accommodating space, making this solution impossible.

The selection of slotted L-profile for the supporting structure, allowed the direct integration of the components of the salt factory, which could be then considered as a functional module to be added according to the needs. Avoiding a dedicated structure reduced the number of components, while still maintaining design flexibility, as perhaps the height where to put the tray and the number of the salt factory-functional module to be implemented.

Figure 2.3 Salt factory detail

2.1.5. Rainwater collection system

The rainwater collection system is another functional module added to the supporting structure. It is made of commercially available white plastic U-profiles, it collects the rainwater to channel it into the buffer freshwater tanks via a dedicated hydraulic circuit (**Figure 2.4**). It is connected to the structure by dedicated supports fixed by bolts. Its purpose is to increase the amount of water available for the Production Greenhouse, especially during the seasons characterized by lower solar irradiance. A plastic mid-mesh filter is placed at the exit of the channel to avoid obstructions due to leaves, small branches and insects.

2.1.5.1. Deviations from the design deliverable

The rainwater collection system is an optimization included in the MSS, following the demonstration of the design deliverable. Its introduction meets the general concept of the HYDROUSA project; utilizing non-conventional water resources. In addition, in order to achieve 200 L/day as a targeted KPI and taking into account the limited available area for the installation of the unit, the implementation of a rainwater collection system became significant, to provide enough water during the winter.

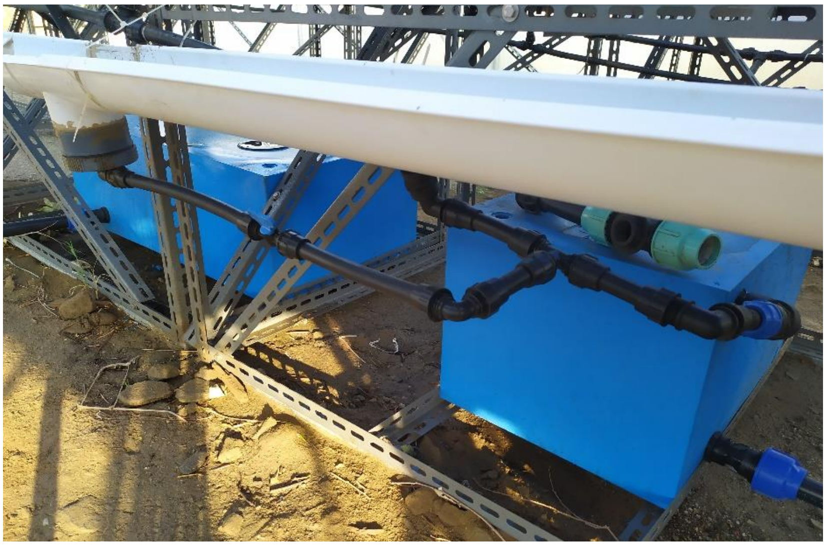


Figure 2.4 Rainwater collection system

2.1.6. Hydraulic circuit

The hydraulic circuit of the Mangrove Still System can be divided in three main independent sections:

A: the inlet section from the desalination plant to the MSS inlet tanks (seawater tanks)
B: the section from the inlet tanks to the panels of the MSS
C: the brine and freshwater's outlet sections from the panels

Schemes per each section are reported in Annex 1

Section A
It includes a pump and two different inlet accumulation points, with the scope to store the inlet seawater coming from the desalination plant 50 m away. The first and main tank has a capacity of 500 L and at this point is integrated a level sensor (under the responsibility of WP5) to detect its minimum and maximum content and therefore to activate the connected feeding pump, which is responsible for drawing seawater from the identified sourcing point (RO plant well).

The second back-up tank with the capacity of 1500 L is intended to store seawater and serve the MSS for at least 2 days (together with the main one). Its application was necessary due to the sodium hypochlorite treatment performed at regular intervals by the local RO plant to clean the RO membranes. Based on that, in order to avoid such chemicals that would affect the Mangrove Still System, before the cleaning treatment, the back-up water is filed completely. The circuit includes also a filter for small particles (metal mesh of 130 micron) at the entrance and the adduction is made by a Low-density polyethylene (LDPE) tube with an external diameter of 32 mm.

Section B
The Section B, see a detail in **Figure 2.5**, represents the internal MSS hydraulic circuit between the seawater tanks and the MS units. It is first of all composed by two monophasic pumps, sucking water from the main tank and feeding the solar stills. They ensure the seawater distribution and work alternately in order to increase the system robustness, in case of malfunction of one device. Instead, under normal operating conditions the two pumps run on alternating days, so as to avoid prolonged rest time, which may cause mechanical issues, when the motor is restarted.

The pumps are regulated by two inverters that control the motor frequency based on the specified hydraulic circuit pressure (monitored by a connected pressure sensor). Basically, the objective is to let the pumps run at optimum efficiency at a lower revolution per minute (rpm). However, if leaks occur along the circuit, the inverters can increase the rpm guaranteeing the system continuously works at the right operative conditions. In the same way, if an obstruction occurs, the inverter can decrease the speed of the motor in order to avoid system overpressure.

Afterwards the seawater moves to the units, via a U-shaped piping route, placed throughout the entire extension of two rows of each clusters. Per each of them, at the entrance, a closing valve is placed to isolate the cluster for maintaining purposes.

Finally, each individual unit is fed via a dedicated inlet system composed firstly by self-regulating micro-drippers, which set the inlet flow rate approximately at 2 L/h. This is a key component, since regardless the inlet flow pressure (ranging between 0.5 and 4 bars), it is able to maintain a constant value of the feeding flow rate. Furthermore, there is a by-pass inlet valve, closed in normal operating conditions; when open it realizes a higher amount of seawater into the unit. It is employed to fill the units, the first day of plant operation, or alternatively, it can be utilized, in case of partial still dry-out, to remove light salt accumulations.

The amount of seawater not entering the distillation unit is piped back into the main seawater tank, closing the loop. Here, a valve enables to regulate the hydraulic circuit pressure, opening or closing it and acting as a shutter for the entire piping route, changing consequently the frequency at which the pumps work. The key parameter is the pressure at the exit of the clusters. It has to be at least 0.7 bars. In this way the minimal pressure to let the self-regulating micro-drippers to work properly is guaranteed. Manometers are placed at the exit of the clusters to properly set this value.

<u>Section C</u>

This section describes the outlet route of the two outputs coming out from the Mangrove Still Units. Once the seawater has undergone the distillation process, freshwater and brine is finally collected. The freshwater is collected by gravity in dedicated tanks. Per each cluster, there is a freshwater buffer tank. Then for the two clusters on the same side, the tanks are connected to a communicating vessel by a pipe of 32 mm in diameter. From there, the freshwater is then pumped to a main freshwater collection tank (500 L), where it is drained by the greenhouse irrigation system, which is directly connected to the freshwater tank. The capacity of the tank is determined from the expected annual average production of 200 L/d and a retention time of at least 2 days. Appling a 20% margin due to the seasonal variations the resulting commercial capacity is of 500 L.

Similar to fresh water, brine is collected by gravity in dedicated buffer tanks, which are connected to each other in the same way as freshwater tanks. From there the brine can be discharged through the RO brine well or, following the ZLD concept as already mentioned, pumped back to the main seawater tank, closing the loop, to be reprocessed by the system. Finally, the brine coming out of the units may deviate from another alternative path. Again, under the ZLD concept, brine, through a 2-way valve installed at the outlet of the unit, can be diverted from the salt mills, where it is collected by gravity to produce salt.

2.1.6.1. Deviations from the design deliverable

The main difference with the deliverable D2.3 is related to the transition from a multi-layer system to a single-level configuration. Having all the units set in parallel instead of both in parallel and in series the layout of the installation was changed, and consequently its hydraulic circuit. Details were also possible thanks to the pilot test, which allowed to identify single components and their materials. Small changes, mainly related to individual components, were also observed during the installation of the system at the HYDRO5 site. Only during the presence on site and with the physical application of all the equipment was it possible to finalize the selection and purchase of components, which were also prone to some technical issues encountered during installation (i.e. pump connections guaranteeing weather tightness). Nevertheless, the general subdivision between the three main sections remained unchanged from the initial design.

Figure 2.5 Detail of the Hydraulic circuit section B

2.1.7. Electrical infrastructure

The electrical infrastructure mainly aims to power and control the equipment embedded in the hydraulic circuit (pumps and inverters) and the salt factories (fans). An appropriate cable was put in place to bring the power from the main electrical cabinet of the RO plant to the warehouse, where the PLANET team installed its own switchboard. From there, cables were then laid to power all the related equipment.

Finally, a programmable logic controller (PLC), see **Figure 2.6**, has been employed for the regulation and supervision of the pumps embedded in the hydraulic circuit. The inserted set of commands deals, mainly, with the switch on/off operations. At present, the regulation is performed through timers, which have been set according to the average filling/emptying times of the different tanks. Certainly, these parameters are variable according to the season and the size of the installed plant, thus for a more flexible and robust regulation, level sensors are installed, so as to regulate the activation of the pumps, directly, when the volume in each tank reaches the upper or lower threshold values.

The actual regulation system is based on an astronomic clock, set according to latitude and longitude coordinates. The seawater pumps run from two hours after the sunrise until two hours before the sunset, although the production time extends slightly more than the operating time of the plant, due to the still thermal inertia.

The filling of the seawater tank from the RO plant well, together with the emptying of the brine tanks during the day, are regulated through programmable relays, that are connected to the PLC. Starting times and operational intervals are adjusted according to the field experience gained. In any case, each device can be turned on and off manually with the respective switchers in the electric cabinet.

2.1.7.1. Deviations from the design deliverable

Electrical estimations at the time of the design deliverable were not possible, so no early infrastructure was defined at that time. The calculations were possible only after the pilot test was carried out during summer 2019 in the north of Italy. However, a real implementation and definition of the electrical infrastructure was only possible once the team was present at the site and the correct and definitive allocation of the equipment was defined. The cable lengths could not be determined before the actual allocation of the pumps within the site.

Figure 2.6 Detail of the installed electrical cabinet

2.2. Analytical technical description of the Productive Greenhouse

The Productive Greenhouse (PGH) is intended to grow tropical fruits, thanks to the control of its internal abiotic factors and being watered by the freshwater produced by the MSS as well as the additional amount produced by the SEG. The PGH, covering an area of 7 m x 28.8 m (201.6 m^2), consists of a Greenhouse Unit Approved Type, according to Greek and European Standards, with the following elements:

- Metallic Framework of approved Greenhouse
- Side Gutters
- Physical Ventilation System, consisting by two 230 V roof openings that will work manually
- Metallic Double doors – two items (2)
- Roof covering by nylon Kritifil TUV 3965, 0.18 mm thickness
- Coating of facades and side surfaces with Fiberglass
- Middle façade with double door covered with Fiberglass

The structure, described as multiple arched Greenhouse type, was made of galvanized steel tubes, and 13 open arches, 7 m width, spaced 2.40 m and with a height side of 2.6 m and a peak height of 3.6 m. The specifics of the context were taken into account in the overall design and selection process of the materials. The PGH has been installed in September 2020 (see **Figure 2.11**). The structure includes an area dedicated for the SEG implementation (Ca. 30 m^2) on its left side, divided by the PGH by a facade with a double door.

2.2.1.1. Deviations from the design deliverable

The design of the installed Greenhouse was defined by July 2019 and was carried out in accordance with Greek and European standards. Based on that, no changes were allowed on the overall structure, but the size, materials and position of the internal dividing door were defined considering the specificities on the local context.

