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HYDROUSA

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Water in the context of circular economy

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Rainwater management systems installed and running

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Responsible authors	**Name:**	Giannis Vasilakos Klio Monokrousou Klisthenis Dimitriadis Mike Styllas Antonis Eleftheriou Evgenia Tsianou Patrik Karlsson	**E-mail:**	vasilakos@hydraspis.gr kmonokrousou@gmail.com klisthenis@gmail.com mstyllas@gmail.com eleftheriou@hydraspis.gr evgenia.tsianou@alchemia-nova.net patrik.karlsson@alchemia-nova.net
	Partner:	NTUA, ALCN, DEL	**Phone:**	+30 2107722842,+306978776424

Brief Description	In the scope of D2.2, two prototype rainwater management systems designed in D2.1 are installed and delivered to the project. Within this deliverable, the intended systems’ function is described in a comprehensive report including the technical drawings of the design phase, several photographs of the construction process and description of the final setup.
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EXECUTIVE SUMMARY

In the scope of this deliverable two prototype rainwater management systems designed in T2.1 are developed, installed and delivered to the project. In this report, the intended systems' function is described including the technical drawings of the design phase, several photographs of the construction process.

HYDRO3 and HYDRO4 sites are implemented in Mykonos Island (Greece) and focus on rainwater management. Through the application of innovative approaches and the use of new technologies, the aim is to create a system for the collection, storage and utilization of rainwater and stormwater in remote and dry areas of the Mediterranean.

HYDRO3 is an innovative, prototype rainwater harvesting system which is applied in a remote agricultural area where there are no rooftops to collect rainwater. The harvested water is used for the cultivation of oregano. Specifically, the HYDRO3 system is implemented in the Ampelokipi area of Ano Mera, in Mykonos Island. A shallow, subsurface water collector is designed to collect rainwater by draining, to transport it to storage tanks, and eventually to utilize water for agricultural irrigation. The design of the entire system follows the "paths" of minimal invasiveness to the natural landscape, simplicity and flexibility (so that it can be applied quickly and easily in different fields of different capacity - size), low demands on both natural resources and energy, which ultimately lead to an economically viable scheme based on the "thought-philosophy" of Circular Economy.

In particular, HYDRO3 consists of the following subsystems:

- One (1) subsurface rainwater collector of approximately 280 m^2 and depth of 60 cm.
- Two (2) flexible cylindrical tanks of structural grid with a diameter of about 5 m and a height of 2 m, having a cumulative capacity of 60 m^3 (2 × 30 m^3) and
- Automated drip irrigation system of oregano crops covering an area of 4000 m^2 (method of deficient irrigation in dry crops)

Figure 1 HYDRO3

The shallow, subsurface rainwater collection system consists of geomembrane at the bottom to seal the water from penetrating into the soil and geotextile at the top to allow the passage of water, but not of soil. The harvested water is used for irrigation. 10 years of precipitation data was processed to estimate the rainwater to be collected. Based on these estimations, the subsurface rainwater collection system, drainage and storage pipeline network were successfully designed. The required equipment and sensors for automation and monitoring were assessed and selected. Earthworks, excavations, and ground levelling were performed and installation of HYDRO3 was finalized.

The ambition is to **open the world market** for these applications and to provide robust, effective, sustainable, cost- and energy-efficient circular solutions of a natural ecosystem service with a technological approach to enhance the protection and utilization of the freshwater resources in water scarce areas worldwide. This solution intents to be adaptive to the environment and the changing socio-economic requirements, considering the relevant legislation as well such as the Water Framework and Groundwater Directives and the Blueprint to safeguard Europe's Water Resources.

The aim of the HYDRO4 site in Mykonos (Greece) is to demonstrate how a residential rainwater collection system is upgraded to enable the optimal use of low-cost rainwater and the natural services provided by the subsurface, with a positive impact on the environment. The purpose is to develop a **novel, decentralized solution for rainwater harvesting, storage and recovery**, in order to store excess water during the winter months to reuse in summer, thus to maximise the utilization of the resource and increase water management efficiency in water scarce areas.

In particular, the concept of this pilot is to develop a configuration from mainly existing infrastructure such us rainwater storage tanks as well as groundwater reservoirs in order to **enable the buffering effect and extend water availability towards the dry period**.

For designing this system, technical and field visits took place on the site, existing regional and local data were collected, experimental activities were conducted and finally monitoring activities were performed. The purpose was to evaluate the characteristics of the system, in terms of the geological structure, the geophysical characteristics and the subsurface conditions, in order to provide a thorough understanding of the hydraulic behaviour of the aquifer of the site and assess the potential to implement aquifer storage and recovery (ASR) schemes.

After the processing of the surveys and the collected data, the system that has been developed is a decentralized, flexible, transferable and scalable solution that comprises of **three separate but interrelated subsystems** that are analytically described below:

- System 1: Residential rainwater harvesting system
- System 2: Slow sand filtration system
- System 3: Aquifer storage and recovery system

This rainwater management system intents to have a high replication potential.

Below the three subsystems are described:

Subsystem 1

In subsystem 1, rainwater is harvested from the residential roofs of the property (from about 438 m^2), transferred through a piping network to a manhole and reserved in the existing water storage tank of 70 m^3. This water is mainly reused for domestic non-potable purposes of the existing households of the site e.g. washing, flushing toilets, etc. With regard to the construction works of this system, the main tasks that took place include the restoration and cleaning of the roofs, the existing tank and the gutters, the construction of a manhole which acts as a control tank as well as the necessary piping works to transfer the water from the roofs to the manhole, to the tank and back to the resident.

Subsystem 2

The Slow Sand Filtration (SSF) system is a well-recognized water purification system that converts raw water like rainwater or water from rivers, groundwater etc. into a potentially potable product. The working principle is that raw water flows through a sand-bed system which is populated by microorganisms. Various biological, physical, chemical and mechanical processes purify the water. In subsystem 2, the SSF system is implemented using a small amount of water, to test whether the treated water could fulfil the quality criteria for potable water in other replication sites, especially in cases where the legal framework allows such use. There are two types of SSF that are to be tested in HYDRO4 site:

(a) SSF - community, which requires continuous flow

(b) SSF - household, which can operate with intermittent flow

Subsystem 3

For the aquifer storage and recovery subsystem, rainwater is collected from two sources:

1. First, the **surface runoff** of the impermeable surfaces of the private property of the site is collected in the wet period and reused for irrigation purposes during the dry period. In particular, the surface runoff is guided through a manhole to be stored in an existing tank on the site. Any excess water is transferred to recharge the aquifer in the location with the maximum storage capacity and recovery potential. In the dry period, water from the tank is used to irrigate a new cultivation (lavender) that is planted on the site. Additionally, water for irrigation is recovered from a new well, which is constructed in the artificial recharge (AR) location.
2. Water is also collected through a **bioswale system** (an open-channel linear drainage system), stored in the open tank and in the subsurface “basin” to be reused in the summer period. The bioswale system, on the one hand, collects and partially treats storm water and on the other, it prevents the lavender crop from flooding, due to the significant amount of stormwater and to the inclination of the site. In particular, during the wet period, water is transferred and reserved in an open tank and the excess water is transferred to the AR location to be stored in the subsurface. This water is then recovered to be reused in the summer for the irrigation of lavender.

With regard to the necessary activities of subsystem 3, the main tasks that took place include the construction of the bioswale system in the north side of the site, the restoration and cleaning of the existing tanks, the construction of the necessary manholes to act as control points as well as the necessary piping works to transfer the water from the tanks to the AR site in the wet period and to recover water for irrigation in the summer period.

For monitoring the subsystems and for enabling controlling and automating capabilities of HYDRO4, a series of equipment, which are presented in section 7, are to be set in the site. The purpose is to gather the demo site data as well as to control the operation of the systems. In particular, sensors are to be installed for monitoring important parameters including: water quantity and quality parameters; also meteorological data parameters are monitored to be interrelated with the water collection and storage parameters.

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1. INTRODUCTION (HYDRO3)

"…(the universe) has never been, nor will it be, because then and now it is the Everything, the One, the Continuum…"

Parmenides, About Nature

Many thoughts "pass" from the author - researcher's mind regarding this project. Questions that must lead to a more mature formulation and evolution in reasoning and in resolving the issues arising from the new challenges. After this first fundamental observation and realization, it would be an omission not to cite, albeit briefly, some elements that give rise to approaches such as the present work of HYDROUSA and seek to respond to the new challenges.

In this chapter, we summarize the points that made the planning and design lead to a successful construction of the HYDRO3 demonstration system; an attempt to unravel and capture in a short and clear way the system of collection, storage and utilization of precipitation in irrigation:

- The axes that "gave birth to" the idea (moral-political-value background).
- The design philosophy that succeeded the idea.
- The basic theoretical and legislative planning framework.
- The data collection and area selection that dictates the system implementation.
- The design decisions that shape the integrated application.
- The final design of the system (dimensioning and siting)
- Construction details of the collection and storage system
- Basic pre-calculation of the construction costs of the main units of the system (collector, reservoirs and water transport network for storage) and finally,
- Parallel operational actions for irrigation (preliminary implementation studies - pumping and basic irrigation network planning, automation, remote monitoring of quantitative and qualitative parameters of the collected water)

HYDRO3 is a Nature-Inspired Solution; specifically, it is inspired by the natural processes and biochemical functions found in the family of fungi GLOMUS. More than thirty years of research have shown that these fungi have the ability to store water and return it to the soil during periods of drought, improving the quality of soil moisture (desalination of water, removal of heavy metals - arsenic (As) etc. a). These fungi contribute to the increase of the efficiency of the agricultural production, the resistance of the plants in periods of drought and the improvement of the products through the better quality of moisture attributed to them. The HYDRO3 system does exactly the same.

The Design Principles and final features of HYDRO3 must be cited. HYDRO3 can be summarized as follows:

HYDRO3: HUMAN - HARMONY - ENVIRONMENT. An Innovative, nature-inspired, sub-surface rainwater harvesting system with a SHALLOW SUB-SURFACE RAINWATER COLLECTOR (280 m^2), 2 WATER RESERVOIRS - TANKS (2 × 30 m^3 STORAGE capacity) & SUPPLY - WATER UTILIZATION (IRRIGATION SYSTEM) for 0.4 ha of oregano. This system accumulates the following principles and characteristics:

A. Simplicity

The main feature of the environmentally friendly constructions and Greek Architecture (Doricity). Simplicity leads to understanding and ease of construction and directs to the following design principles.

B. Practicality and workability

Every applied technique and technology must be governed by these basic principles.

C. Multilateral and creative approach

Taking into account the new challenges, while being aware of the goals you are called to achieve, we approach the design not one-sided, sterile, but holistically, integrally, "circularly" with a strong feeling for creation. It is then that one comes even closer to finding solutions, responding to new challenges.

D. Adaptable and adoptable system

A pilot and research approach should be open, for dissemination, to bring socio-economic benefits to a wide range of applications. Then and only then will it have accomplished its purpose.

E. Robust design-strong structure

The system is intended to be applied in isolated areas where the difficulty in accessibility combined with the lack of resources (water, raw materials - materials etc.) create a "hard" landscape, aggressive to any intervention. So, the requirement is a solid, robust construction for a system exposed to an inhospitable environment.

F. Scalable system

It should be possible for the demonstration system to easily change size and shape, while being operational for different sizes of requirements (water collection volumes, different irrigation requirements, etc.)

G. Flexibility

Flexibility and adaptability both in design and construction

H. Low constructional and operational cost

The construction and operating costs of the system will critically impact on its potential exploitation. HYDROUSA is an Innovation Action project interconnecting innovation with entrepreneurship.

I. Efficient-sustainable

The main challenge of every designer-engineer is for his project to finally accomplish the goal he/she is called to achieve. Simply, for the idea to take life and work!

J. Harmonization with landscape architecture

Finally, the design, the architectural approach of the construction components must "mix" in harmony and be "embraced" by space, the landscape; as if it were always there. Mild interventions, the choice of local materials and construction techniques that have been adopted over the years in the demonstration area, not only make the construction blend with space, but also serve towards an environmentally friendly constructional approach, as the energy footprint of the system is the minimum possible. The main constructional components of the system, as already mentioned, are a shallow underground rainwater drainage collector and two (2) cylindrical reservoirs for storing the collected water. So, mild and shallow excavations, flexible but also solid and low-cost tanks, lined with stone (dry stone), with an overcoat of reeds is what one would call Hellenic Cycladic Project.

The above basic points direct the original idea to a configuration. HYDRO3 acquires substance.
Design and contraction decisions, in addition to the objectives and data collected, are affected to a great extent by the qualitative understanding and quantification of the above-described concepts.
Construction acts are governed by the harmony and balance between practicality and conservative spirit, having the knowledge of the complexity of the mechanisms that affect the whole concept.

The integrated approach from the first moment of the conception of the idea and the design, led to a fast and complete construction of HYDRO3.

Also, key role to this success was the methodical application in the field, as well as the careful selection of materials and construction workshops. Additionally, one extra positive point was that the construction engineers/researchers were also the designers of the system.

2. SYSTEM DESCRIPTION

The analytical design (design deliverable D2.1: Design of rainwater management systems) with theoretical and construction design background-review, the thorough study of the implementation area, the precise data collection, the variation of computational approaches and the pre-selected construction decisions gave a finalised HYDRO3 construction with no significant deviations from the initial design.

2.1. First Technical key points

As a beginning of the technical description of the system we must outline the minimum requirements for achieving the objectives of this innovative system for collecting, storing and utilizing rainwater for irrigation in remote, arid, unbuilt agricultural areas.

Minimum System Requirements - Minimum Expected Results

The design basis apart from the intangible concept is based on tangible minimum expected results - minimum targets. For this demonstration system, the following should run cumulatively:

- To collect and store at least 50 m^3 of rainwater per year in order to irrigate oregano crops.
- The irrigated **cultivation area** should cover at least **0.4 ha**
- **The annual production target of aromatic plants (oregano) is 800 kg.**
- The **cost** of irrigated water should be **0.05 €/m^3**

The system aims at low-cost water supply in remote, arid areas, so farming activities can be developed.

Parameters & Data

At this point, all the data and parameters that influenced the technical characteristics, are collected (design deliverable D2.1). The centralized listing of the above-mentioned parameters, requirements and data facilitates the acquisition of a complete picture.

- **LOCATION:** **"Ampelokipi" -Ano Mera Mykonos (**Inland of the island**)**
- **PLOT:** **Area 4284.00 m^2** (see section 4.3.2 & attached topographic diagram)
- **GROUND:** **Mild slope, Sandy, Homogeneous, Rock formations are present**
- **AVERAGE ANNUAL PRECIPITATION:** **311.1 mm**
- **AVERAGE ANNUAL TEMPERATURE:** **19.0°C**
- **MINIMUM REQUIRED VOLUME OF COLLECTED WATER:** **50 m^3/year**
- **HYDROLOGICAL LOSSES:** **Evapotranspiration, Surface run-off, Water retention in soil pores**
- **CULTIVATION:** **Oregano in an area of 4000 m^2**
- **CONSTRUCTION AND OPERATION COST:** **Minimization so that the system can be economically viable and profitable**

The above-mentioned data and requirements were fully integrated in the designing process. Outlining the technical information of the system we should mention the following calculations - dimensioning and construction key points.

60 m^3 of rainwater per year will be collected even though the target is 50 m^3

The hydro-meteorological uncertainty and the difficulty in accurately quantifying climatic parameters and "water cycle" mechanisms call for a conservative approach. An over-dimensioning of 20%, of a system of this size, significance (security) and manufacturing complexity, limits the chances of failing to achieve the goals, without going beyond the available budget.

Limitation of losses

It is chosen to "get" the parameter of any resulting surface runoff "out" of the frame of losses. The surface runoff resulting from the area of the collection basin will be collected, while at the same time resulting runoffs around the perimeter of the collection system will be limited and will not be collected. This decision will eliminate the surface runoff from the list of losses in the hydrological balance, while the exclusion of the perimeter runoffs will not "distort" the system's performance result.

Construction Techniques and Materials

Construction techniques of mild invasiveness and environmentally friendly materials are selected (see design principle I - Harmonization with landscape architecture).

The use of materials from the site and the avoidance of the use of concrete as a building block in a cultivation facility is a major construction decision. "Flexible" building blocks will synthesize the plant. The use of dry-stone walling and reeds (cauldrons) as cover of the constructions will integrate the plant into the existing landscape.

Use of the Collector

In addition to the water and drainage construction project, the collector could also have storage use. That is, for the plant itself to be also able to store the collected water. Although it will have the design and construction characteristics that allow such use, this will not be applied for the following reasons:

- The collector would occupy a larger area or volume (increase of the construction cost of the entire system)
- There would be difficulty in managing and abstracting water
- Possible problems could arise with the quality of the stored water (microbial growth, etc.)
- There would be difficulty in checking the qualitative and quantitative characteristics of the collected water
- Maintenance would be more frequent (more severe wear) and it would have practical application difficulties (underground collector)

However, in cases where this is deemed necessary, the collector can be used for storage (excess of collected water - additional storage, maintenance of other components or even a drainage pipeline obstruction problem without the need for heavy losses of the collected water).

The computational decisions and the previous remarks "reflect" the construction process. These technical points that have qualitative and practical characteristics which have to do with the site (ground slope, siting), the ease and safety of construction, the choice of techniques and materials (philosophy of mild environmentally friendly interventions), the operation and maintenance of the project facilities, the rules of the existing legislation.

All points that have already been mentioned, together with the description below, are considered in the light of the economic and, ultimately, the business component.

2.2. Description of the Construction Parts

In the sections below, a description of the characteristics of the key construction components is given.

Water Storage Tanks

The storage of 60 m³ water volume was divided in 2 independent tanks with a capacity of 30 m³ (each) and of cylindrical shape. The use of the collector, leads to storage tank construction. The collected water is sent for storage in the 2 flexible reservoirs made of structural grid and waterproofing materials. The volume of water is chosen to be shared and stored in 2 tanks for convenience and maintenance (maintenance of one and parallel use of the other). Each tank is about 5 m in diameter and has a useful height (water level) of 1.60 m. The tanks are half-immersed into the ground (for reasons of strength, a simpler procedure for granting building permission and aesthetics). Externally, the perimeter is covered with dry stone and the roof is covered with reed. The cost of constructing such reservoirs is much lower than conventional ones (metal, reinforced concrete, synthetic). They are also more environmentally friendly. Here is a description of the construction components of the planned reservoirs.

Flexible water collapsible tanks - Tanks of light metal structure.
Lightweight metal tanks are one of the safest liquid reservoir storage systems.
Structure
A suitable galvanized wire mesh of various dimensions (in this case 30 × 30 × 3mm) with perimeter metal reinforcement (tubular uprights or retaining rings) is used to shape the structure. It is a steel structure with flexibility and portability (easy to transport due to the split structure and assembly in the field). As far as construction is concerned, various shapes of tanks can be formed with capacities of 5 to 150 m³ (in the present 2 × 30m³)

Mounting base
Depending on the size of the tank, the soil is sanitized or strengthened properly (sand or concrete).

Lining - Waterproofing
The tank becomes waterproof having an inner lining of a sealant cloth suitable for water storage and resistant to sunlight. The cloth is attached to the grid on the upper lip of the structure, which is protected by a flexible pipe (to avoid tearing the fabric).

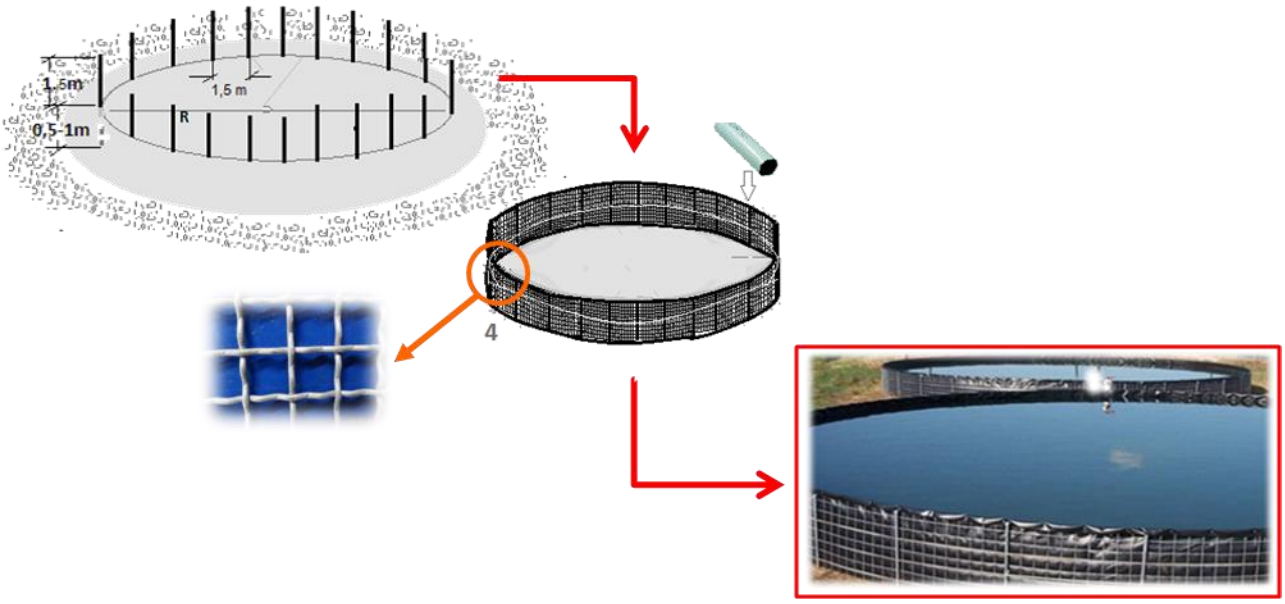

Figure 2.1 Construction steps of the reservoir mounting

Reservoir Cover

The tank can be covered with a flat, conical or floating cover. (In the present, the conical cover was made by the same material as the inner lining (geomembrane) (evaporation limitation) which was coated with reeds.

Figure 2.2 Types of tank cover

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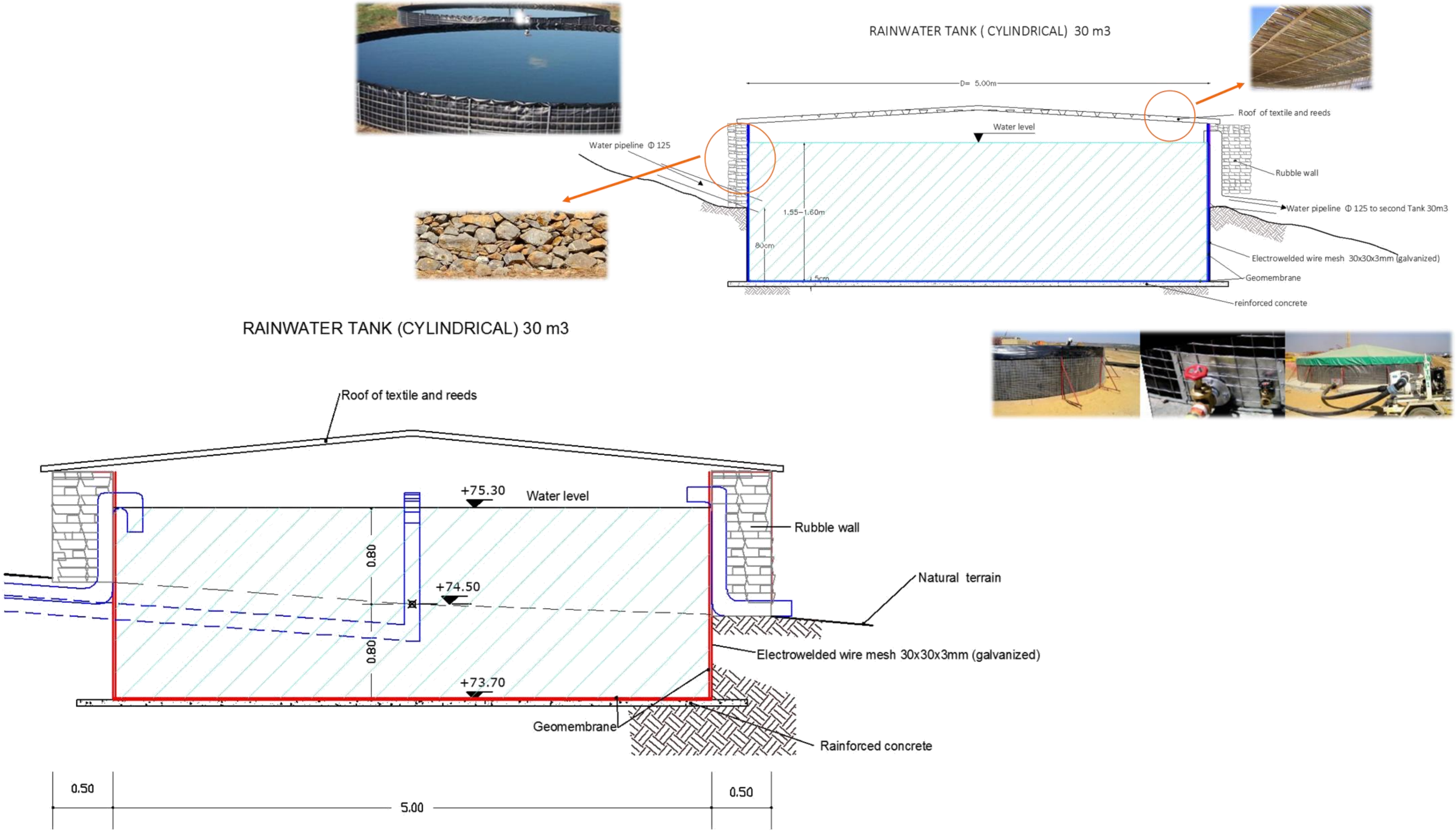

Figure 2.3 Schematic cross-section and structural grid design details

Sub - surface rainwater Collector

Main construction principles:

- The drainage system follows the slope of the soil (drainage and supply of collected water at the lowest altitude). In addition, there is uniformity - stability of the depth of excavation.
- Levelling of the excavation (excavation slope gradient 1: 1) by laying a thin layer (3-5 cm) of sand (sand - sea type).
- Sealant geotextile (geomembrane) covers the collector basin.
- A drainage pipeline network "sweeps" the bottom of the collector. The drainage pipes are flexible. The network (Ø90 pipelines) end up in the central drainage pipeline (also Ø90) (the distances between the pipes are approximately 5 m). The main drainage pipeline ends at the lowest altitude point of the bottom of the basin and in an operation control pit. In this special section - a pit of dimensions 40 × 40cm, apart from the end of the main drainage pipeline, the main water supply pipeline was connected to lead the water to the storage tanks (Ø125).
- A 40 cm thick layer of gravel (d5-13 cm) covers the basin and drainage pipeline network.
- A double water-permeable geotextile coating covers the gravel. The coating is chosen to prevent soil from penetrating into the layer and clog the drainage works. The double layer is chosen for greater protection (the geotextile that comes in direct contact with the gravel can be torn, both during mounting and during operation).
- Small size gravel (d8-16 mm) laid over the double geotextile. The thickness is 5 cm. The gravel was placed to protect and hold the geotextile; and that is where the layers of this type of collection basin end.
- In order to collect the almost zero resulting surface runoff (very good drainage conditions - rapid infiltration of rainwater), but also to prevent infiltration into the water basin, a low watertight enclosure of the basin of 10 cm height was created from natural soil. The fencing follows the construction approach with the storage tank. It was made of small uprights - piles. The sealing geotextile "ties" on this "small fence".
- The collector is "submerged" 10 cm from the surface of the soil (if necessary, i.e. if it is chosen as a test-pilot, a part of the collector with overhead cultivation or soil so that experimental results can be extracted and conclusions on soil permeability, as well as other critical sizes).