2.3. Analytical technical description of the Saltwater Evaporation Greenhouse

In the Saltwater Evaporation Greenhouse (SEG), the combination of evaporation and transpiration is intended to generate atmospheric moisture, which is converted into usable fresh water by means of condensation. The SEG was designed as a prefabricated kit with the dimensions 700 x 480 x 220 cm side height and 140 cm central ridge height. The foundation used is a point foundation with galvanized steel tubes.

The evaporation surfaces are the water surface in the pond area of the SEG and the free ground surfaces, which are kept moist by the pond water surface and irrigation. In the ground, the saltwater saline water rises to the capillaries and evaporates. To prevent the encrustation of the soil by salt crystallization, water is applied by spray nozzles near the ground at regular intervals. The concentrated saltwater in the pond is pumped off when a critical conductivity is reached, to avoid exceeding the salinity tolerance of the marsh plants. Afterwards, it is refilled with fresh seawater. Halophyte plants (salt tolerant plants) are grown inside the greenhouse because of their ability to take up salty water and by evapotranspiration produce additional humidity and water vapour inside the greenhouse. Some tropical fruit crops next to the salt-water pond also contribute some evapotranspiration humidity to the air. The salt residues in the soil of the pond are flushed out once a week using freshwater. The resulting relative humidity in the warm air at about 25°C of at least 75% relative humidity has a water content of about 17 g/kg air. The water vapour held by the air is harvested from the air by cold traps and condensation nuclei processes. The cold-water condensation traps are cooled by heat pumps: either by a Peltier element or by the compressor of a standard household refrigerator repurposed for this function.

2.3.1. Pond Condenser

The concept of the Pond Condenser is to make use of the simplicity of thermoelectric coolers (Peltier elements) as heat pumps, increasingthe efficiency of thermoelectric cooling and at the same time make use of the otherwise wasted by-product of a heat pump, the heat of the process. The by-product of a Peltier element is the waste heat that must be withdrawn from its warm side. Most commonly, cooling is achieved by passive or active ventilation, but in HYDROUSA project, water is used, which has a much higher heat capacity (especially by volume) than air and the heat can be withdrawn more effectively. The nominal temperature difference that a Peltier module can create between its two sides is an element specific constant. Any reduction of the hot-side temperature also reduces the temperature of the cold-side and increases the efficiency of the aggregate. Therefore, the withdrawal of the excess heat with cool water leads to a higher cooling potential of the Peltier element. In the Peltier condenser (**Figure 2.7**), the cold sides of the Peltier elements are in direct contact with an aluminium heat sink, which in this case has the function of increasing the cold area in contact with air. This (cold) heat sink is encased, and air is blown through the encasing across the cooled heat sink and on its fins water vapour condensates. Once large enough droplets formed, they run down the fins and are eventually collected in a funnel below, by which the condensate is directed into the tipping gauge that measures the water amount.

In the case of the Pond Condenser, the hot side of the plate is cooled via salt-water, which is sourced from the saline pond inside the greenhouse. The water is continuously pumped from the pond through an aluminium block that is in direct contact with the hot side of the Peltier elements. Then, the warm water is directed back into the pond. By this constant inflow, the water temperature of the pond is raised, which is beneficial to the biological activity of mangroves and halophytes in and around the pond, but also the temperature-dependent evaporation from the pond- surface is increased. Hence, the overall evapotranspiration of the SEG is increased and more fresh water can be sourced from the air inside. The freshwater produced is then used for the production of tropical fruits in the conventional greenhouse.

The air inlet is situated about 100 cm above ground, but can be heightened by 25 cm, 50 cm or 75 cm. With some adaptations, it could be extended further or even be directed closer to the ground. In this way, the air layer with the higher potential condensation yield (which is a function of absolute air temperature, relative humidity, convective air currents inside the SEG and dew point) can be accessed. The Peltier condenser is an affordable, simple and small construction with a footprint of only around 0.25 cm or 75 cm. With some adaptations, it could be extended further or even be directed closer to the ground. In this printed elements and a wooden holding structure. The material has a low cost and a small construction has a footprint of only about 0.25 m^2. The total constant power consumption of the system under current conditions lies around 180 W.

Figure 2.7 Example of the Peltier condenser

2.3.1.1. Pond Condenser installation

The concept of the pond condenser is based on the idea to combine two elements that are readily available everywhere (discarded fridge and car cooler), **(Figure 2.8**), to an active condensation unit. The fridge fulfils its function as compressor heat pump that cools a water-glycol mixture, which is pumped through an aluminium-plastic compound pipe spiral inside the fridge. The water is then flowing in a closed cycle through the pond condenser, which is therefore cooled below the dew point. The car cooler offers a high but compact surface for condensation to take place. That condensation surface is shielded from the sun and ambient IR radiation by a roof to enable day and night operation. Air is blown from top through the car cooler; below the unit there is a collecting sheet that diverts the condensate to a water meter and further to a collection container.

The pond condenser is integrated in a way into the SEG that the heat pump (fridge) is working most effectively; hence it is placed outside the GH to enable better cooling of the heat exchanger on the back of the fridge. The rest of the condensation unit is placed inside the SEG. The air inlet is situated about 120 cm above ground, but can be heightened by 25 cm, 50 cm or 75 cm. With some adaptations, it could be extended further or even be directed closer to the ground. In this way, the air layer with the higher potential condensation yield (which is a function of absolute air temperature, relative humidity and dew point) can be accessed. The total constant power consumption of the system lies around 130 W.

The pond condenser system is very cheap and made from components that are readily available in most places, and due to its design, it can operate under most meteorological conditions. As an active system only, it is dependent on external power supply.

After both prototypes have been made fully operational in the SEG, the optimum operation points in terms of 1) Air intake level, 2) Air inflow rate, and 3) Operation times, will be assessed and the two prototypes will be compared against each other and also a commercial dehumidifier.

Figure 2.8 Pond Condenser

2.3.1.2. Deviations from the design deliverable

The whole Saltwater Evaporation Greenhouse (see **Figure 2.9**) is something extra to the signed Grant Agreement. The latter includes the Mangrove Still System and the greenhouse for the cultivation of tropical fruits. The Peltier elements are not integrated into the GH structure, as originally suggested. For reasons of cost efficiency and easy replicability, the GH is a standard construction and including a Peltier-condensation system in them would have made its construction and delivery much more expensive. The Condensation elements are now stand-alone constructions. This also gives the flexibility to place the cold condensation surfaces flexibly at various locations to find the optimal placement based on air flows and relative humidity patterns inside the SEG. Same is true for the compressor-based cooling plates, which are stand-alone movable solutions that have a large funnel design, so that the water collection is integrated.

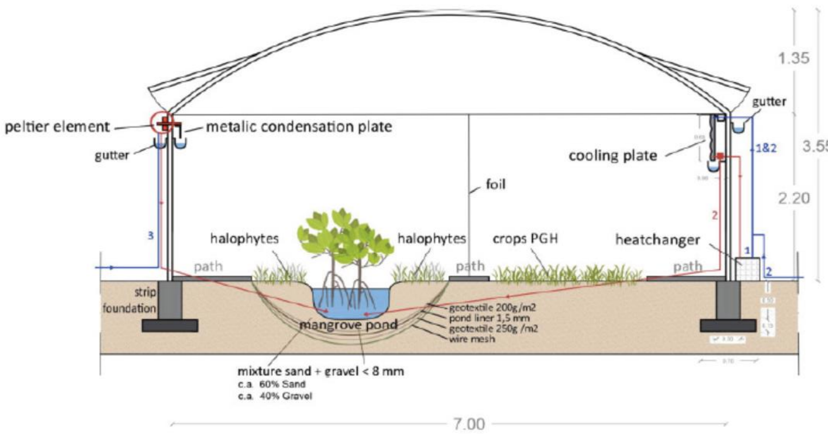


Figure 2.9 The Seawater Evaporation Greenhouse

2.4. List of Drawings as built

In this section drawings and pictures per each system installed at the HYDRO 5 site are reported.

2.4.1. Mangrove Still System: general layout

The general layout reported in **Figure 2.10** aims to represent the schematic view of the system, and how it has been sub-dived. Such approach helps both during the installation and maintenance processes to quickly identify the specific section and/or unit to be replaced/monitored. The system counts 80 modular distillation units (**Figure 2.11**), subdivided as follow:

- The system has been split in 4 main clusters counter-clockwise disposed A-B-C-D. The two halves of the system are divided by a central corridor, 3 m width, where tanks and main hydraulic equipment are allocated. Because of the site conformation, clusters on the left are composed by two rows of 10 units each. On the right hand instead, cluster C is made of two rows of 11 units, including 4 experimental units dedicated for research and development purposes, while cluster D count 2 rows of 9 units each.
- A further sub-division sees the system split in rows from 1 to 8 counter-clockwise oriented. They are reciprocally spaced with a corridor of 0.9 m width, in order to allow the passage of a technician and to have the possibility to easily operate on the units, as well as transport small and mid-size equipment.
- Finally, per each cluster units have been clockwise numbered, following the direction of the seawater flow. Units are instead next to each other and connected by bolts in order to increase the stability of the overall system.

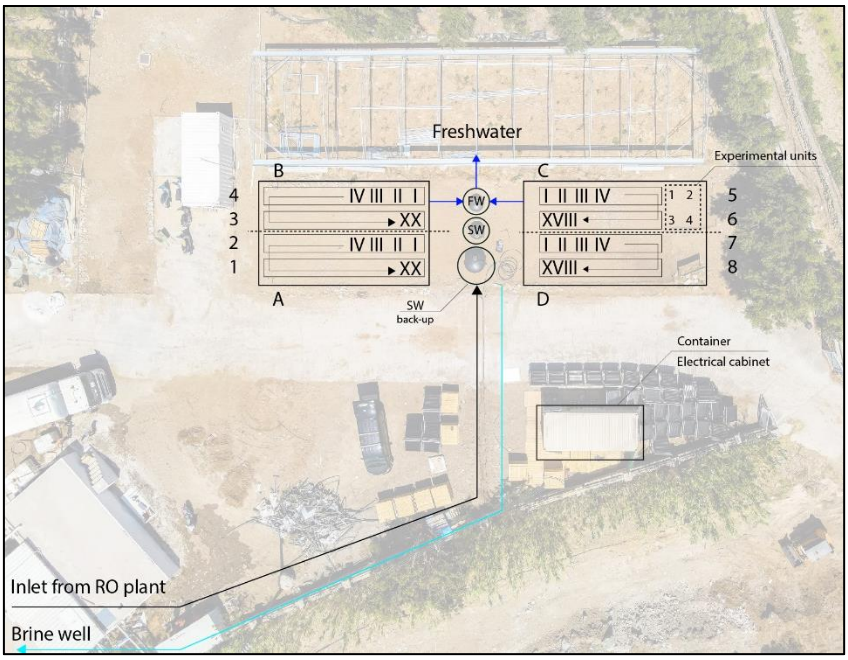


Figure 2.10 Mangrove Still System general layout

Figure 2.11 Mangrove Still System plan view, including the Greenhouse

2.4.2. Mangrove Still System: P&ID

The Mangrove Still System's P&ID is reported on Annex 2.

2.4.3. Productive Greenhouse general layout

The general layout of the greenhouse is reproduced in Annex 3.