Finally, the cross-section of the collector is about 60 cm and its bottom is 70 cm from the ground.

The Collector is "shallow" simple in construction and of low-cost. For a better understanding of the above structural description of the collector, schematic sections and detail drawings are given. Also, reference may be found in the drawings in the design deliverable (D2.1).

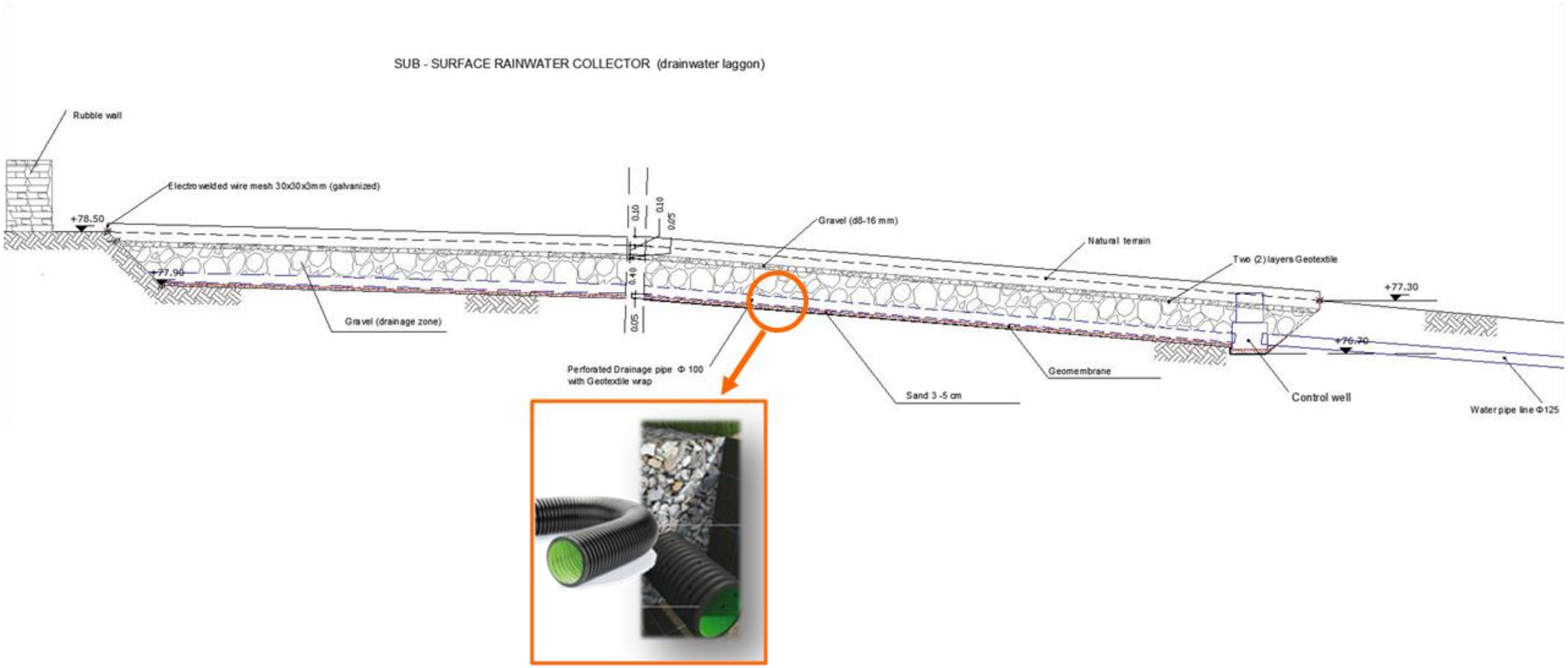

Figure 2.4 Schematic cross section and details of collector without cultivation overlay

Positioning of the system

If the landscape allows so, the collector is positioned at a higher point than the storage tanks, so that the water flows by gravity. In this way, a natural flow under gravity, with zero external energy consumption is achieved. This means that the elevation of the outlet pipeline from the collector should be the same as the maximum water level in the storage tank. Considering the hydraulic flow losses (due to friction, etc.), an elevation difference between the collection basing outlet - tank entry is decided, of more than 0.5 m. In addition, the whole system should not restrict the agricultural work, the crop and irrigation network.

The existence and location of an old warehouse and its utilization as auxiliary housing for the system, leads to the placement of tanks and metering facilities near the cells. It is preferable if the tanks, the pumping irrigation system, the meteorological station, the Remote Parameter Monitoring Unit (telemetric monitoring station) are installed close to the warehouse for protection and also to facilitate the concentration of power supply to all systems. The electrical panel and the data logger were installed inside the cell.

Water flow through a pipeline network

The principle and characteristics of the main transport pipeline of the water to be stored are described above. The water flow terminates in the water storage tanks. As a means of design flow, the tanks are connected to the main pipeline, but also to each other. The flow of water can be done in series. The first tank feeds and after filling, the second tank fills through overflow. There is the option of bypassing the supply to the first tank (hydraulic bypass) whenever it is deemed appropriate. The second tank in series has a security overflow. The feed pipelines have a cross-section 2×2in), a cross-section that covers the expected abstraction supply.

Similarly, the irrigation system uses the water from the tanks through a low pressure pump system and low energy consumption. The main irrigation pipelines (Ø32) drive the water through pumping to the hoses of drip irrigation. At major points in the network, there are flow control switches. Tank outflow meters and irrigation automation systems are installed. Tank level gauges (level meters) are also installed.

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3. CONSTRUCTION AND START-UP

3.1. Construction and installation process

Excavations - Earthworks

Figure 3.1 Day one & Excavations Alignment.

For every construction part, subsystem of the HYDRO3, the first and the most important process is the precise earthworks and excavations. Mainly, in a constructional point of view, HYDRO3 is a geotechnical task and secondary a hydraulic work.

The longest construction process was the excavations works. Careful excavations led to trouble-free installation of the system, while maintaining the slopes of the terrain.

Figure 3.2 Water Storage Tanks Excavations

Figure 3.3 Rainwater Collector Excavations

Figure 3.4 General earthworks & rocks moving

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Sub - surface Rainwater Collector

The construction details were described in the above section.

Through the quotation of the following photographic material and following description, the construction and installation process is presented.

Figure 3.5 Geomembrane installation - collector basin

Figure 3.6 Drainage pipeline network "sweeps" the bottom of the collector

Figure 3.7 Drainage gravel zone

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Figure 3.8 Control well & 1st Drainage gravel zone

Figure 3.9 Fencing - low watertight enclosure of the basin of 10 cm height. The sealing geomembrane "ties" on this "small fence"

Figure 3.10 A double layer water-permeable geotextile coating covers the 1st gravel zone. Small size gravel (d8-16 mm) laid over the double geotextile

Figure 3.11 The Rainwater Collector finalized

Water Tanks - water storage reservoirs

The two flexible water collapsible cylindrical tanks of light metal structure were installed and hydraulic and safety tests took place during every construction stage. Step by step, the progress is presented below.

Figure 3.12 The main structural framework of the tanks. Perimeter metal reinforcement (tubular uprights or retaining rings) was used

Figure 3.13 The inner layering of the Tanks with geomembrane.

Figure 3.14 Hydraulic and safety tests

Figure 3.15 Tanks excavation backfilling

Figure 3.16 Tank Roofs covering

Water flow - Pipeline network

The main water pipeline connects the collector with the tanks. As a means of design flow, the two tanks are connected with the collector, but also to each other (in series and in parallel). The first tank feeds and after filling, the second tank fills through overflow. The second tank in series has a security overflow.

Construction details are shown in the following pictures (Figures 3.17, 3.18).

Figure 3.17 Main water pipeline. Flow control switches (valves). Robust structure and safe functioning. The rainwater network does not restrict the agricultural work and the crop and irrigation network is protected

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Figure 3.18 Hydraulic connection of the tanks (in series, parallel and security overflow)

Pumping irrigation system & drip irrigation lining

This section presents some parallel actions, inextricably linked to the construction activities of the demonstration system that have to do with the preparation of the site for the oregano crop plantation, the pumping system for water supply, the drip irrigation lining system and the hydraulic and safety tests.

For the irrigation of oregano, the technique of precision irrigation is used with the aim of saving water. Precision irrigation is a smart approach where only the required amount of water is applied and at the right time. It comes to meet the need to increase the efficiency of water use in the agricultural sector. To accomplish its purpose, precision irrigation relies on a set of technologies such as ground moisture sensors, weather stations, flow meters and solenoid valves. In the application of Mykonos, an innovative precision irrigation system for oregano is developed based on the above principles, but also considering the amount of rainwater collected in the tanks. In particular, this irrigation system calculates both the amount of water stored at a given time and the stage of cultivation to optimize its utilization; all the above are based on the existing and future needs of the plant.

Pumping irrigation system was designed and constructed

The electromechanical design of the whole system follows the "paths" of low demand on both natural and energy resources, which ultimately lead to an economically viable scheme based on the "thought-philosophy" of the Circular Economy.

Figure 3.19 Pumping system

The pumped irrigation system designs resulted in the selection of 2 identical pumps in parallel and simultaneous operation. Using electro-valves it can supply water for irrigation from any rainwater storage tank needed.

The type and characteristics of the pump are:
PUMP EBARA CDA / B 1.50 M
Two-stage cast iron centrifugal pump. Winged brass, stainless steel shaft AISI303, shaft seal with Carbon / Ceramic / NBR mechanical seal. IP44 motor, insulation class F. Voltage 1 ~ 230 V. Maximum operating pressure 10 bar. Maximum water temperature 90°C. Nozzles 1 1/4 "x1". Power 1.5 HP (1.1 kW). Flow rate 4 m^3/h (1.2 – 6 m^3/h). Manometric 42 m (50.8 - 27.5 m).

Field preparation for oregano cultivation (0.4 ha)

Figure 3.20 Field preparation

Oregano crop plantation and irrigation system

Hydraulic and safety tests were performed to the pumping and irrigation systems. At the time of these systems' installation, the rainwater harvesting system had been completed and was already operational. Collection, storage and supply systems were running (rainwater was already collected and stored in the tanks). Irrigation system was then tested and the first irrigation of the oregano cultivation was done in November 2019.

Figure 3.21 Drip irrigation pipeline network installation

Figure 3.22 Oregano crop plantation

Sensors, Weather Station & Agricultural Electricity supply Installation

All sensors (flow meters, level sensors, electro - valves, water quality sensors, soil moisture sensors etc.) and the weather station result in significant decrease of the operation labour. In Figures 3.23, 3.24 and 3.25 the sensors, the weather station and the installation of the electricity supply are presented.

Table 3.1 Monitoring equipment for HYDRO3

Type of sensor	Process monitored	Installation point
Tank level sensor	Monitor the water level of tanks	Installed in the existing tanks (2)
Turbidity meters	Monitor turbidity of water stored in tanks	Installed in the existing tanks (3)
Conductivity meters	Monitor conductivity of water stored in tanks and in the wells	Installed in the existing tanks (2) & in the wells (2)
pH meter	Monitor pH of water stored in tanks and in the wells	Installed in the existing tanks (2) & in the wells (2)
Moisture meter	Monitor the soil moisture of the plantation	Installed in the oregano cultivation (2)
Weather station	Monitor meteorological parameters online in real time (www.ardefsi.gr)	HYDRO4 demo site (set in a roof)

Figure 3.23 Electricity pillar & electricity meter box construction

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Figure 3.24 Weather Station

Figure 3.25 Tank level and water quality sensors installation

Stone works - Rubble walls - Harmonization with landscape architecture - Main entrance & Old warehouse repair and restoration

HYDRO3 is not only an innovative system. It is a demonstration site that follows the ‘soul of cycle thinking’. The choice of local materials and traditional construction techniques characterizes the work as if HYDRO3 is standing in the field more than 100 years. The photos that follow testify this approach.

The old rubble wall - stone paddock - fence of HYDRO3 site was repaired. The construction stages are shown in Figures 3.26, 3.27, 3.28 and 3.29.





Figure 3.26 Rubble wall traditional technique

The use of dry-stone walling as tanks stone cladding

Figure 3.27 Tanks stone cladding

Main entrance & Old warehouse repair and restoration

The configuration of the main entrance and the HYDRO3 surrounding area will create a friendly place to visit. Objective: A demonstration site that will finally give the visitor immense satisfaction and pleasure.

Figure 3.28 Site & Main entrance construction works

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Old warehouse repair and restoration - Harmonization with landscape architecture

Figure 3.29 Old warehouse repair and restoration under the view of Cycladic traditional Architecture

3.2. Start-up

During the construction stage several hydraulic, endurance and operational tests were performed. After the successful hydraulic connection of the tanks to the collector, the system became operational and was ready to collect rainwater. Much of the water used during the construction phase, which continued after the start-up of the system, was rainwater collecting from the system. The system started collecting and storing water as early as November 17, 2019, while the works continued until December 19, 2019.

Figures 3.30 and 3.31 show the initial water collection moments

Figure 3.30 Start-up. Rainwater collection & storage

Figure 3.31 Start-up. Oregano irrigation

4. HYDRO3 CONSTRUCTION EPILOQUE

...from the first stone, till the last plant!

All construction work are fundamentally a team work. Through the following photos the whole construction team and the HYDROUSA team are referenced for the incredible collaboration!

HYDRO 3 Journey has already begun! Though, Theory, Planning, Design, Construction, Interplay, Implementation.

HYDRO 3 CONSTRUCTION VIDEO

All the excavations and earthworks, construction of the subsurface rainwater collector and the water storage tanks, pipelines, stone works (rubble wall and harmonization with landscape architecture), field preparation, drip irrigation network and plantation of oregano crop, until the final HYDRO3 prototype system (operational phase – rainwater collection) were reported through photos and videos. A time lapse construction video was developed from these (https://www.youtube.com/watch?v=c5xlv-vB6B4&t=62s), in order to get a small "taste" of how this innovative system was made!

#HYDRO3 time lapse construction video!

The water flows. It is the connection link of everything. Of the material (or better, energy) and spiritual world. Of our Existence and Experiences. The "golden rain" is teaching, the EVOLUTION, the knowledge, the Technology. GRATEFUL TO PROMETHEUS!

«Ψυχήσιν Θάνατος ύδωρ γενέσθαι, ύδατι δε θάνατος γην γενέσθαι, εκ γης δε ύδωρ γίνεται, εξ ύδατος δε ψυχή»
"For souls death is to become water, for water death to become earth, from the earth becomes the water, from the water, soul"

"ποταμοῖς τοῖς αὐτοῖς ἐμβαίνομέν τε καὶ οὐκ ἐμβαίνομεν, εἶμέν τε καὶ οὐκ εἶμεν"
"Into the same rivers we enter and do not enter, and we are and we are not"

Heraclitus 544-484 B.C.

5. INTRODUCTION ON HYDRO4

The aim of the HYDRO4 site in Mykonos Island (Greece) is to demonstrate how a residential rainwater collection system is upgraded to enable the optimal use of low-cost rainwater and the natural services provided by the subsurface, with a positive impact on the environment. The purpose is to develop a **novel decentralised solution for rainwater harvesting, storage and recovery**, in order to store excess water during the winter months to utilize in summer, and thus to maximise the utilization of the resource and increase water management efficiency in water scarce areas.

In particular, the concept of this design is to develop a configuration using also the existing infrastructure in order to **store excess rainwater of winter to valorise it in summer in the point of demand both for domestic and irrigation purposes**. In particular, rainwater storage tanks as well as subsurface natural water reservoirs have been used to **enable the buffering effect and extend water availability towards the dry period**.

The infrastructure of HYDRO4 is located in the village of Ano Mera in Mykonos Island. The site has several buildings with roofs, two water storage tanks (40 m^3 and 70 m^3), an open tank (20 m^3), three traditional wells and a borehole. Also, on the site there are natural occurring subsurface water reservoirs. All of this infrastructure is upgraded into a modern and novel decentralised system for rainwater harvesting, storage and recovery.

For designing this system, in order to establish the current status of the demo case before the implementation of the pilot, **a technical visit** took place in the site (September 2018), to establish the particular technical characteristics and obtain a visual perception of the potential solutions to be implemented in the respective systems.

Additionally, a **field work visit** took place (November – December 2018) to conduct geological and geophysical non-destructive surveys as well as topographical measurements. At the same period, existing regional and local climate **data were collected** and a **review of the existing literature** concerning the geological, tectonic and hydrological conditions of the Cyclades and especially of Mykonos Island was performed. The investigations purpose was to assess the aquifer potential and have maximum accuracy on the elevations and water level of the pilot site both on the surface and in the subsurface as well as to locate a subsurface impermeable basement to store rainwater through artificial recharge and recovery (ASR) schemes.

After the processing of the surveys and the collected data, the regional and local hydrogeological system has been evaluated, in terms of regional and local geology, climate and hydrogeological characteristics. Next, the geophysical characteristics of the system have been assessed, regarding the potential to implement aquifer storage and recovery schemes as well as the potential exploitation of the existing wells.

Through this process, *Deliverable 2.1: Design of rainwater management systems (D2.1)*, was compiled and submitted, which referred to the design of all the **three separate but interrelated subsystems**:

- System 1: Residential rainwater harvesting system
- System 2: Slow sand filtration system

- System 3: Aquifer storage and recovery system

For subsystems 1 and 3, specific **construction activities** took place according to the design specifications of D2.1, the analytical technical description of which is compiled in Section 2 of the present document.

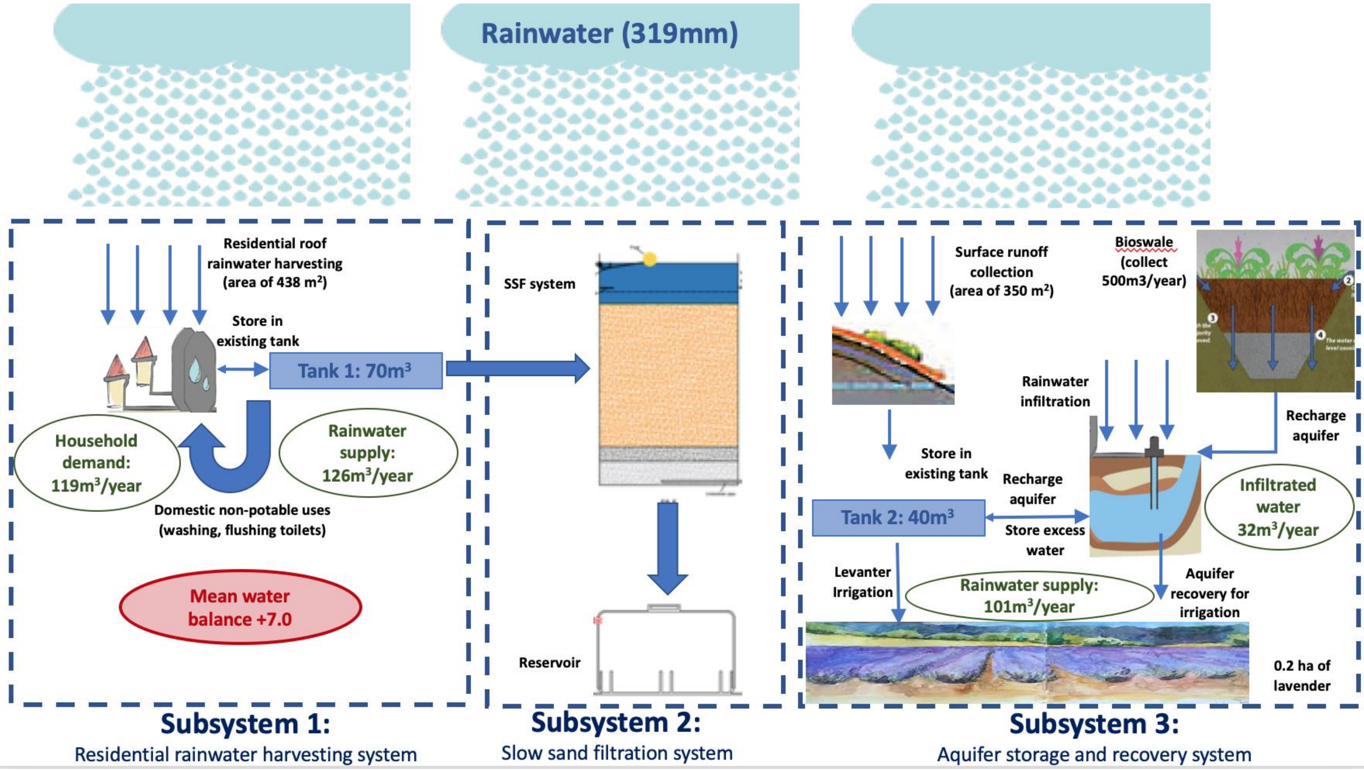

Figure 5.1 Schematic illustration of the three subsystems of HYDRO4

For subsystem 3, **a series of field experiments were undertaken** to provide a thorough understanding of the hydraulic behaviour of the aquifer selected to act as the buffer for water storage. The artificial recharge (AR) experiments provided a unique opportunity to verify the geological structure and subsurface conditions of the selected aquifer as described in D2.1 and to evaluate its water retention capacity, but to also optimize the system set-up. Also, **monitoring activities** took place during the wet period of 2020, in order to assess the aquifer recharge and storage potential, presented in Section 6.

This rainwater management system intends to be **flexible**, as it is regulated according to the conditions of each hydrological period through the buffering effect that extends water availability towards the dry period; **transferable** as it can be implemented in similar environments with seasonal water variability and **scalable** as it could apply to various scales of rainwater systems.

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6. SYSTEM DESCRIPTION AND CONSTRUCTION (HYDRO4)

This novel rainwater harvesting and aquifer storage and recovery system comprises of **three separate, but interrelated subsystems** (Figure 5.1), as described in Section 5:

- System 1: Residential Rainwater Harvesting system
- System 2: Slow Sand Filtration system
- System 3: Aquifer Storage and Recovery system

Figure 6.1 Panoramic view of the site, from north to south

The analytical technical description of systems as well as the research that has been conducted to assess the behaviour of the aquifer recharge capacity and storage potential are described in the following sections.

6.1 Residential Rainwater Harvesting system

6.1.1 Analytical technical description of subsystem 1

In Subsystem 1 of the configuration (Figure 6.2), rainwater is harvested from the residential roofs of the site (from about 438 m^2), transferred through a manhole and reserved in the existing water storage tank of 70 m^3 (Figure 6.3). This water is used mainly for domestic non-potable purposes of the existing buildings in the site e.g. washing, flushing toilets according to the water management design of D2.1.

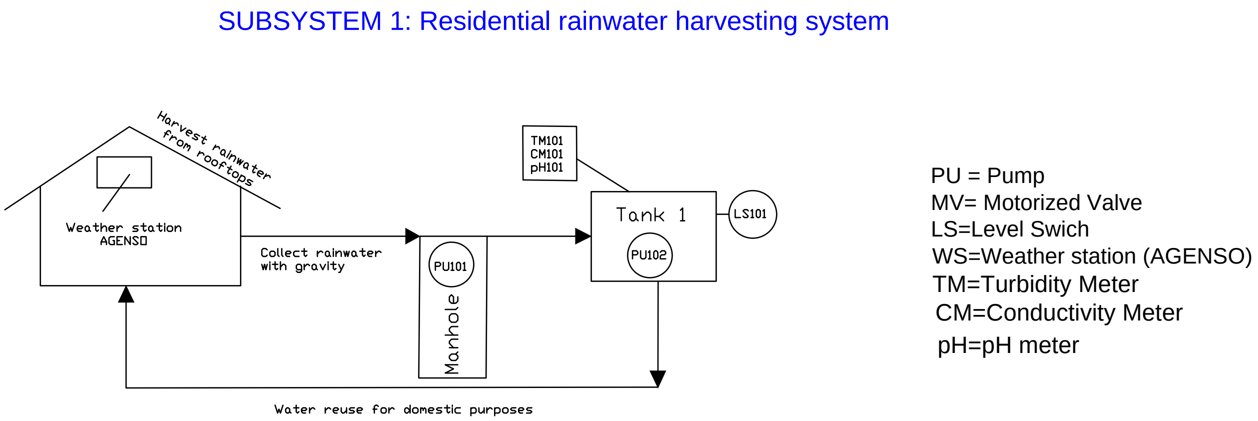


Figure 6.2 P&ID of the Residential Rainwater Harvesting System (subsystem 1)

Figure 6.3 Existing tank T1 with a capacity of 70m^3

Calculations & water management design

According to the initial calculations, the needs for non-potable uses can be fully covered at an annual level by rainwater harvesting from the building roofs, with a positive mean water balance of about 7 m^3. At a monthly level, for the wet period, October to March, an excess of water (about 50 m^3) has been estimated, which can be stored in the tank of 70 m^3 to be reused in the dry period of April to September, when a negative water balance of about 43 m^3 is expected.

Based on the current estimations, most probably Subsystem 1 should have excess water of about 7 m^3 at an annual level, which can be further reused in Subsystem 3 for aquifer storage and recovery schemes. For this purpose, any overflow of the subsystem 1 is sent through a piping network to subsystem 3 and in particular to manhole M2 (Figure 6.6).

Construction work

With regard to the construction works of this system, the main tasks that took place according to the design specifications of D2.1 include:

- Restoration and cleaning of the existing tank T1 (70 m^3) (Figure 6.3).
- Restoration of the roofs and adaptation of the roof gradient to collect the rainwater (Figure 6.4).