2.4.4. Seawater Evaporation Greenhouse general layout

The SEG has an area of 33.6 m²; the location within the premises of the demonstration site is shown in **Figure 2.12**. The SEG is a construction consisting of standard elements, affordable and quick to deploy. It was built on point foundation, which makes the granting of legal permits as well as possible deconstruction much easier. The materials are PP-foil as roofing, galvanized steel as structure and fiberglass corrugated panels as walls, to minimize corrosion and save weight. The flaps on the sides and the roof can be opened with automatic window opening mechanisms.

The central salt-water pond currently is an open water body of approx. 1.5 x 2.5 x 0.75 m, the halophyte growth area is 3.4 x 4.8 m. The soil inside the SEG is a mixture of sand and fertile soil plus some compost. The whole halophyte growth area as well as the pond itself is lined with a thick PE-foil, which lies on top of a geotextile protection layer (250 g/m²). This way the salt-water pond is effectively sealed and has a capillary barrier towards the ground soil, which prevents the salt-water from percolating into the ground.

Large stones are placed into the sides of the mangrove pond so that the land area substrate does not slip continuously into the open pond; the bottom of the pond is filled with fine sand. Due to the evaporation both directly from the water surface of the pond as well as from the soil the salt concentration of the water increases. Therefore, 2 times a week the salt-water of the pond is exchanged with new seawater (automated through timers). A conductivity sensor is applied so that pumping and refilling of the pond with saline water from the sea starts, when the conductivity significantly increases. Due to the fluidization of the sediment in the pond, the pipe diameter used is 1 inch. To avoid salt crystallization in the pond due to water evaporation, saltwater is distributed by spray nozzles near the ground, occasionally sweet water may be used. The shutdown of refilling is done by means of level switch. In the area around the mangrove, halophytes are grown to increase evaporation-transpiration surface by means of the leave canopy. Halophytes have a generally weak transpiration, which is assumed to be about 1-2 L/m². The tropical crop plants next to the pond are anticipated to evapotranspirate more water, up to 5 L/m². The moisture produced in the SEG condenses and is then fed to the irrigation of the conventional greenhouse. The p&Id of the peltier and the pond condensers are presented in Figures 2.13 and 2.14 resptectively. In the SEG the humidity is about 75%. The air then contains about 17g water/kg air, 1 kg air can be equated with approx. 1 m³. The dew point is on average about 19 °C, so temperatures below this level lead to condensation of the water in the cold traps. The aim is to reach approx. 10-15 °C. The amount of condensation is now dependent on the area and the tracking of the moist air on the condensation fins. The SEG is operated in the temperature field of about 20 °C (+/- 5) and 35 °C (+/- 5) for maximum evapotranspiration.

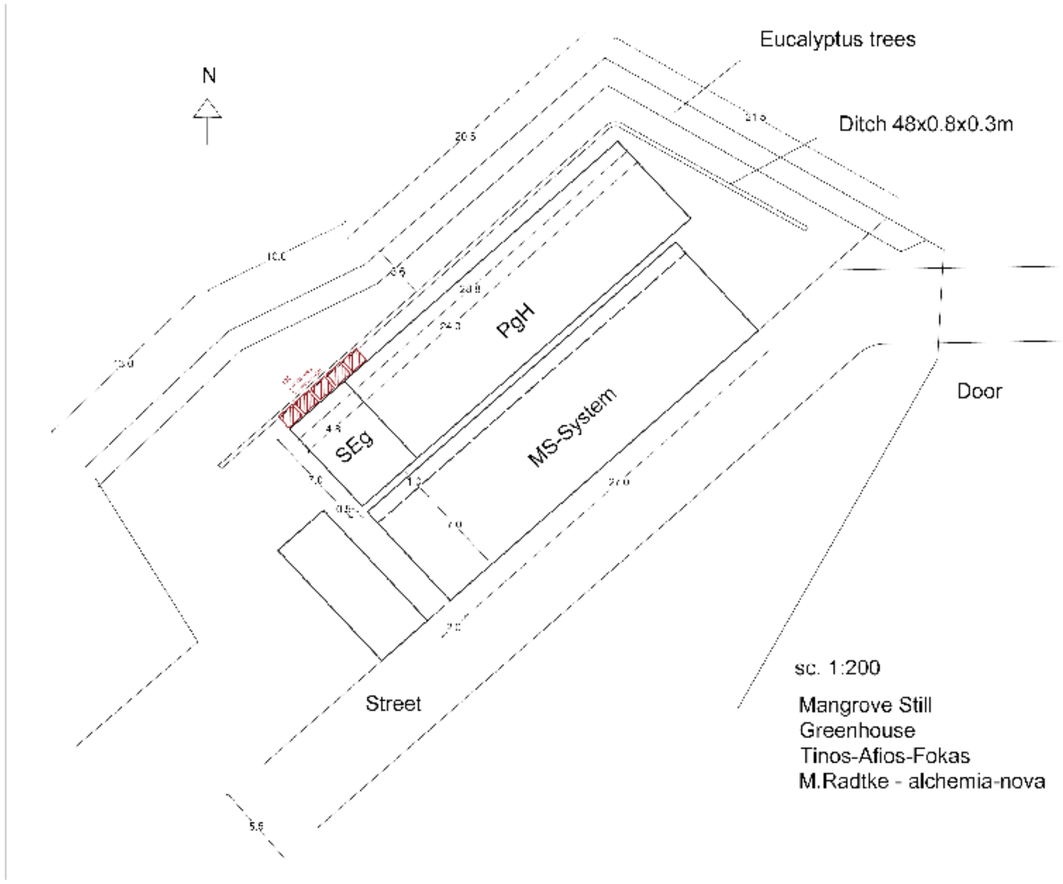


Figure 2.12 General Layout of SEG

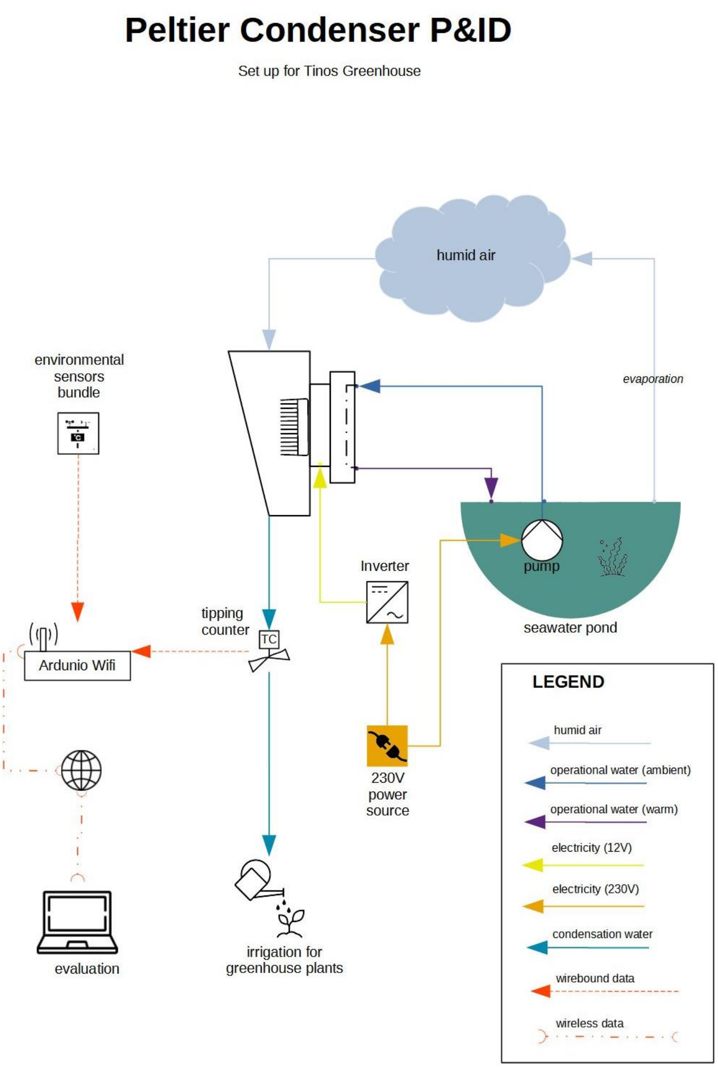


Figure 2.13 Peltier Condenser P&ID

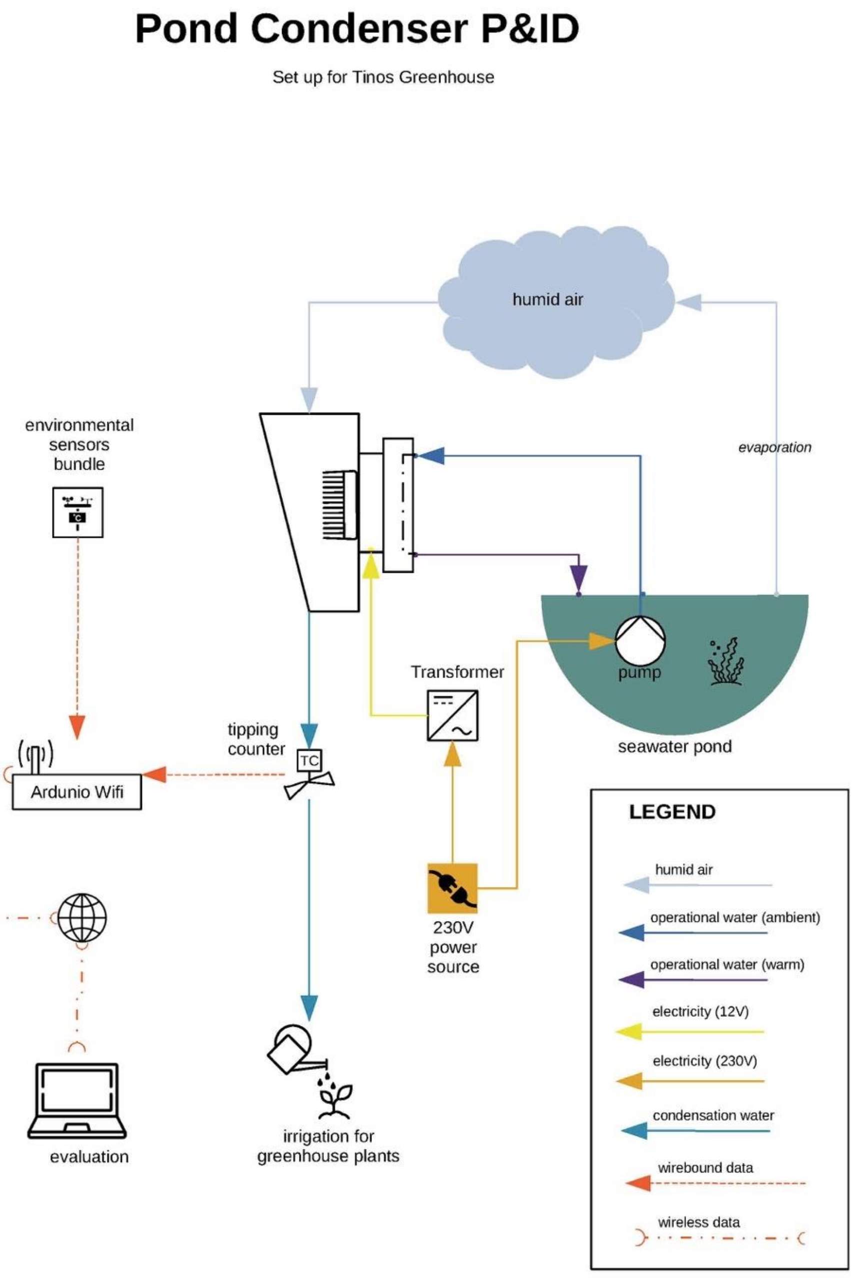


Figure 2.14 Pond Condenser P&ID

3. EQUIPMENT

In this section the main equipment installed within the HYDRO 5 are listed. The chapter is divided according to the three installed systems, namely the Mangrove Still System (MSS) the Seawater Evaporation Greenhouse (SEG) and the Production Greenhouse (PGH).