Figure 6.4 Upgrade and restoration of the rainwater collection surfaces in the roof

- Restoration of the gutters of the buildings and installation of new ones (Figure 6.5).
- Construction of a new manhole (M1) of about 1m x 1m x 1m (L x W x H) to collect the rainwater from the roofs through the piping network (Figure 6.5).
- Installation of a network of appropriate pipelines and two pumps to transfer water from the roofs to the manhole M1 and the water tank T1 and from the tank back to the houses (Figure 6.5).
- Set up of the piping work for any potential overflow of tank T1 to be sent to the manhole M2 for subsystem 3.

Figure 6.5 Restoration / installation of gutters, construction of a manhole & setup of water pipe network

Monitoring

Additionally, monitoring activities that include measuring the water level of the tank as well as the quality parameters such as the pH, the turbidity and the conductivity of water are monitored through sensors that are installed in this subsystem. With regard to the automation plan (shown and explained in D5.*5 Design and Implementation of ICT infrastructure for data gathering and controlling*), the design of the initial scenario is complete. Also, the electrical diagram of this system has been produced and the implementation of the automations are in the process of being developed. The purpose is to monitor the wet period of 2020-2021 and propose optimisation set up if necessary.

List of Drawings as built

The flow diagram of subsystem 1 for the residential rainwater harvesting system is illustrated on the site topographic map in Figure 6.6.

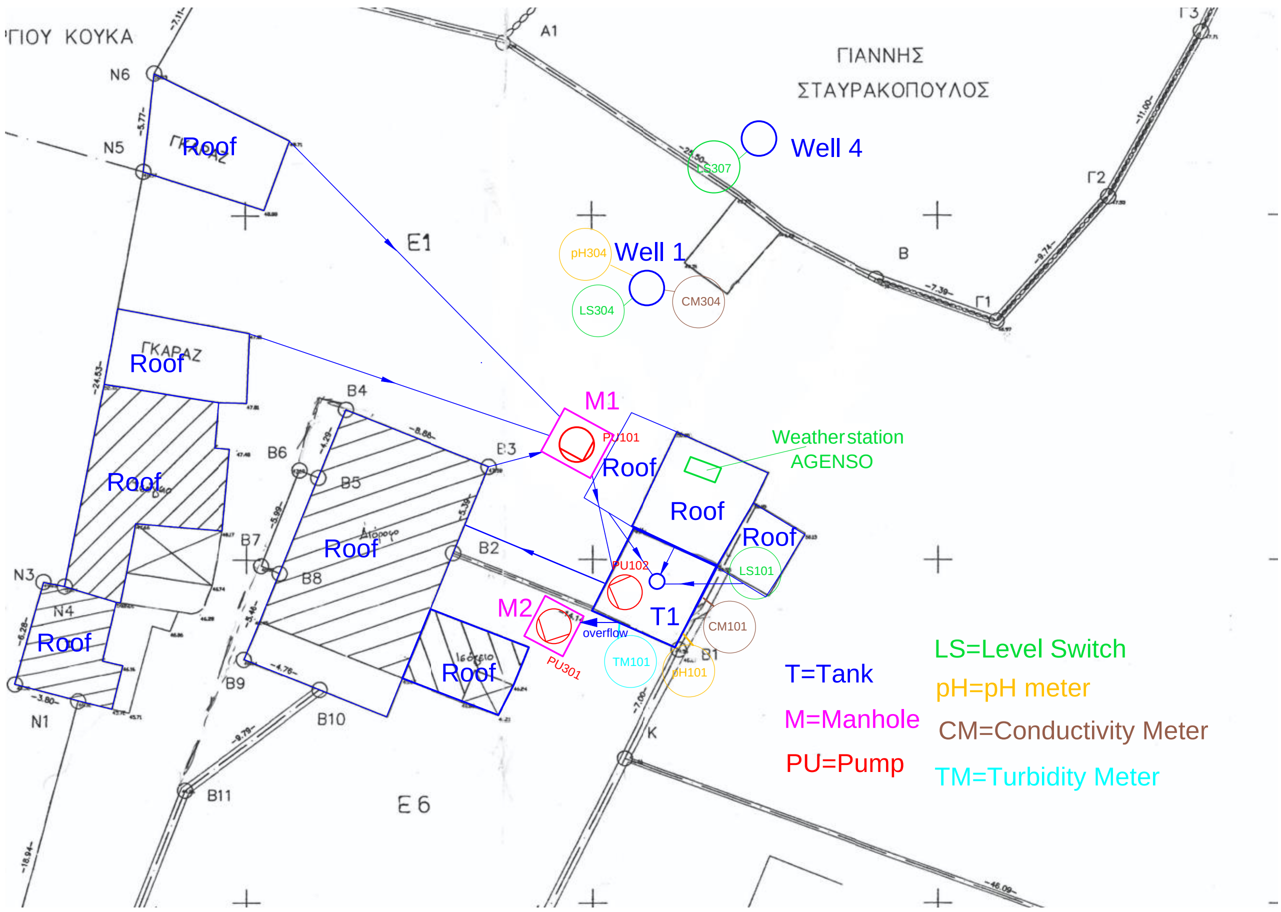


Figure 6.6 Flow diagram of the Residential Rainwater Harvesting System (subsystem 1)

6.1.2 Deviations from the design deliverable for Subsystem 1

HYDRO4 is currently operational with some automations already installed (level sensors in tanks, pH meters). We intend to complete the automation in order to facilitate the two-year monitoring of the residential rainwater harvesting system. This includes:

- Full implementation of the automation plan to be installed on the site for the automated control of the system (linked with WP5)
- Further installation of sensors for monitoring activities, which include monitoring of the water level (quantity) as well as the pH, the conductivity and the turbidity of water (quality) in Tank 1 (linked with WP5). The respective sensors will be monitoring the wet period of 2020-2021 and optimise the operation of the system.

These activities were planned to be completed in 2020; however, due to the COVID-19 there was a deviation from the initial planning.

6.2 Slow Sand Filtration system

The Slow Sand Filtration system (SSF) is a well-recognized water purification system that converts raw water like rainwater or water from rivers, groundwater etc. into a potable product. The working principle is that raw water flows through a sand-bed system which is populated by microorganisms. Various biological, physical, chemical and mechanical processes purify the water. SSF systems are available with different construction types.

In subsystem 2, the Slow Sand Filtration system is implemented using a small amount of water, to test whether the treated water could fulfil the quality criteria for potable water in other replication sites, especially in cases where the legal framework allows such use. There are two types of SSF that will be tested in the HYDRO4 site:

(a) **SSF-community**, which requires continuous flow

(b) **SSF-household**, which can operate with intermittent flow

A technical description of the SSF is provided in section 6.2.1 Analytical technical description of subsystem 2.

6.2.1 Analytical technical description of subsystem 2

There are two types of SSF that will be tested in the HYDRO4 site: (a) SSF-community, which requires continuous flow and (b) SSF-household, which can operate with intermittent flow. The pilot validation of the SSF occurs once per year. Within HYDROUSA, the developed system can be operated either as SSF-community or SSF-household. This system is connected to the water storage tank as a floater system and sensors control the operation of the pump to allow for correct water flow during the testing period (detailed description of the system in the D2.1). In HYDPOUSA, two tests are conducted with the SSF: i) as SSF-community tests in year 2 (2021) and ii) for SSF-household tests in year 3 (2022). These two systems will be demonstrated in two SSF types; one SSF will be developed with reused materials by ALCN and one with new materials by DELAROS.

In HYDRO4, 10 L per day of potable water is required to be produced, that is sufficient to cover the drinking purpose needs of 5 people per day. The test shall run during or after the rainy season. The time required to test the SSF system is about 45 days. During this time, 30 days are needed for the development of the biolayer (filter) and 15 for monitoring the water quality. It will start operating around April 2021 after the wet period. Test periods of 1-1.5 months will take place at different times in the year in order to check the water quality. In year 3 of HYDROUSA, the SSF will operate with SSF-community's type.

The construction of the first SSF prototype and the preparation of SSF installation at HYDRO4, the sieving of sand and gravel are described in the following section.

Calculations & water management design

The SSF design of ALCN is based on the principle of upcycling. A low-cost plastic barrel (Figure 6.7) available in the local market has been reused for the SSF. These barrels are often used in Greece to store olives or used to store various liquids. In HYDROUSA, the aim is to produce low cost technologies on nature-based solutions. In this way, low-cost and environmentally friendly technologies are becoming attractive to rural and remote areas where they can easily be replicated. We choose a barrel of half a meter with a height ca 1m so that it is easy to be transported if required. Water flow calculation was based on the selected tank dimensions. In addition, the materials to develop the layers, also mentioned in Table 6.1, were locally sourced in HYDRO4. The sieves were build based on the requirements of the project (see Table 6.1), they are DIY.

Figure 6.7 SSF tank – 230L for food transportation or liquid

Table 6.1 Material required to build HYDROUSA's SSF

SSF layer	Material
Fine sand-Filtration sand layer	60 cm of sand with size <1 mm, around 150 L
Gravel-Separating layer	5-7 cm of gravel with size 0.7-6 mm, around 12-17 L
Coarse gravel-Underdrain layer	10 cm of gravel with size 6-12 mm, around 25 L

Construction activities

Within the project's framework, the required construction effort could be summarized based on the numbers of hours required to run the test as explained below.

The total test period will be 6 weeks and the necessary construction activities include:

- construct the SSF
- connect the SSF with the rest of the water management systems in HYDRO4
- biolayer formation and monitor its development - 30 days to develop (at least 3 weeks) (Clark, Pinedo, Fadus, & Capuzzi, 2012)

- monitor water quality and observe the system daily
- collect water samples
- clean the system if required
- refurbish the system if required
- post-treatment of water with UV if required

Figure 6.8 depicts the stages required to obtain the various layers of sand and gravel.

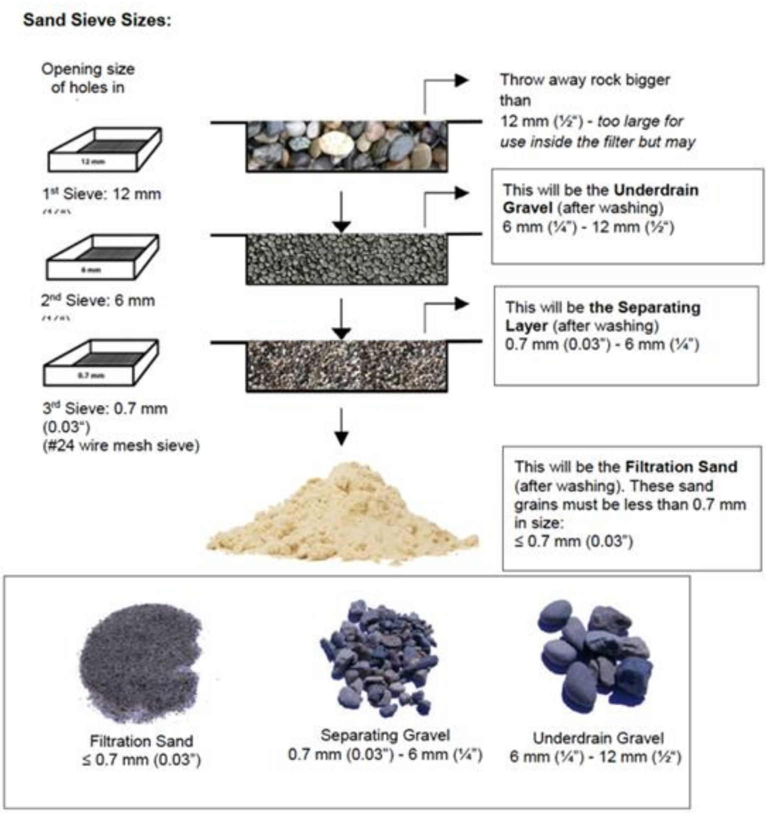


Figure 6.8 Description of steps how to sieve the sand & gravels for filter's construction

(Source: Samaritan's Purse Canada & CAWST, 2017)

List of Drawings as built

In Figure 6.9 the cross section of the SSF system is illustrated.

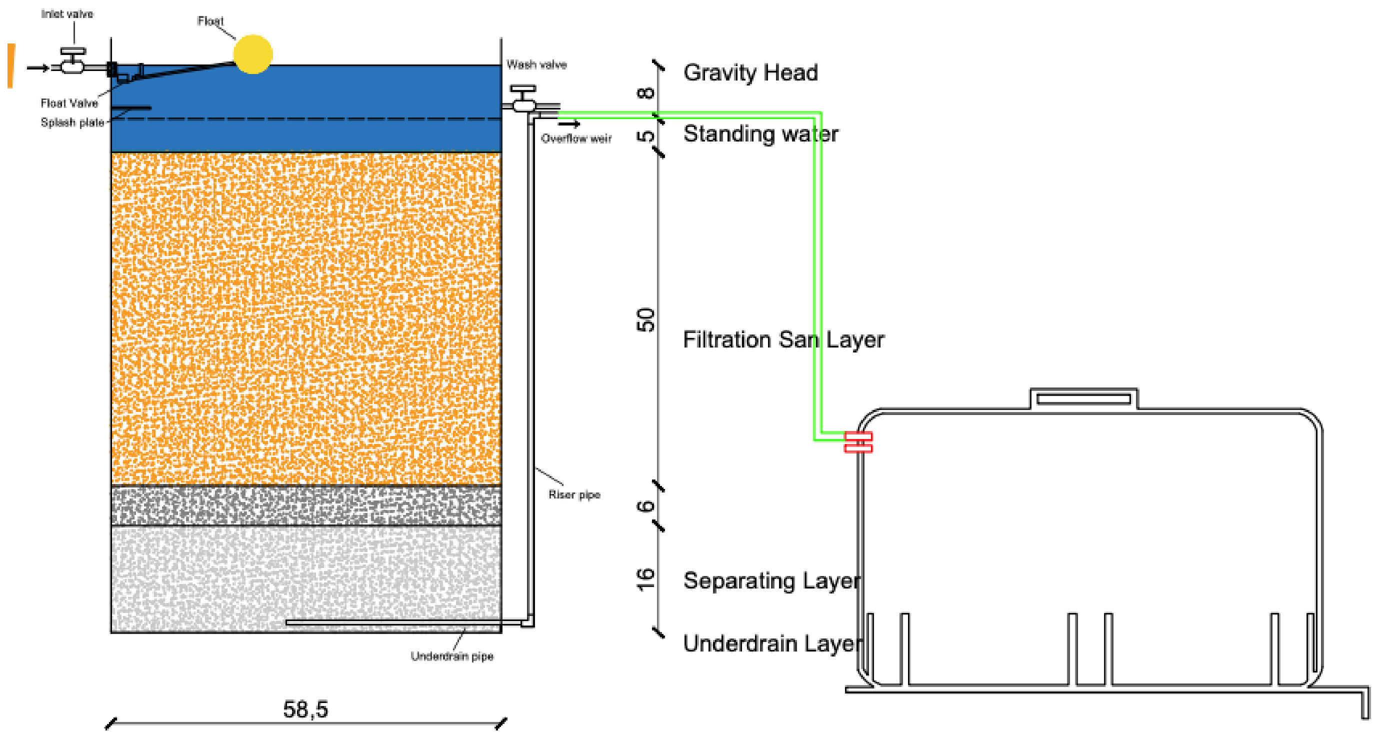


Figure 6.9 Cross section of SSF system

SSF System - forthcoming and remaining activities

The next steps of the SSF installation are to wash the material which will form the layers, connect it to the system, operate and run the tests. The barrel at the site is marked for the height for each layer.

Monitoring

The SSF system will be connected to the storage reservoir of system 1 (Tank 1) and will also be linked to a storage tank/bucket. A constant flow of water will be fed for year 1, while the flow rate will be adjusted in year 2 when the SSF-household will run. The volume of filtered water will be monitored. The daily filtered water volume shall be constant in all cases. If it changes, cleaning is required.

6.2.2 Deviations from the design deliverable for Subsystem 2

Some deviations from the designed deliverable occurred, for example the site of the layers had to be adjusted according to the barrel that was reused.

Based on the dimension of the tank the biolayers were calculated as follows:

Filter tank Diameter: 58-59 cm

Height: 95 cm

Surface area: 0.27 m^2

Gravity Head: 8 cm height

Standing water: 5 cm height

Filtration Sand Layer: 50 cm height

Separating Layer: 6 cm height

Underdrain Layer: from bottom 16 cm height

6.3 Aquifer Storage and Recovery system

6.3.1 Concept of subsystem 3

The main concept of the Aquifer Storage and Recovery system, illustrated in Figure 6.10 , is described below. Rainwater is collected from two sources:

1. The **surface runoff** of the impermeable surfaces of the private property of the site (from about 596 m^2) is designed to be collected in the wet period and used for irrigation purposes during the dry period. In particular, the surface runoff is guided to a new manhole (M2) and then transferred to be reserved in the existing water storage tank T2 (Figure 6.10). Once tank T2 is almost full, the excess water is transferred, through the new piping network to recharge the aquifer in the optimum location that was identified through the previous research that was conducted in the framework of the project for this purpose (see D2.1). In the dry period, excess water from the surface runoff, already collected in tank T2, is sent through the pipes to irrigate the lavender field. Additionally, water for irrigation is recovered from the new AR well. Finally, excess water of the AR well can be stored in tank T2 to be used for irrigation later in the dry period.

2. Additionally, water is collected through a **bioswale system** (an open-channel linear drainage system), stored in the open tank and in the subsurface “basin” to be used in the summer period (Figure 6.10). The bioswale is placed in a NE-SW direction of the site, to collect and partially treat storm water. The purpose of this system is twofold: First, the water is used for recharging the aquifer and using it for irrigation purposes of the lavender field. Second, this system attempts to prevent the lavender field from flooding, as the storm water originating from nearby upstream properties often floods the site, preventing the field from growing crops. In particular, during the wet period, water is transferred and reserved in the open tank T through a new manhole (M3) that has been constructed to act as a buffer tank (Figure 6.10). Once the open tank is full, water is reserved in the tank and the excess water from the bioswale is transferred through pipes and a pump to the location that has been identified for recharging the aquifer and storing water in the subsurface. It should be noted that from previous research, the optimum area for the subsurface basin (with impermeable layers of granite) has been identified to act as a temporary water buffer, in order to extend water availability, towards the dry period. Thus, this water is stored in the ground until the end of the wet period to recover it in the summer for the irrigation of the lavender.

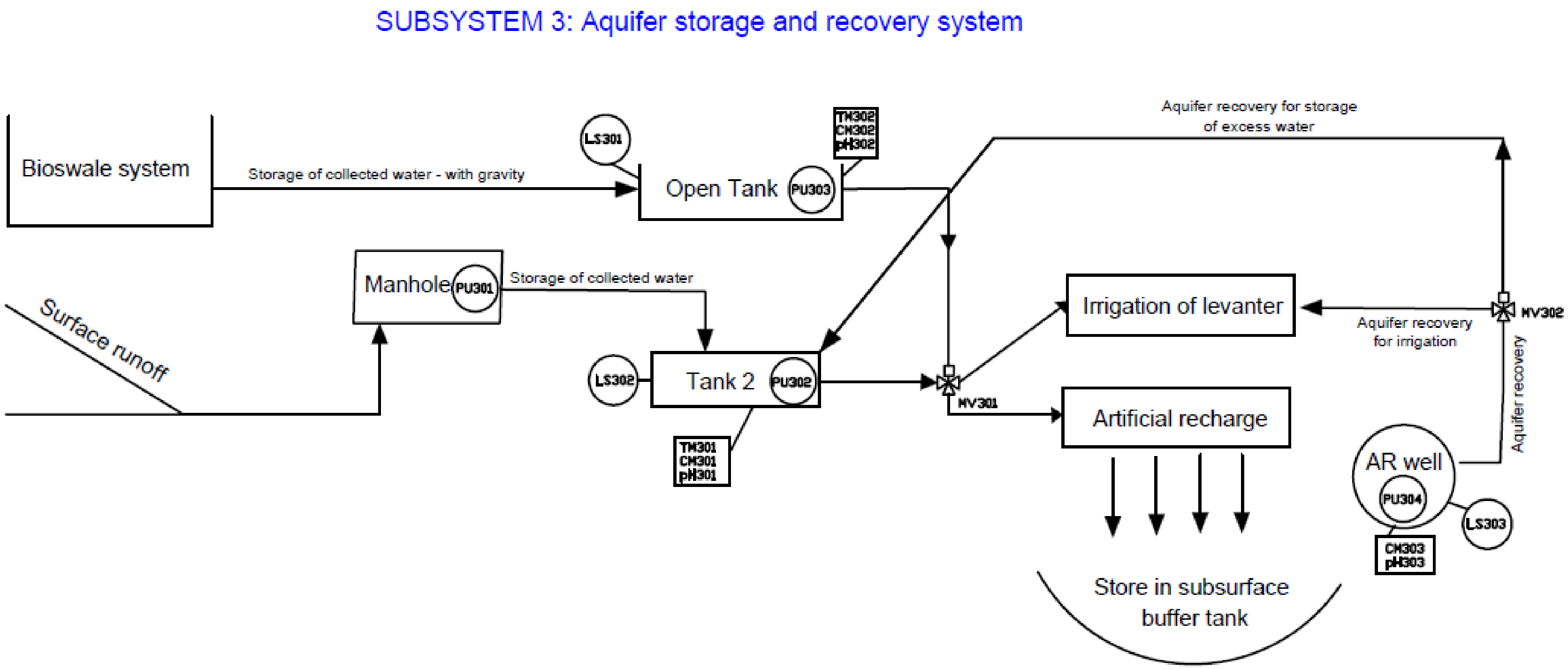


Figure 6.10 P&ID of the Aquifer Storage and Recovery System (subsystem 3)

6.3.2 Assessment of the soil and aquifer characteristics

For the implementation of the previously mentioned systems, first an assessment of the soil and aquifer characteristics has been performed based on the field surveys that were conducted in November – December 2018.

Stratigraphic layering of the selected aquifer

The test site of Ano Mera rests on Mykonos granite, along a junction of two major faults (D2.1). Field observations and ERT transects testify to the presence of a fault, which splits the HYDRO4 site in two parts (Figure 6.11).

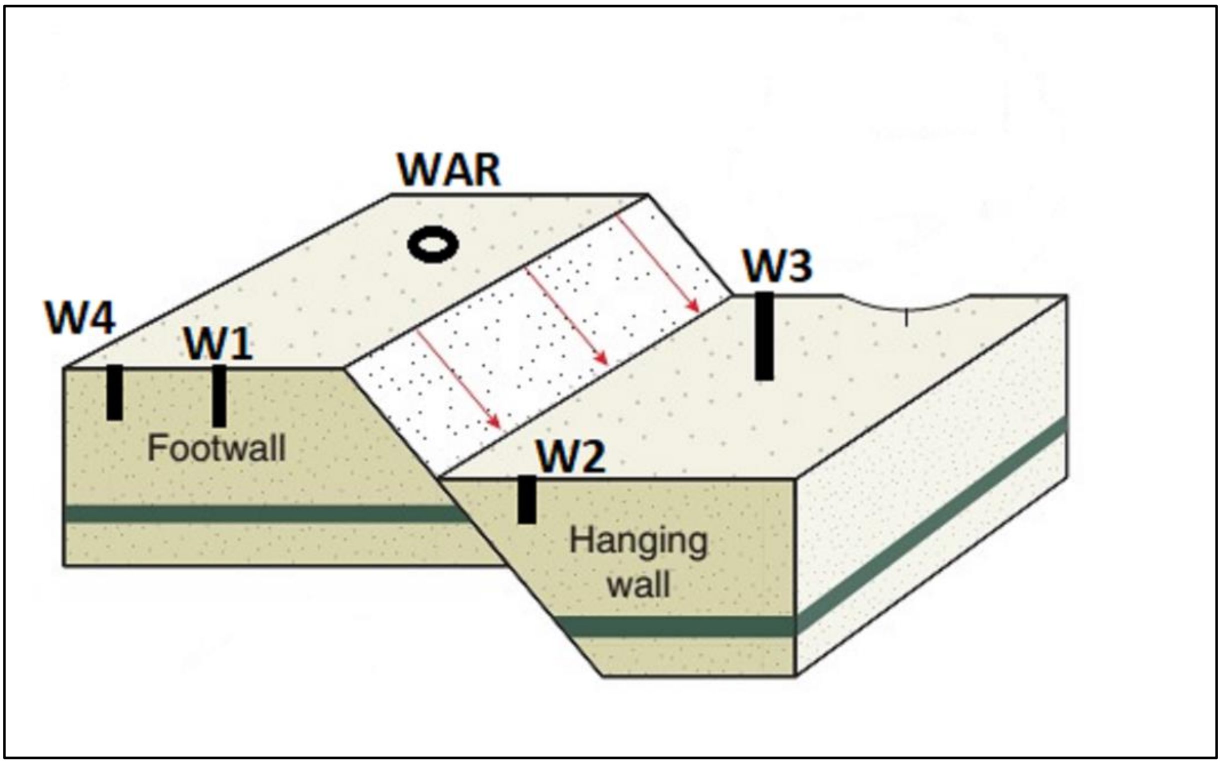


Figure 6.11 Generalized illustration of the tectonic setting of HYDRO4 site

Such a geological and tectonic setting confines the favourable groundwater storage buffer along the footwall, where several natural depressions are evident from ERT transects. This area was selected for the exaction of the artificial recharge (AR) well (W_{AR}).

The stratigraphic structure of the W_{AR} is typical of the granitic formations weathering zones, with subsequent residual soil formation. During the W_{AR} excavation, the soil profile was revealed (Figure 6.12).