3.1. Equipment list: Mangrove Still System

In order to facilitate the overview of all the installed equipment, the main components are reported according the sub-categories in which the system can be divided, namely, as already reported:

- Mangrove Still Unit
- Supporting structure
- Salt factory
- Rainwater collection system
- Hydraulic circuit
- Electrical infrastructure

3.1.1. Mangrove Still Unit's components

The Mangrove Still Unit is composed of a main black polycarbonate body, with an approximate size of 1 m^2, manufactured via thermoforming. It is then completed by a glass panel working as a condensation surface, closed upon it by metal profiles. The metal profiles are then fixed on the unit by screws accommodated on threaded rivets mounted on the external perimeter of the unit itself. Seals placed around and at the bottom of the glass, avoid heat and water vapour dispersion. A glass wool panel, placed on the unit's rear part, thermally isolate it from the environment. In **Table 3.1**, a list of the Mangrove Still Unit's components.

Table 3.1 Mangrove Still Units' components list

Equipment	Material	Function
Mangrove Still Unit	Polycarbonate (PC)	Main body
Condensation surface	Glass	Condensate water vapour
Metal profiles	Galvanized metal	Closing the condensation surface
Hydraulic joints	Polypropylene (PP)	Manage inlet/outlet flows
Seals	Polymeric rubber (Neoprene)	Avoid thermal and water vapour dispersions
Thermal insulation	Glass wool	Thermally isolate the unit from the environment
Bolts	Metal	Fasten the hydraulic joints and the metal profiles

3.1.2. Supporting structure's components

The supporting structure (see **Figure 3.1**) is composed by galvanized metal slotted L-profiles, in only three different lengths according to their position and function within the unit, joined together by stainless steel bolts. The extreme conditions of Tinos Island (constant and strong wind with gusts up to 40 knots) required then the implementation of three extra-systems in order to create an integral wind-resistant frame:

i. aluminium square-tube bases,
ii. metal pales fixed at the ground
iii. connecting elements between the supporting structures

Below, in **Table 3.2**, the list of the supporting structure components is presented.

Table 3.2 Supporting structure components list

Equipment	Material	Function
Slotted L-profiles	Galvanized metal	Composing the structure, providing structural support and accommodating the functional modules
Pales	Metal	Fixing the structure at the ground
Square sized profiles	Aluminium	Providing integral frame base
Bolts	metal	Joining together profiles and the different sub-systems

Figure 3.1 Assembled supporting structure detail

3.1.3. Salt factory's components

The salt factory is one of the functional modules that can be implemented into the supporting structure. It is composed by an aluminium tray of 0.8 m^2, 4 fans and protecting panels. Below in **Table 3.3**, the list of the components of the salt factory is presented.

Table 3.3 Salt factory component list

Equipment	Material	Function
Tray	Aluminium	Containing brine and salt
Fans	Aluminium	Increasing brine evaporation rate
Protecting panels	Polymer (SAN + PP)	Protecting the trays from dirt and channelling the air from the fans
Bolts	Metal	Joining the fans and the panels at the supporting structure

3.1.4. Rainwater collection system's components

The rainwater collection system (see **Figure 3.2**) is another functional module that has been added to the supporting structure. It is made of white plastic U-profiles commercially available, the related supports and a plastic mid-mesh. In **Table 3.4** the components of the rainwater collection are presented.

Table 3.4 Rainwater collection component list

Equipment	Material	Function
U-profiles	Polymer	Collect and channel the rainwater
Supporting elements	Polymer	Support the U-profiles and connect them with the supporting structure
Mesh	Plastic	Filtering big-size solids (leaves, small branches, etc.)
Bolts	Metal	Joints the supporting elements to the structure

Figure 3.2 Assembled rainwater collection system detail

3.1.5. Hydraulic circuit's components

The hydraulic circuit of the Mangrove Still System consist of few main components, namely tanks, pumps and inverters (see **Figure 3.3** and **Figure 3.4**). All the other components can be generally defined as auxiliaries and are reported in Table 3.5 according to their main function.

Figure 3.3 Assembled components for Unit's feeding

Figure 3.4 Seawater pumps for the feeding of the system

Table 3.5 Hydraulic circuit components list

Equipment	Material	Function
Tanks	Polymer	Collecting seawater, brine and freshwater
Pumps (for seawater and brine)	Stainless steel 316L	Pumping seawater as a feeding flow for the system and brine as an outlet of the system
Pumps (for freshwater)	Metal	Pumping freshwater as an outlet of the system
Inverters	Polymer	Regulate the frequency of the pumps feeding the units
Manometers	Metal	Measuring the pressure
Hydraulic joints	Polymer	Manage inlet/outlet flows
Pipes	Light Density Poly Ethylene (LDPE)	Flows circulation and seawater pre-heating
Valves	Polymeric and metal	Regulating and deviating flows, isolating clusters
Filters	Polymeric and metal mesh	Filtering small size particles (mesh 130 micron)

3.1.6. Electrical infrastructure

Table 3.6 Electrical infrastructure's component list

Equipment	Material	Function
Electrical cabinet	Polymer	Containing and protecting electrical equipment
Wiring		Equipment powering
Switchers		Equipment on/off
PLC		Programming equipment activations
Energy meter		Monitoring consumes
Inverter		Pumps management

3.2. Equipment list: PGH

Table 3.7 Equipment list of PGH

Equipment	Material	Function
Frame	Galvanized steel	Structural
Film	Nylon	Roof covering
Panels	Fiberglass	Facades surface covering
Engines		Windows opening

3.3. Equipment list: SEG

Table 3.8 Electric feature of Pond Condenser

Component	Type	Amount	Nominal power consumption per unit [W]	Nominal power consumption [W]
Peltier element	TEC1-12706	4	72	288
AC/DC Power supply	12V, 550W	1	3	5
Pond pump	Eheim 1250	1	28	28
Fan	Pure Wings 2 12V 80mm fan	1	1.68	1.68
Small AC/DC Power supply	Goobay 3V 12V Universal Power Supply	1	0	0
			Total	320.68

Table 3.9 Electric feature of Peltier condenser

Component	Type	Amount	Nominal power consumption per unit [W]	Nominal power consumption [W]
Water pump	12 V membrane pump	1	15	15
Fridge	2nd hand household fridge	1	120	120
Fan	Pure Wings 2 12 V 80 mm fan	1	1.68	1.68
Power supply	12 V. for fan	1	10	10
			Total	146.68

3.4. Operating manuals: Mangrove Still System

In this section the operating manuals for those components that require specific operating instructions are provided. Not all of them require a particular management; nevertheless, general guidelines for an appropriate use and installation, avoiding risky situations and damage of the components are reported. Further guidelines are reported in Section 3.5. As for the previous sections, the descriptions are reported according to the main sub-categories identified in the Mangrove Still System.

3.4.1. Mangrove Still Unit's operating manual

The Mangrove Still Units is an independent passive device, which bases its operation on gravity and the natural process of evaporation and condensation triggered by solar irradiation. This means that no chemicals are involved in the production process of freshwater. Based on this, the Mangrove Still Unit does not need particular operating manuals, indeed once assembled, installed upon the supporting structure and connected to the hydraulic feeding circuit; the unit can run without further intervention. However, it is recommended to carry out weekly checks to ensure its general good maintenance, paying particular attention to the condition of the condensation surface and the salt crystallization.

The condensation surface may need external cleaning due to the deposition of sand and dirt. In case of damage, replacement with a new glass panel is required. The operator must wear appropriate personal protective equipment (e.g. gloves) for this activity. The salt crystallization is a phenomenon that naturally occurs within the units as a consequence of the evaporation process. Its severity depends on the dry state of the unit and might vary from light depositions to solid salt crystal formation. The former is generally a sign for a too low feeding flow rate, which might derive from obstructions at the inlet (i.e. occlusion of the self-regulating micro-dripper). In case of salt crystallization, according to its severity, the operator can proceed in two different ways:

- Opening the by-pass circuit, increasing the seawater feeding flow in order to remove the deposited salt, leveraging both on flow energy and dilution (it is recommended to be performed once per month)
- Closing the inlet flow via the dedicated unit inlet valve, removing the condensation surface and operating a manual cleaning of the unit (recommended every 6 months). A cleaning or replacement of the micro-dripper may be necessary

The proposed time was derived from a first estimate made during the installation and operation period between July and October 2020. Further detailed information will be gathered on its future operation. Among the components of the Mangrove Still Unit's the condensation surface needs particular attention. It is made of glass and relatively heavy, the operator must always wear appropriate work gloves and safety shoes during its handling.

3.4.2. Supporting structure's operating manual

The supporting structure is composed of galvanized metal slotted L-profiles, joined together by stainless steel bolts. Once the structure is assembled and put in place, thanks to its characteristics, it allows for the implementation of the different functional modules (desalination unit, salt factory and rainwater collection system). Operations related to its installation and maintenance, as well as for the Mangrove Still Unit, during the normal operation of the system, no intervention is required.

The assembly of the structure involves the clamping of the profiles with bolts by means of screwdrivers. Once prepared, the structure is then posed and secured at the ground, fixing it on a long square profile and with pales dag into the soil, creating an integral wind-resistant frame. Slight adjustments, possible thanks to the slots present along the profiles, allow the technician to compensate small ground irregularities and confer the right inclination to the different functional modules. Operators must wear proper personal protective equipment when assembling and handling the supporting structure.

Despite the selected material for the supporting structure, which is considered a valid choice in terms of cost and durability, the manual functions for its assembly and installation (causing scratching) along with the sand and the salty environment that exists in the space and the galvanic effect due to coupling with other metals, a post-process of rust-converter and priming is required, see **Figure 3.5.,** especially at the most susceptible points, to ensure and extend the lifespan of the structure.

Figure 3.5 Rust converter and priming treatment

3.4.3. Salt factory's operating manual

The salt factory is aimed to produce salt and is composed by a tray, fans and protective panels, and all of them can be implemented on the supporting structures. Fans and protective panels, specifically, are installed during the assembling of the structure, whereas the tray is inserted directly on the site. Fans are then lastly connected to the electrical infrastructure.

In order to launch the salt production, the operator needs to:
i) Open the two-way valve put at the exit of the units, in order to deviate the brine flow, from the collection pipe to the tube directed towards the salt factory. In this way brine will be collected inside the tray. The complete filling of the plate will take almost 2 operative days (ca. 20 hours)
ii) Turn on the fans by the opposite switches allocated within the electrical cabinet.

During its functioning no interventions are required from the operators, but for checks on its status, which can be done every 2-3 days. The salt production process, based on early calculations and the first operation period, requires 10 days, with fans constantly active for 24 hours. At the end of the process, when the major part of the brine has been evaporated, the operator can turn off the fans and extract the tray. At that point the salt can be removed by a spatula. Finally, a washing post-process with brine to remove dirt and a drying process under the sun is required.