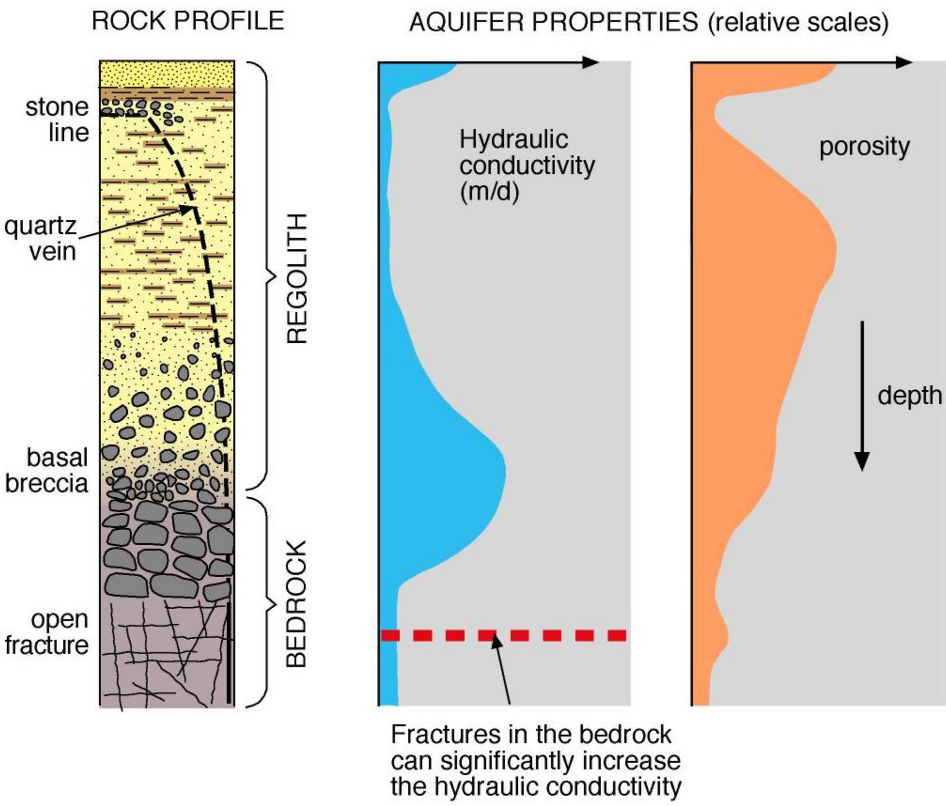


Figure 6.12 Soil profile and aquifer subsurface stratigraphic layering

The excavation and construction of W_{AR} well in June 2019, provided a visual representation of the stratigraphic layering of the selected aquifer. As expected, water level recuperation in both W_{AR} and W1 was slow due to the sedimenotological characteristics of the weathering zone of the underlying granite formation and of the under saturation of the zone during the summer months due to intense evaporation.

Taking into account the geological and geophysical results of the field investigations carried out, calculations of the porosity and storativity of HYDRO4 aquifer have been conducted. In-situ soil characterization in combinations with the ERT profile results confirmed the existence of three (3) distinct layers / Zones (I, II and III), with different textural and electrical resistivity values as follows:

Zone I: Granitic weathered mantle (saprolite). Red stiff residual soil in the surface, with granitic in-situ weathered unconsolidated products. Variable clay content within a silty sand matrix and electrical resistivity values between 0 and 60 Ohm·m.

Zone II: Granitic weathered zone. Red – yellow sandy soil with gravels and basal breccia (60 – 100 Ohm·m).

Zone III: Granitic bedrock usually fractured. Defined only from the ERT profiles (> 150 Ohm·m).

The vertical variation granite weathering profile can define the soil-water retention capacities of HYDRO4 test site, but water permeability in Zones I and II, where W_{AR} was emplaced, is expected to be low.

HYDRO4 local aquifer configuration

HYDRO4 aquifer is located along an NW-SE trending fault and this geological setting confines the favourable groundwater storage buffer along the footwall plane, where several natural depressions are evident from the ERT transects. Potential leakage of groundwater during the wet season towards the fault plane surface cannot be ruled out, but this process may be restricted due to the minimal topographic and hydraulic slopes along the test site. Potential leakage of the HYDRO4 aquifer towards the fault plane (black arrow) is likely to occur upon saturation of Zone I during the wet season (Figure 6.13).

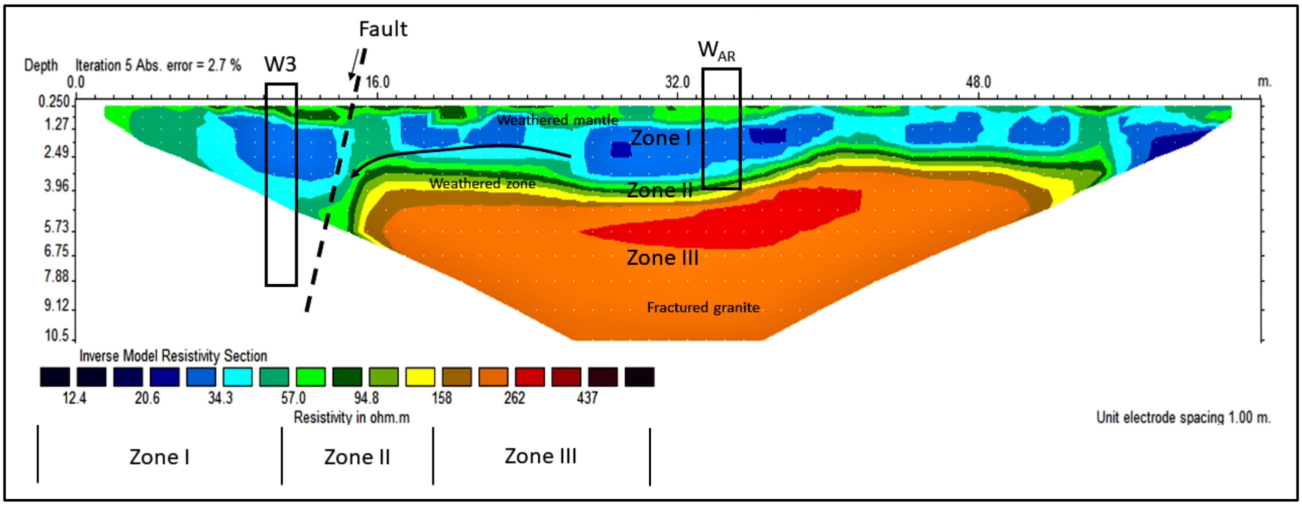


Figure 6.13 HYDRO4 aquifer illustrated by the Electrical Resistivity Tomography (ERT) profile LR25

Note: for location see relevant Figures in D2.1

The conceptual model of HYDRO4 local aquifer is illustrated in Figure 6.14 . Direct measurements by the end of the 2019 wet season placed the regional piezometric level at 5.5 mbgl (below ground level). Blue arrows of Figure 6.14 correspond to the W_{AR} recharge patterns, which can be either from vertical and lateral recharge and surface seepage flow along the contact with the bedrock, or from groundwater pump from the wet season rising regional piezometric level. ERT profile LR27 is also illustrated (in respective figures of D2.1) along with the conceptual setting of wells W1, W2, W3 and W4.

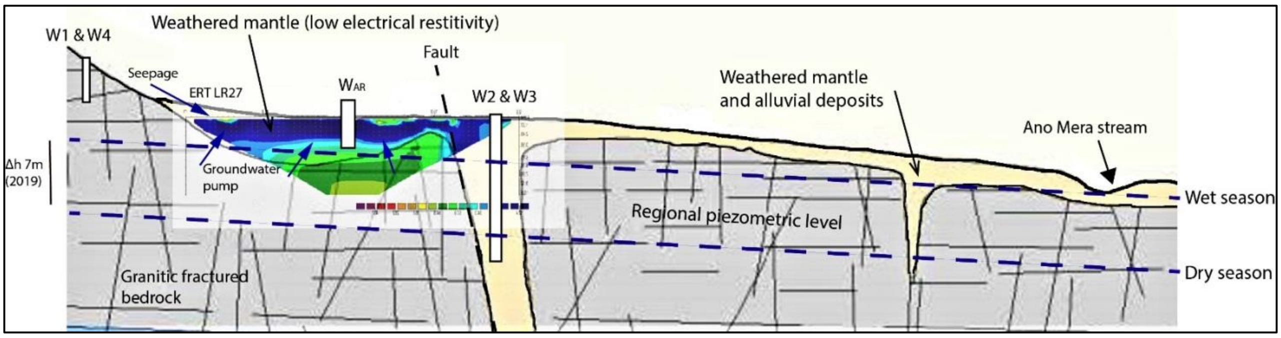


Figure 6.14 Conceptual model of HYDRO4 local aquifer

The HYDRO4 local aquifer, where W_{AR} is excavated, has a thickness of 4 mbgl (meters below ground level) and consists mainly of Zone I and at its basal part of Zone II sediments. Zone I has a small amount of clay with resistivity values below 20 Ohm·m (Figure 6.15), which locally reduce the hydraulic conductivity (K) of the aquifer.

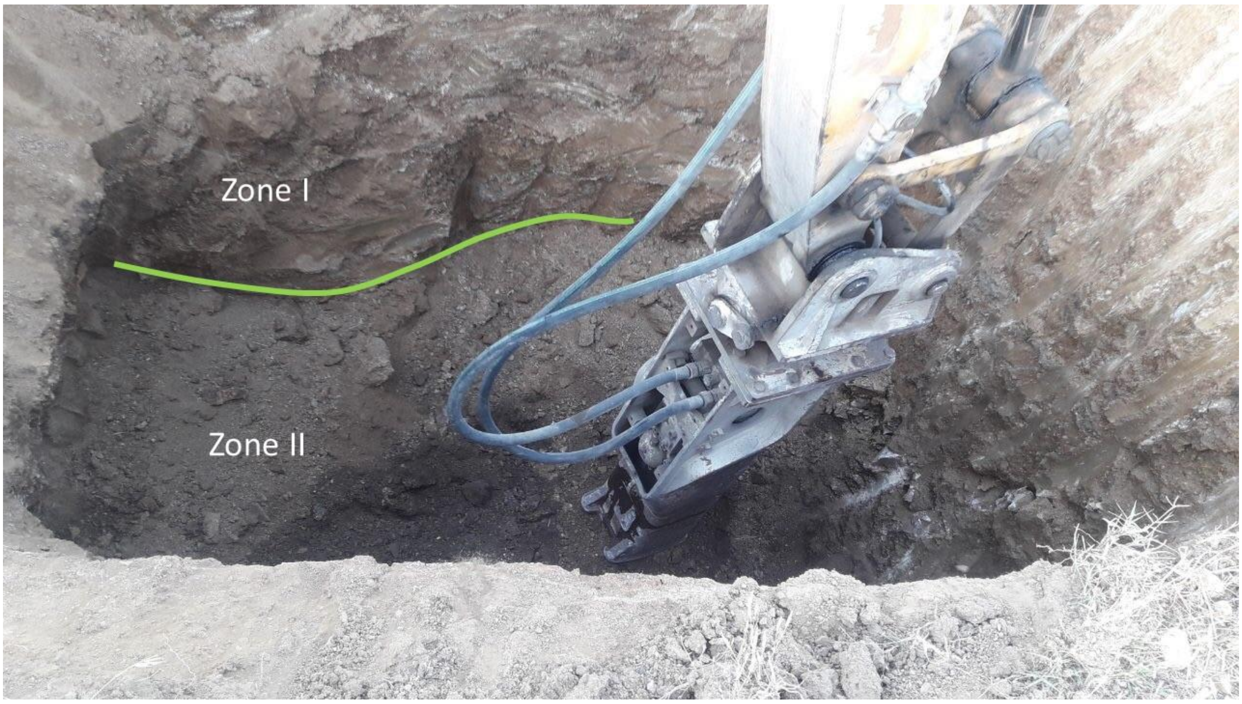


Figure 6.15 Weathering and residual soil profile vertical variation with Zones I and II of HYDRO4, during W_{AR} excavation

Average K values of granitic weathered mantle soils range between $7 \cdot 10^{-7}$ to $1 \cdot 10^{-5}$ m/s (Dewandel et al., 2006, Table 5), but given the small appearances of clay in ERT profile LR25 (deep blue colours), K values are expected to be in the upper range of these values (e.g. K = 1 x 10^{-6} m/s).

At the base of W_{AR}, the amount of sand and gravel increase in expanse of the finer fractions and comprise the thin granitic weathered zone (Zone II). Zone II, which is the transition layer between the unsaturated zone (Zone I) and the fractured bedrock (Zone III) and should only be considered as a recovery zone of the stored groundwater, irrespective of whether the recharge is natural (rainfall) or artificial.

<u>Water levels in wells W1-4</u>

Following a wet winter period 2018-2019 with a total of 473.6 mm of rainfall (December - June), being 152 mm above last decade's average (319 mm, D2.1), the levels of the existing wells were considerable higher (Table 6.2), all measured from the edges of the wells. During the excavation of W_{AR}, high moisture amounts were observed at the base layer, implying that the saturated zone at least during the dry (summer) season is below the depth of W_{AR} (5 m).

Table 6.2 Water levels in November 2018 and June 2019

Well	24/11/2018	20/06/2019
W1	5.43	3
W2	9.43	5.14
W3	14.3	5.32
W4	2.3	1.38
W_{AR}	not excavated	moisture

The water levels of wells W2 and W3 along the fault's hanging wall, had a significant increase (4.3 m and 9 m respectively) in comparison to wells W1 and W4, which are excavated in the granitic bedrock. The difference between the recharge capacity between W2, W3 and W1, W4 points to different groundwater paths for the footwall and hanging wall respectively. The restricted nature of W1 and W4, which are excavated in the bedrock and potentially of W_{AR}, which was constructed in the granitic weathering zone, constitute them a potential good solution for subsurface water storage. Surface aquifer saturation under wet conditions with reduced evaporation (winter period) may saturate the aquifer and lead to surface seepage flow in the area near W_{AR}, with potential leakage of water along the fault plane towards W2 and W3.