3.4.4. Rainwater collection system's operating manual

The rainwater collection system is composed by U-profile ducts, the related supporting structure and plastic mid-mesh filter. During the installation the operator needs to pay attention that the tilt angle guarantees a smooth flow of the water towards the exit. No further operations are required, but weekly checks to its status. Maintaining operation includes the cleaning of the filter to remove possible leaves, small branches, insects or other materials blown in by the wind.

3.4.5. Hydraulic circuit operating manual

The hydraulic circuit supports the overall Mangrove Still System functioning, as it manages the inlet and outlet flows and its operating manual is mainly related to the setting of the pumps and inverters. Its functioning is also strictly related to the electrical infrastructure. The description below will follow the three sections into which the circuit is divided.

Section A

It describes the inlet section from the desalination plant to the Mangrove Still System, in particular to the seawater collection tanks. The main equipment consists on the Seawater pump, which sucks the seawater from the RO plant well, and the communicating vessels system between the main and back-up seawater tanks.

Regarding the pump, during its launching, the operator needs to pay attention on its priming, making sure the suction pipe is completely full of water. No operations are required during its normal running, but checks to its status and to the connected filter at the entrance, which requires to be cleaned every 6 months. The pump functioning is regulated through a programmable relay, connected to a PLC within the electrical cabinet. Starting times, as well as intervals when the tank needs to be refilled, have been set according to the gained on-field experience. In any case, the device can be turned on and off manually with the respective switch in the electric cabinet. Its automation, under the WP5, includes the presence of seawater levels installed into the main seawater tank.

Moving to the tanks instead, the implementation of a back-up vessel was required due to the treatment with sodium hypochlorite that time by time the local RO plant executes in order to clean the RO membranes. In order to avoid that such chemicals affect the Mangrove Still System, before the cleaning treatment, the back-up tank needs to be filled completely, manually opening the closing valve at its entrance. At that point the seawater pump can be disconnected, turning off the related switch. The tank is then connected as a communicating vessel to the main tank, where the seawater is pumped to the MSS. Thanks to its capacity of 1500 L, it is set to store seawater and serve the MSS for at least 2 days.

Section B

It describes the hydraulic section from the tanks to the Mangrove Still Unit's entrance. The main equipment is the pump group that is responsible for the system feeding. It guarantees the seawater distribution and works alternately in order to increase the system robustness in case of malfunction of one device.

In normal operative conditions, the two pumps run on alternating days, to avoid a prolonged resting time that may cause issues with restarting the motor. The pumps switch logic is controlled by the PLC, based on an internal configurable calendar. The operator can control on which days to turn on/off the two pumps. Their activation time is on the other hand controlled by the PLC internal programmable clock, based on an astronomic time set thanks to geographical coordinates. The system running time foresees the pump activation 2 hours after the sunset and their stop 2 hours before the dawn. Thanks to the astronomic clock, this interval is automatically set with the daytime.

In the case of malfunctioning, the pumps switch logic is still controlled by the PLC, but is based on the pressure measured by the inverters. Each pump is in fact regulated by an inverter, which control the motor frequency according to a series of set pressure values, monitored by a connected pressure sensor and placed along the pump delivery.

A pump malfunctioning may cause an issue with the seawater adduction, meaning no (or too small) flow rate is pumped into the circuit. Consequently, the inverter detects a low-pressure value. In the case it goes under the minimum pressure value set on the inverter control panel, it automatically turns off the pump. After some attempts to restart the device, if no pressure is still detected, the inverter sends a signal to the PLC, which based on the set programme, switch the system to the second pump.

In the case, an obstruction should occur along the pump delivery section, the inverter detects an increase of the pressure value, and starts to reduce the motor frequency for maintaining the pressure at the desired set level. This value represents the desired hydraulic circuit pressure and is set according to the minimum pressure value necessary at the entrance of the units, to let the self-regulating micro-drippers work properly.

The pressure value at the entrance of the unit, as mentioned, is imposed by the self-regulating micro-drippers and according to the technical data sheet, such device properly works in a range between 0.5 and 4 bars. It means that in the furthest point of the system (from the pump group), the minimum pressure value required is 0.5 bar. That is why a manometer has also been installed at the end of the section B, to control indeed, that enough pressure is guaranteed on every micro-dripper.

To set this value, a proper regulation of the shutter valve installed at the end of the closing-loop pipe is required. The optimal regulation will allow to have the required minimum pressure and to reduce the frequency at which the pumps work, avoiding device overstressing.

<u>Section C</u>

This section describes the outlet route of the two outputs coming out from the Mangrove Still Units. Once the seawater has undergone the distillation process, what is collected at the end are freshwater and brine. Both of them are being collected in the corresponding buffer tanks by gravity; no interventions are required from the operator during the normal running of the system. To guarantee a proper collection, the technician during the installation phase needs to pay attention on the tilt angle of the collecting pipes, in order to allow a smooth flow of the fluids.

Regarding the freshwater, it is then pumped from the clusters A/B and C/D, to a main freshwater collection tank (500 L), from where it is drained by the greenhouse irrigation system. The corresponding pumps are activated by the related switches.

The brine, as already described, can be discharged, back-pumped to the seawater tank or collected in the salt factories. For the latter, operations have already been described in section 3.4.3. Unlike for the freshwater section, only one pump manages the brine's outlet circulation from all the four clusters. Operators may decide to allow the brine to discharge or deviate the flow back to the seawater tank by closing / opening the respective valves placed on the brine pump delivery section.

The emptying of the brine tanks, during the day, is regulated through programmable relays, connected to the PLC. Starting times and operational intervals have been set according to the gained on-filed experience. In any case, each device can be turned on and off manually with the respective switches in the electric cabinet. As for the freshwater circuit, sensors installed into the tanks, allow to automatically regulate the pump activation based on the monitored brine level.

3.4.6. Electrical infrastructure operating manual

The electrical infrastructure, power and control the hydraulic equipment and its installation has been carried out by a professional technician. Operations are related to the manual activation of the switches, according to the needs described in the hydraulic section.

The PLC programme includes:
- Seawater pump activation for the seawater tank filling (hydraulic section A): Starting times and operational intervals have been set according to the gained field experience. In any case, the device can be turned on and off manually with the respective switcher in the electric cabinet.

- Seawater pumps activation for the system feeding (hydraulic section B): Starting and stop time have been set through the astronomical clock, from two hours after the sunset to two hours before the dawn.

- Seawater pumps alternating (hydraulic section B): The pumps alternation has been set thanks to the PLC internal calendar.

- Seawater pumps switching (hydraulic section B): Pumps switching, in case of malfunctioning, is controlled by the inverter. The inverter sends a signal to the PLC based on which it performs the switch.

- Freshwater pumps activation (hydraulic section C): These pumps are actually manually activated by the corresponding switches.

- Brine pump activation (hydraulic section C): Starting times and operational intervals have been set according to the gained field experience. In any case, the device can be turned on and off manually with the respective switcher in the electric cabinet.

3.5. PGH Operating manuals

The Tinos production greenhouse with tropical plants was finished and planted at the end of summer of 2020, in a window of opportunity when travel restrictions and wind conditions on the island made this possible. The main water buffer tank of the GH is fed with tap water from the desalination plant and also from rainwater run-off of the GH roof itself. A floater-controlled valve in the tank makes sure that a minimum of irrigation water is always available in the tank.

Through gravity this irrigation water reaches a pressure booster pump. This pump is set to always provide approximately 3 bars of water pressure to an "off-the-shelf" irrigation control unit (Gardena system). This timer-based irrigation control opens the irrigation 2 times per day, once in the early morning and once in the evening for 8 minutes. When the control system of the pump notices a drop in the pressure of the system then the watering unit opens the valves, the pump automatically starts running and feeds enough water to the drip irrigation hoses. The water flows and irrigation time has been calculated based on the average water output of 4 random drippers within the existing system configuration measured twice. The current water output is 200 L per day for the whole GH.

Currently, the system that feeds the condensed water of the Mangrove Still system to the GH is being readied and will be in full operation in early 2021. At this time also a custom soil-moisture based irrigation control system from AGENSO will be implemented to deliver a more precise amount of water to the plants, bypassing the existing timer based solution.

4. CONSTRUCTION AND START-UP

This section presents an analytical description of the construction and installation processes, including the development challenges and the solutions provided. The first sections focus on the installation of the Mangrove Still System and the PGH and SEG together, since implemented within the same structure. The last two sections present respectively the start-up and operation manual of the whole HYDRO5 demonstration site.

4.1. Mangrove Still System: construction and installation process

The construction and installation process of the Mangrove Still System can be split in 5 main steps, described below.

Phase I: site preparation

The first step occurred once the PLANET team arrived at the site and was to organize all the shipped materials and components (**Figure 4.1**). Afterwards, the area where the Mangrove Still System was to be installed, was demarcated through green poles fixed into the ground and remarked by red and white strips as show in **Figure 4.2**. This allowed signalling the presence of ongoing works and to identify the right allocation of all the equipment and define the system layout (see 2.2.1 Mangrove Still System: general layout).

Before proceeding with the actual installation of the system, soil levelling was required. To work properly, the system needs to be placed in a horizontal position and in order to compensate small ground inclination and hollows, the supporting structure has been conceived to compensate such irregularities. However, the slots present along the metal profiles only permit slight adjustments, while the site at the moment of the PLANET team arrival was characterized by the presence of several rocks and an inclination estimated to be around 3-5%. Based on this, the PLANET team in agreement with the other partners decided to proceed to a ground levelling.

Also, the allocation for the passage of the electrical cables and hydraulic pipes was identified in agreement with project's partners and the RO plant company (**Figure 4.3**). These operations were required due to the general layout of the site. The main electrical cabinet from where the power for all the system is provided, as well as the seawater RO's well, were on the opposite side of the area dedicated to the MSS.

Figure 4.1 Planet team at work organizing materials and components for the MSS construction

Figure 4.2 MSS' perimetral area delimitation

Figure 4.3 Works for the soil flattening and concrete drilling

Phase II: electrical infrastructure installation

The second relevant phase carried out at the site concerns the installation of the electrical infrastructure. This phase is part of the overall preparation of the site and is functional to the connection and powering of the equipment, as pumps and fans, and their controlling/monitoring.
The activities, performed by local technicians, included:

- Posing cable from the RO's main electrical cabinet to the warehouse for the supplying of 10 kW;
- Wiring of the warehouse's electrical cabinet (**Figure 4.4**);
- Posing cables from the warehouse's electrical cabinet to the corresponding equipment (**Figure 4.5**)
- Electrical equipment connection

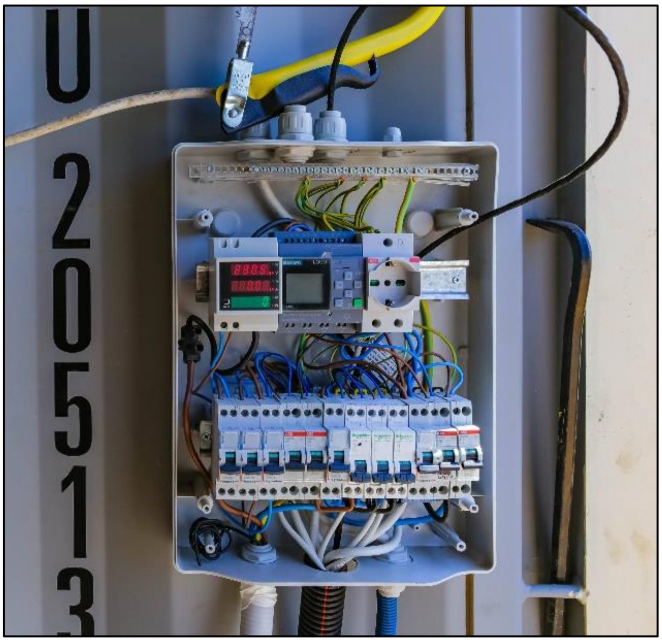


Figure 4.4 Warehouse's electrical cabinet wiring

Figure 4.5 Technicians at work for the electrical infrastructure installation

Phase III: Mangrove Still System installation

This phase consists of assembling and installing the support structure and the three functional modules: i) Mangrove Still Unit, ii) Salt factory iii) Rainwater collection system.
Pictures below show some steps of the installation (**Figure 4.6, Figure 4.7, Figure 4.8 and Figure 4.9**).
The main challenges were due to two factors:

- Site conditions
- Wind

The first, causing difficulties on setting the different elements at the right tilt angle, was initially tried to be solved by PLANET, through the modification of the supporting structure and the application of additional elements. It was solved by appropriate levelling of the land.

The strong wind blowing in a North-South direction was a challenge for the stability of the system. The lightness of the structure and the functional modules, achieved to optimize the use of materials and the shipment-related costs, was a compromise in terms of overall stability. Nevertheless, not all the countries where the Mangrove Still System can find application are subject to such extreme weather conditions (constant wind with gusts up to 40 knots). In the specific context of HYDRO5, in order to create an integral wind-resistant frame, three sub-elements were added to the supporting structure:

- Square-tube base, connecting the front and rear of six supporting structures in once
- Poles fixed at the ground
- Bolts transversally connecting the supporting structures

The overall Mangrove Still System installation proceeded with the construction of one cluster per time. This gave the opportunity to step by step optimize the operations and understand the correlated issues, improving the required time demand for their implementation. Furthermore, and more relevant, this logic allowed for hydraulic testing the clusters once they were finalized.

Figure 4.6 Planet team at work for the MSS assembling

Figure 4.7 Unit's inlet assembling

Figure 4.8 Unit's sealing

Figure 4.9 PLANET team at work for the MSS installation

Phase IV: Hydraulic circuit installation

This phase foresaw the proper positioning of the main equipment and connection of all the hydraulic components. Detailed hydraulic schemes allowed to proceed step by step towards the installation of the three sections. Minor changes on configuration and purchased parts were required to conform to the site's specific characteristics. **Figure 4.10** and **Figure 4.11** show some steps of the installation. The main challenges faced by PLANET were:

- guaranteeing watertight connection to the pumps, solved with the use of canopy and sealing paste;
- setting of the hydraulic circuit pressure, set after testing all the system;
- pump activation management, solved with the installation of a PLC

Figure 4.10 Hydraulic circuit installation

Figure 4.11 Pump and inverter testing

4.2. PGH/SEG construction and installation process

The planning of the greenhouse was guided by the following considerations: available space, achieve affordable price points, easy replicability and use of simple components to make it attractive for a wide range of possible adopters. The initial goal was to finish the greenhouse in the spring of 2020 (around April). The tropical plants as well as the halophytes for the SEG pond were ordered with proper anticipation (from a nursery in Crete) (**Figure 4.12).** The fact that this demo site is located in Tinos meant that there was quite a complexity in organizing all the logistics for material transports, coordination with suppliers, etc.

From the 13th to 18th of February 2020 a ditch lined with a PP plastic foil was placed along the Eucalyptus tree lines on the North and East facing sides of the terrain. This was done to prevent the roots from the Eucalyptus trees from invading the irrigated soil of the GH and deprive the water and nutrients meant for the tropical crops. The trees were also cut back partially to avoid shading on the GH and also avoid the risk of branches falling or scratching against the GH because of wind. At this time, compost and soil amendments and fertile top-soil was added to the GH cultivation area. The improved substrate reached a depth of about 40 cm. This work was organized by the municipality partner (TINOS) and partially involved heavy machinery for digging and transport (**Figure 4.12,**

Figure 4.13**, Figure 4.14 and Figure 4.15**).

Unfortunately, the lockdowns caused by the COVID-19 pandemic meant that all works in the later spring of

2020 had to be postponed. After the lock-down was lifted, the fundaments of the GH could be constructed. The greenhouse contractor then had the difficulty that the strong prevailing winds on the island of Tinos during summer made the construction of the GH tricky. A proper time with several days of low wind occurrence had to be observed and flexibly be taken advantage of. This happened in the first half of September, almost simultaneous to the days when the plants were delivered from Crete and the planting works started almost immediately after the GH finished (**Figure 4.15**). In fact, some parts of the GH, like the doors, were finalized while the first plants were already being planted inside the GH. Once all components of the SEG were on site, the construction itself lasted about 3 days with 4 persons. The production of the condensation solutions, the procurement of all components and plants as well as the planning itself took much longer than that, several weeks for a number of different experts.

Figure 4.12 Evaporation Pond (left), tropical plants irrigated (right)

Figure 4.13 Plastic foil lined ditch to prevent roots from adjacent trees to grow into the GH

Figure 4.14 Fertile top-soil and compost added to the GH cultivation area

Figure 4.15 Final stages of the SEG construction phase, with the MSS construction in front

4.3. Start-up

Between March 2019 and October 2020, a multidisciplinary team of experts from the partners involved worked on prototyping and testing the concepts as reported in Deliverable 2.3 and finally produced and installed the technologies in Tinos Island to achieve the foreseen KPIs (70 m^3/year freshwater production from saltwater/brine, 700 kg/year recovered salt, and production of tropical fruit (1.5 tons)).

Delays in installation compared to the original working plan are due to COVID-19 restrictions and the necessary health and safety measures imposed by countries in 2020.

The Mangrove Still System installation was finalized by the end of September. The system was constructed according to the logic of independent-clusters: every time the PLANET team had completed one of them, it was consequently tested and activated, to then pass to construction and installation of the subsequent cluster.

It follows that the start-up of the MSS proceeded step by step with its installation (**Figure 4.16, Figure 4.17** and **Figure 4.18**). The whole logic of its activation follows the points below:

- Seawater tank filling, via the dedicated hydraulic circuit section A. It sucks up seawater from the identified point at the Reverse Osmosis plant;
- Desalination units feeding, via section B of the hydraulic circuit. Here the evaporation/condensation process takes place and brine and freshwater flow out from the system;
- Brine and freshwater are collected in the buffer tanks and from there managed thanks to the hydraulic circuit section C. Brine can be pumped back to the seawater tank, closing the loop, or otherwise discharged to the Reverse Osmosis's disposal well. The freshwater instead is pumped to the main freshwater collector.
- The salt factory is activated by deviating the brine flowing out from the units, through the 2 ways-valves. Once filled the trays, the fans are switched on, starting the salt production process.

The freshwater collected at the end of the MSS, is then pumped to the collector next to the PGH, where thanks to dedicated pumps, is used to irrigate the tropical plants.

During October 2020 the system worked for a trial period of 20 days. In this time-window different tests were performed in order to: i) stress the different sections of the hydraulic circuit and evaluate its water-tightness ii) evaluate the interdependence of the clusters (closing them in turn) iii) evaluate salt crystallization related issues iv) preliminary evaluate the freshwater production.

The system showed a good structural integrity and a preliminary freshwater production of an average of 1.4 L/day per unit, with a peak up to 2.05 L/day. Such production, which we expect would decrease during November and December, is in line with the freshwater production estimation during the winter period (0.9 L/day), reported in the previous design report. We are therefore confident the estimation is also correct for the summer period and more broadly for the annual average. Considering the number of installed units, this would allow to get really close to the target KPI of 70 m^3/year just with the installed units, and therefore without considering rainwater collection.

During the running period we have also tested the salt factory, with a first salt production (**Figure 4.19**), which will be analysed in order to evaluate its quality and consequently understand its possibly final uses. Moreover, during the system start-up and running, we identified minor improvements as valves location, hydraulic circuit connections and inverter management for optimize the overall system.

Figure 4.16 Second cluster installed (2 out of 4)

Figure 4.17 Three installed clusters (3 out of 4)

Figure 4.18 Mangrove Still System complete

Figure 4.19 Salt production process and collection

5. CONCLUSIONS

The HYDRO 5 demonstration site, part of a broader European project named HYDROUSA, aims to demonstrate the capability of nature-based technologies to produce freshwater from non-conventional water resources, specifically seawater, and to supply it for agricultural purposes and effectively deal with its current unsustainable water consumption.

In order to accomplish this goal, three technologies have been installed in Tinos Island (Cyclades Archipelago, Greece), next to the local Reverse Osmosis plant, between July and September 2020, which include:

- The **Mangrove Still System.** A PLANET-owned bio-inspired desalination system, capable to produce freshwater and salt from seawater, leveraging on a passive distillation process triggered by sun irradiation. It consists of 80 configurable desalination units (Mangrove Still Units) connected in parallel and fed by a dedicated hydraulic circuit.

- The **Productive Greenhouse** to grow tropical and local crops. It occupies an area of 200 m^2, which includes 100 m^2 for the actual plant cultivation and 30 m^2 for the SEG implementation, and consists of a Unit Approved Type, according to Greek and European Standards. The crops are watered via a dedicated irrigation system, using the freshwater produced by the MSS and the complementary production from the SEG.

- The **Seawater Evaporation Greenhouse.** A nature-based integrated system, which utilizes plants tolerant to salinity (halophytes) to extract fresh water from seawater via evapotranspiration and condensation leveraged on Peltier elements.

The three technologies, designed according to the specific characteristics of the site, aim to achieve the following defined target goals (KPIs): i) production of 70 m^3/year of freshwater from saltwater/brine, ii) 700 kg/year recovered salt and iii) grow of 1.5 tons of tropical fruit.

Following some days of operation of the plant during October, despite the sub-optimal weather conditions (shortening of daily light and rains), the Mangrove Still System already showed the strong potential for achieving the KPI for freshwater. However, for freshwater, salt production and agricultural yield, longer time of operation is needed to confirm the achievement of the related KPI.

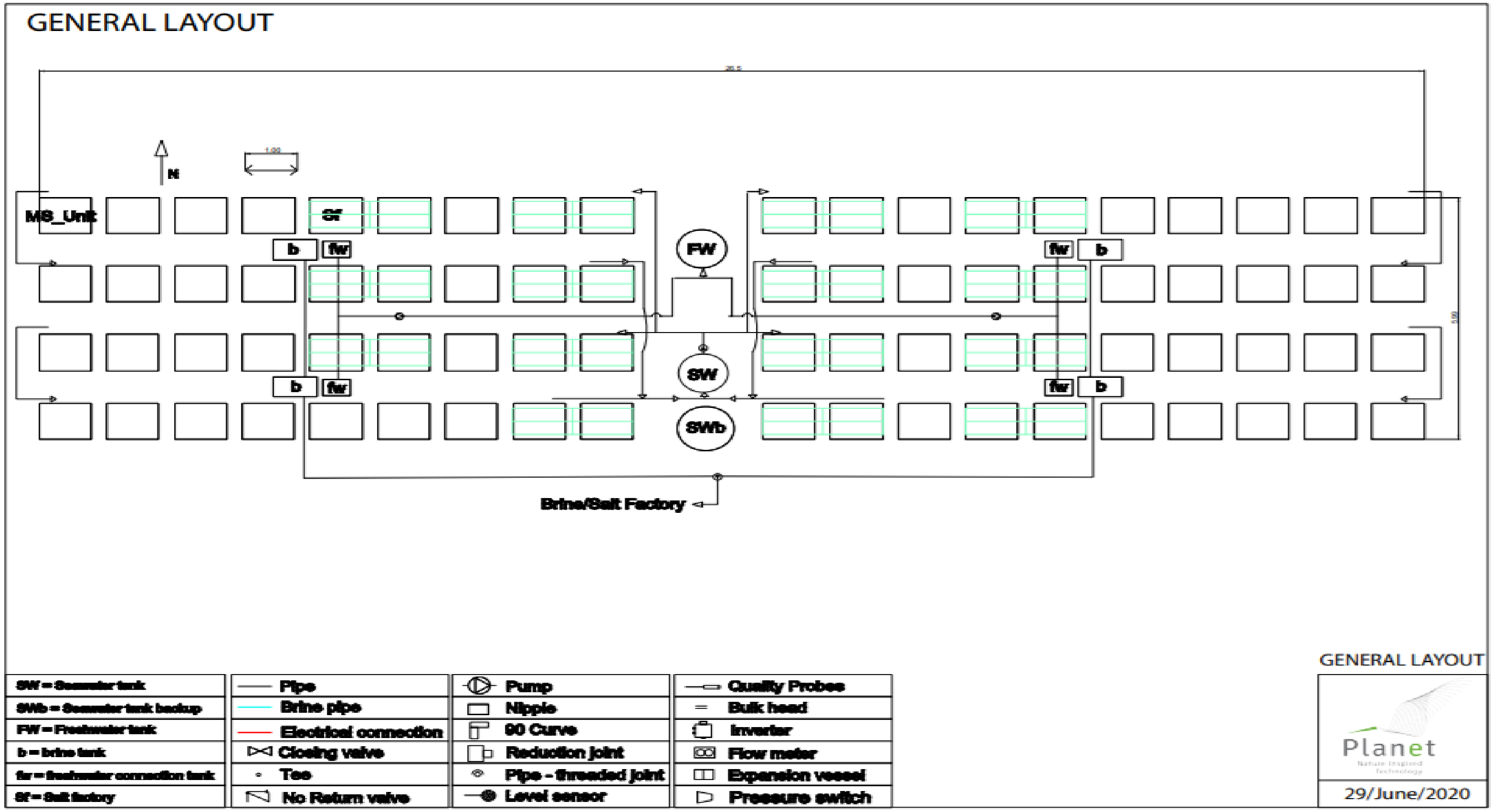
Regarding the salt recovery, HYDROUSA partners works towards the identification of local businesses able to handle and valorize the daily salt production.
Following a series of interviews in Tinos Island, some companies have already shown interest in the salt/brine produced by the MSS, operating on businesses such as:

- Dairy products production: both salt and brine can be utilized to regulate the saltiness of cheese;
- Food production: salt and brine could be used to preserve pickled vegetables.
- Cosmetics production: salt crystals can be utilized for aromatic skin scrubbers creams and for baths

The project increased awareness for considering salt as well as brine as a resource for local products. In Tinos Island, brine was never considered a potential good quality raw material for producing cheese or pickles. Likewise, dry salt produced locally could be utilized to develop cosmetic products.

6. ANNEX

Annex 1: Mangrove Still System Hydraulic Circuit



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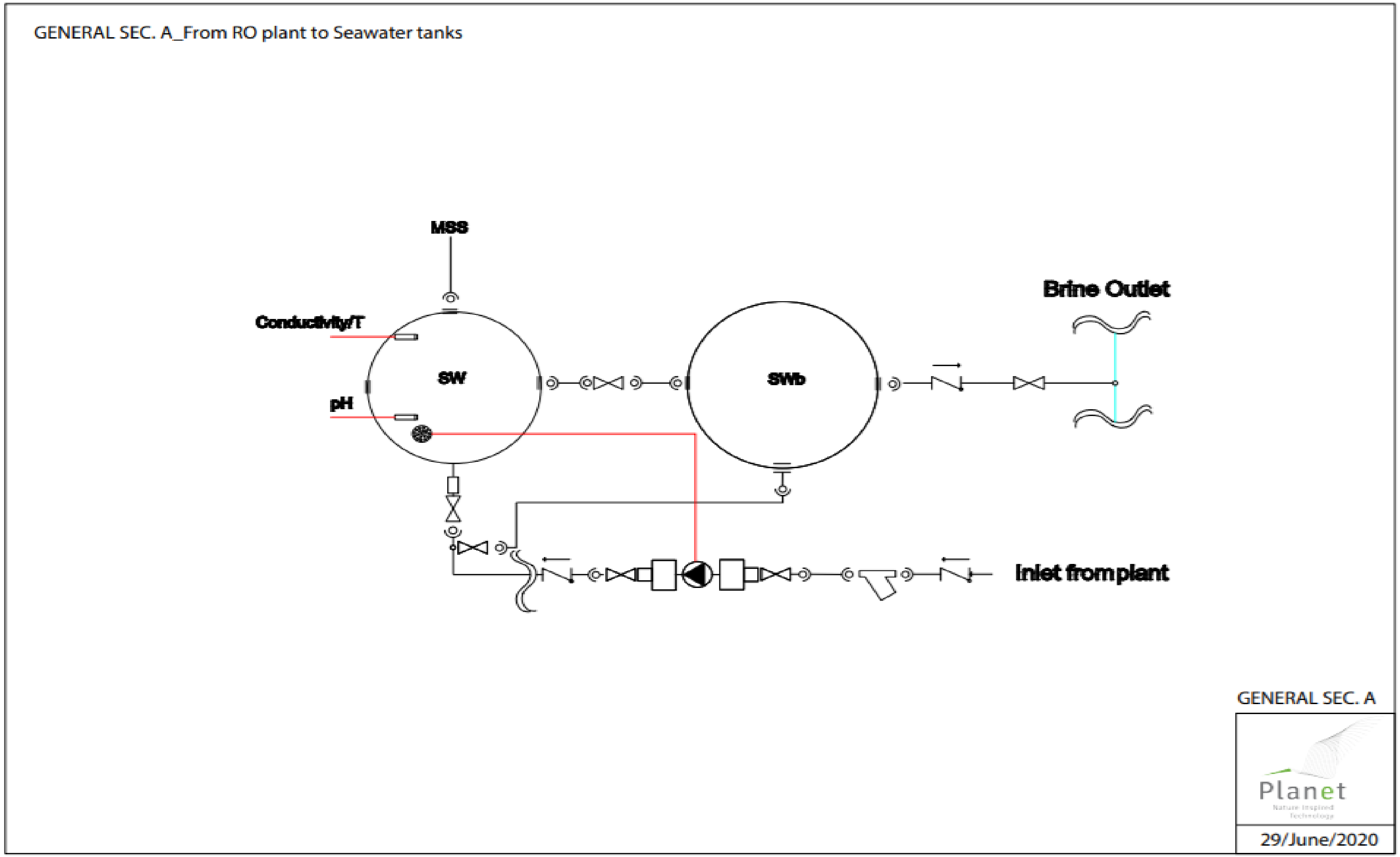
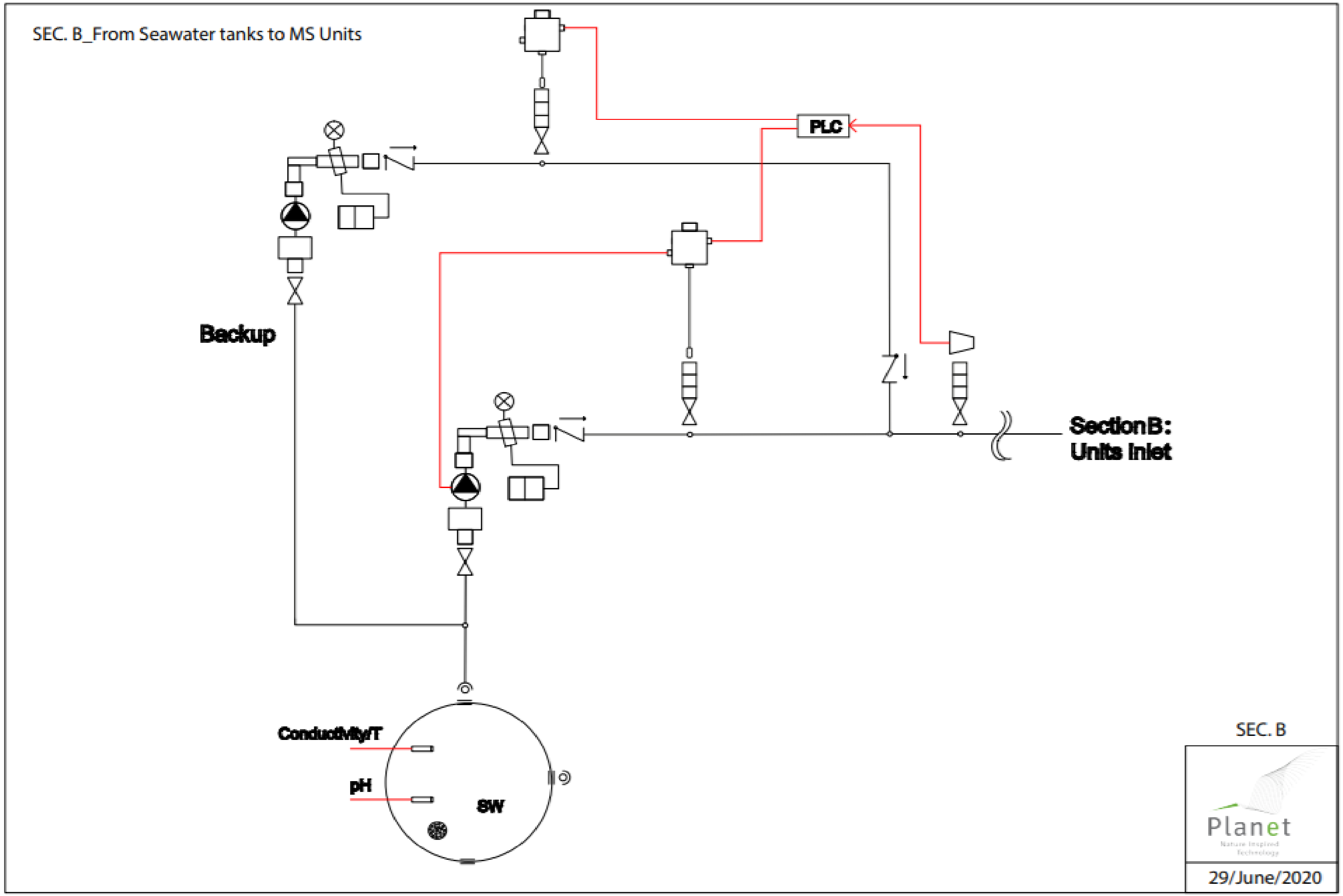
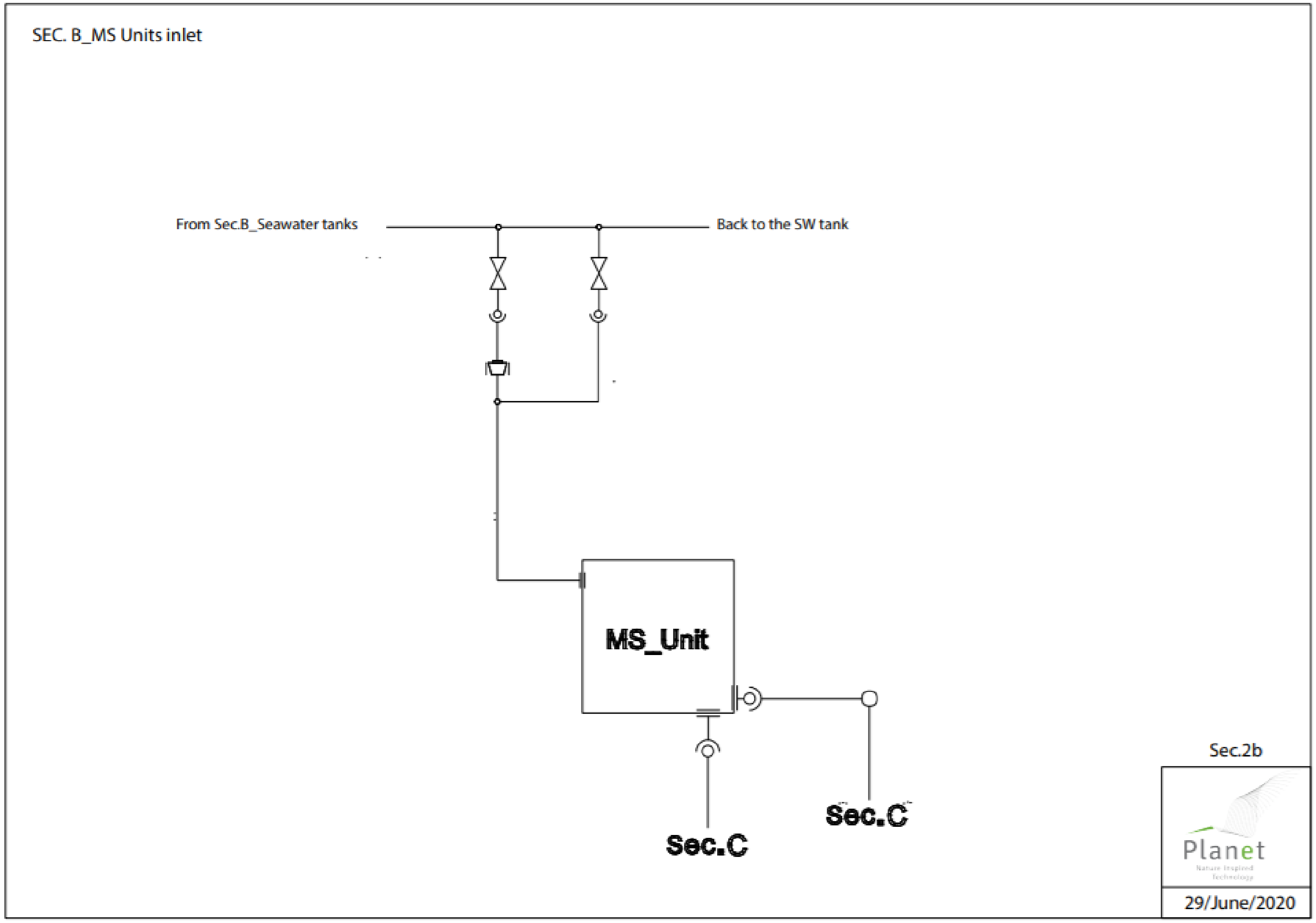



SEC. B_From Seawater tanks to MS Units
PLC
Backup
SectionB:
Units Inlet
Conductivity/T
pH
SW
SEC. B
Planet
29/June/2020



SEC. B_MS Units inlet
From Sec.B_Seawater tanks
Back to the SW tank
MS_Unit
Sec.C
Sec.C
Sec.2b
Planet
29/June/2020

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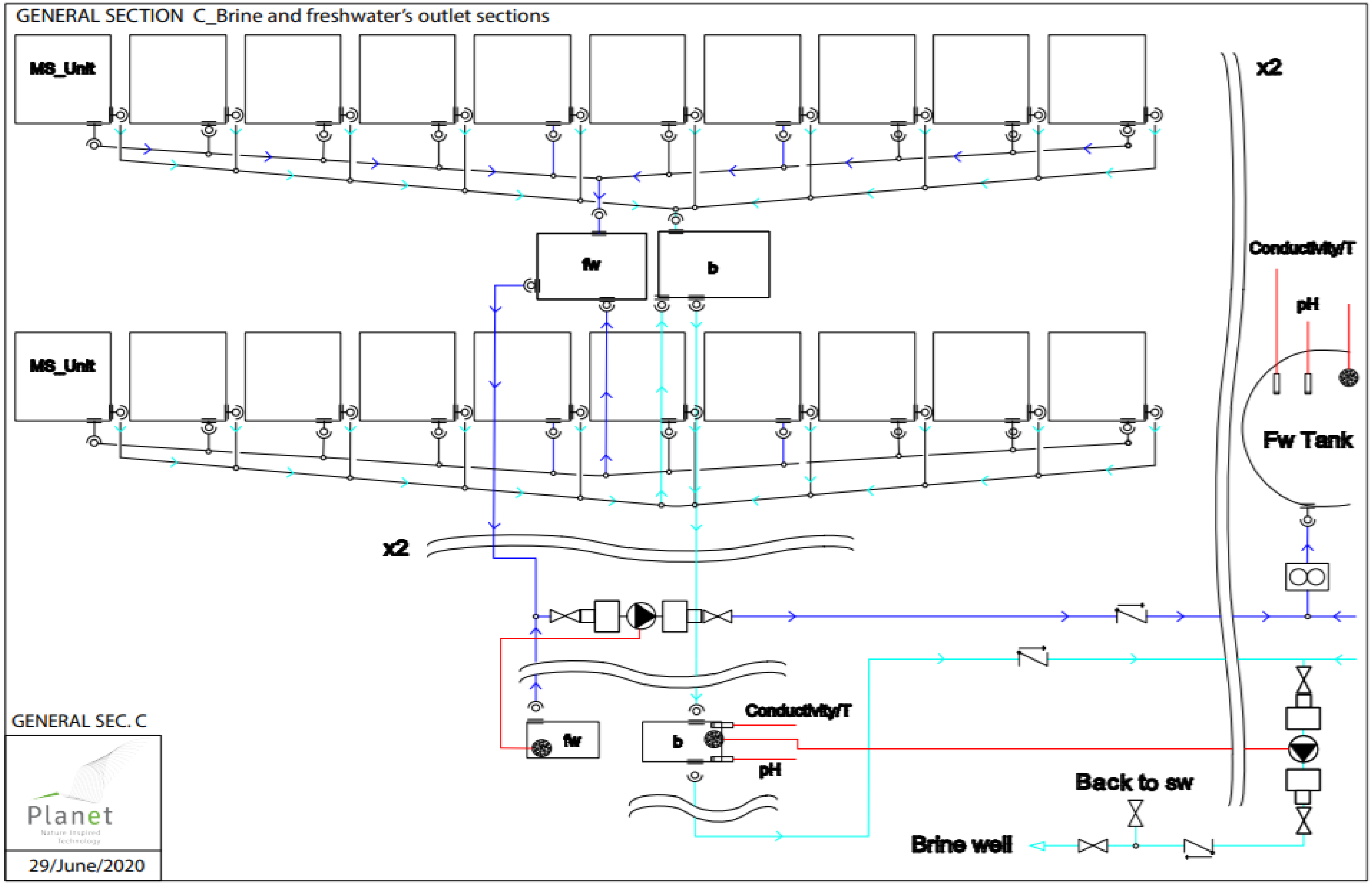

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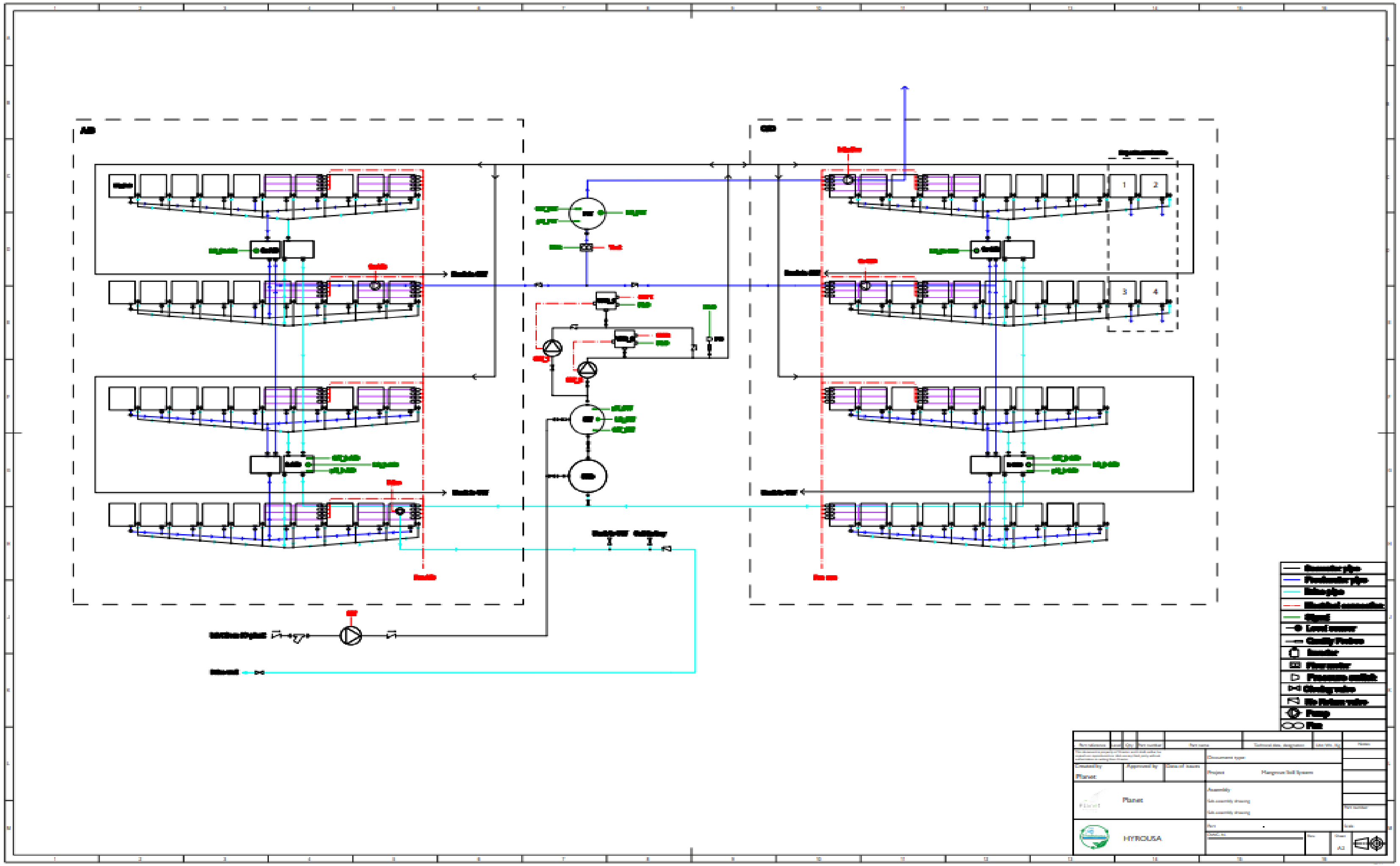
Annex 2: The Mangrove Still System's P&ID



Annex 3: Productive Greenhouse general layout