6.3.3 Experimental activities to assess the aquifer behaviour

As a follow-up to the geological and geophysical investigations conducted in November – December 2018, a series of field experiments were undertaken in June 2019 to provide a thorough understanding of the hydraulic behaviour of the aquifer selected to act as the buffer for water storage. In particular, four AR experiments were implemented in the constructed AR well (W_{AR}) and the oldest W1 well, complemented by water level recuperation monitoring (Figure 6.16).

Figure 6.16 Field experiments (June 2019)

Artificial Recharge (AR) experiments

Due to the above mentioned geological constraints and the geological partitioning between W1, W4 and W2, W3, the recharge experiments focused on wells W1 and W_{AR}, located on the upper part of the fault line (footwall), with parallel monitoring of W2, W3 and W4. A recharge rate of 2.7 m^3/h was applied to both W1 and W_{AR} injection – recovery tests and for different time intervals. Recharge experiments duration, with direct water injection in the wells was 2 h for W1 (Figure 6.17) and 4 h for W_{AR}, which was followed by a 10 h (600 min) recovery of the water level (Figure 6.18).

Following the recovery interval, water was directly infiltrated in the soil within a 5 m radius from W_{AR} (surface area of 80 m^2), in an effort to imitate the natural rain conditions. In total, 73 m^3 of water were injected directly inside and around W_{AR}, a volume of nearly two times larger, than the estimated infiltrated water volume of 32 m^3 resulting from the average wet season (winter – spring) rainfall of 319 mm (D2.1).

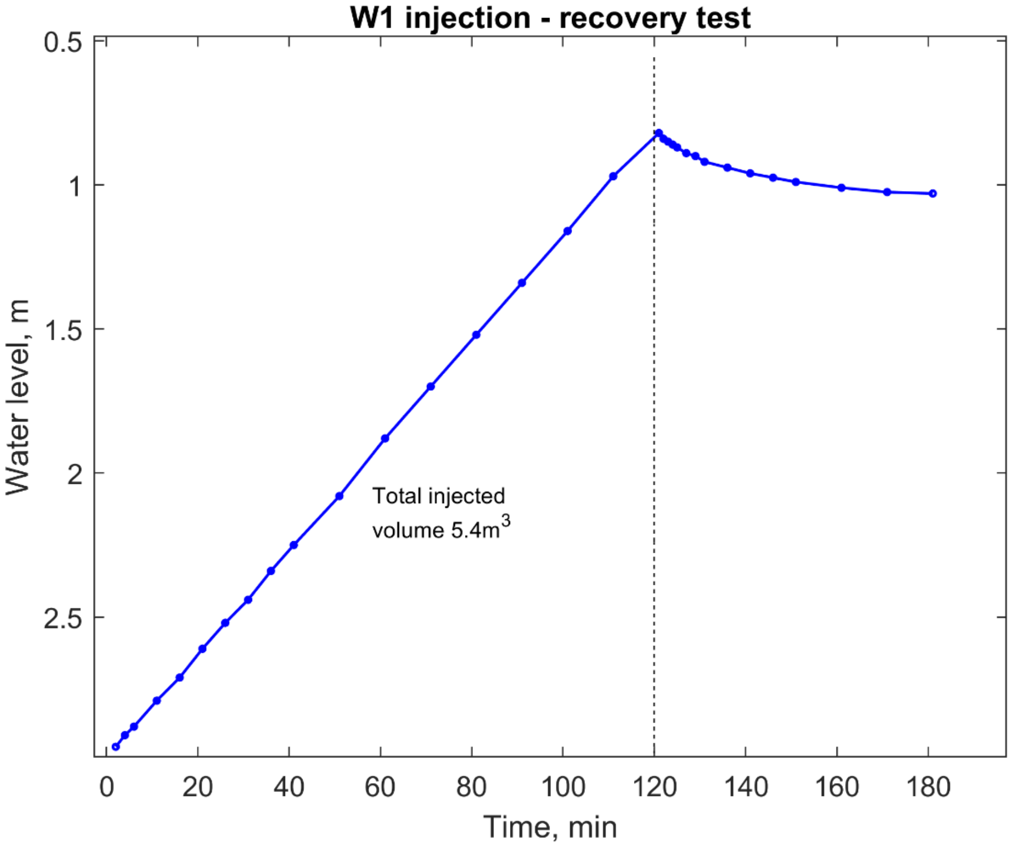


Figure 6.17 Well W1 hydraulic behaviour with 2 hours of injection and 1 hour of recovery monitoring

W1 injection – recovery test

The hydraulic behaviour of W1 is characteristic of a well excavated in the bedrock, with recharge through the granitic fractures. Groundwater flow after an “above average” wet season like the winter-spring period of 2018 - 2019, resulted to a recharge water volume of approximately 2 m^3 and a “little gain – little loss” hydraulic behaviour. W1 hydraulic behaviour becomes evident from the injection – recovery test, where the asymptotic loss was reached 1 hour following the injection of 5.4 m^3 (Figure 6.17).

WAR injection – recovery tests

The main goal of the AR, is to have enough water stored under the ground during the wet season, with subsequent recovery during the dry season for the irrigation of lavender. In order to test the behaviour of the surface aquifer in close proximity to W_{AR}, AR recharge was realized both with direct injection and with surface wetting of the bare soil in 4 points within the surface area of 80 m^2. The position of the surface infiltration / wetting points, changed every 4 hours to ensure the largest surface infiltration area possible. The average water discharge at each point was 0.65 m^3/h, which accounts to an average infiltration rate of approximately 8mm/h for the entire area, and a total of 96 mm of total infiltrated water during infiltration / wetting experiment.

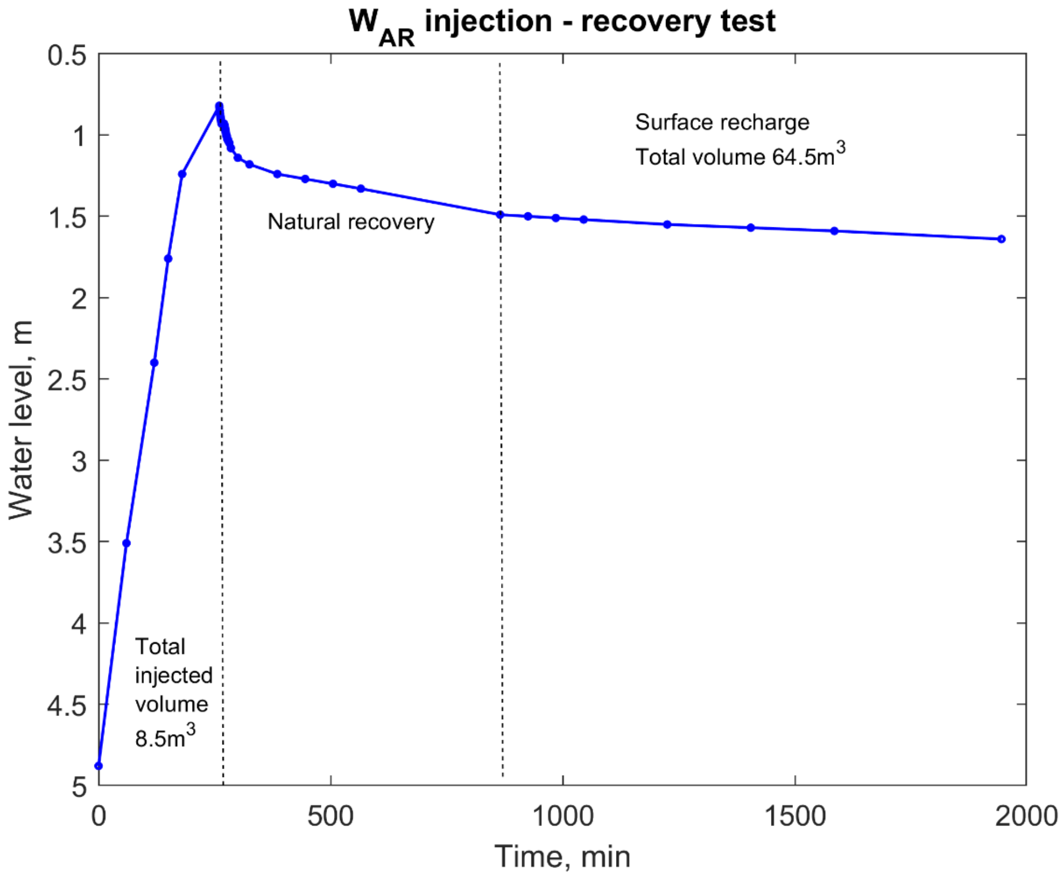


Figure 6.18 Results of the double AR experiment in W_{AR}, with the subsequent direct injection, natural recovery and surface infiltration / wetting parts, respectively

During the direct injection experiment, the water level rose rapidly to 0.82 cm, and the natural recovery was very slow, as illustrated in Figure 6.18. This trend continued despite the 24 h surface wetting of the soil, implying that the surface infiltrated water did not reach the W_{AR} saturated zone. The hydraulic detachment between the unsaturated and saturated zones, can be attributed to the low permeability and hydraulic conductivity of Zones I and II, to the large volume of the unsaturated zone as evidenced by the ERT profiles, to the high values of surface and groundwater evaporation and/or to insufficient time and water volume of the recharge experiment. Leakage of the injected and infiltrated water towards the faults hanging wall and well W3, is plausible but monitoring of the water level in W3 did not show any significant increase. The low permeability of Zones I and II may require more time and infiltrated volume of water for any significant changes to occur in W3, but other mechanisms have also to be considered.

In semi-arid areas, like the Cyclades groundwater evaporation has been found to account for 30% of the total evaporation (Lubczynski, 2011). The average annual evapotranspiration in the island of Mykonos is 282.2 mm/yr[1], and occurs mainly during the dry season due to increased solar radiation and higher air temperatures, so the groundwater evaporation during the dry season can potentially account for 85 mm. Such high values of

[1] http://environ.chemeng.ntua.gr/wsm/Newsletters/Issue2/Cyclades.htm

evaporation can result to complete dryness of the unsaturated zone, with very little or nearly zero capillary flow between the saturated zone and the ground surface (Balugani et al., 2017). Despite the infiltrated volume of 64.5 m^3, hydraulic connection between the saturated and unsaturated zones, through surface infiltration and wetting of the surface residual soil, was not achieved.

Conclusions

The artificial recharge (AR) experiments, described above, provided a unique opportunity to verify the geological structure and subsurface conditions of the selected aquifer, to evaluate its water retention capacity, but to also optimize the domestic set up of the site. With regards to the four (4) AR experiments that took place in HYDRO4 site, some basic conclusions were drawn:

- The aquifer near W_{AR} is characterized by 2 distinct zones of granitic weathered residual soil (Zone I) and of the uppermost part of basal breccia with a mixture of silt, sand, gravel and boulders (Zone II). The base of Zone II retained significant moisture 2 months after the termination of the wet season.
- Wet season was above average with an additional 152 mm of rainfall.
- Zones I and II demonstrate low permeability of the weathered material with potential limitations in the unsaturated zone storage and recovery capacity.
- Well W1 is indicative of an excavated well within the granitic bedrock and basal breccia, demonstrating a “little gain – little loss” hydraulic behaviour. Natural recharge occurs mainly through the granitic fracture system.
- Well W_{AR}, was artificially recharged by both direct water injection into the well and by surface infiltration and wetting of the soil across a surface area of 80 m^2, with a total recharge water volume of 73 m^3.
- Recovery of W_{AR} was slow due to the unsaturated aquifer, low permeability, large volume and high surface and groundwater evaporation values.
- Based on the above conclusions it is recommended that monitoring of the level of W_{AR} during the wet season will better define its hydraulic behaviour, storage capacity and recovery potential to meet the initial goals of HYDRO4.

6.3.4 Assessment of groundwater aquifer recharge and storage potential

This section presents the assessment of the HYDRO4 aquifer recharge and storage potential, with data derived from the monitoring of meteorological variables and of the aquifer groundwater level (GWL) over the 2019/2020 wet season. It also considers all the previous existing field experiments, along with the geophysical and geological assessment of the HYDRO4 test site in Ano Mera.

HYDRO4 aquifer recharge patterns

Observation wells W1 and W4, excavated directly in the granitic bedrock along the fault’s footwall, are recharged during the wet season either by seepage surface flow over the bedrock, or by the bedrock’s crack system and exhibit a “little gain – little loss” hydraulic behaviour. W2 and W3 represent the regional piezometric level. Monitoring well W_{AR} is a concrete well with an open base excavated in the granitic weathered mantle and weathered zone (Zone I and II) sediments (Figure 6.19).

W_{AR} is screened along the lower 1 m. Numerous holes have been manually drilled in the concrete wall to permit groundwater recharge (Figure 6.19). Aquifer recharge near W_{AR} mainly occurs as vertical infiltration from the ground surface, as the topographic and hydraulic gradients across the test site are very low. Seepage flow and subsequent lateral recharge as well as groundwater pump from Zone II may also occur during the wet season and contribute to the natural recharge of HYDRO4 aquifer.

Upon excavation of W_{AR} (June 2019), the basal part of Zone II retained moisture below 4 mbgl, with the regional piezometric level measured in W2 and W3, being at 5.5 mbgl, suggesting hydraulic connectivity during the onset of the dry season. Thus, the synergistic action of the vertical infiltration, seepage lateral infiltration and groundwater pump mechanisms, during the wet season is the dominant mechanism of the HYDRO4 aquifer recharge.

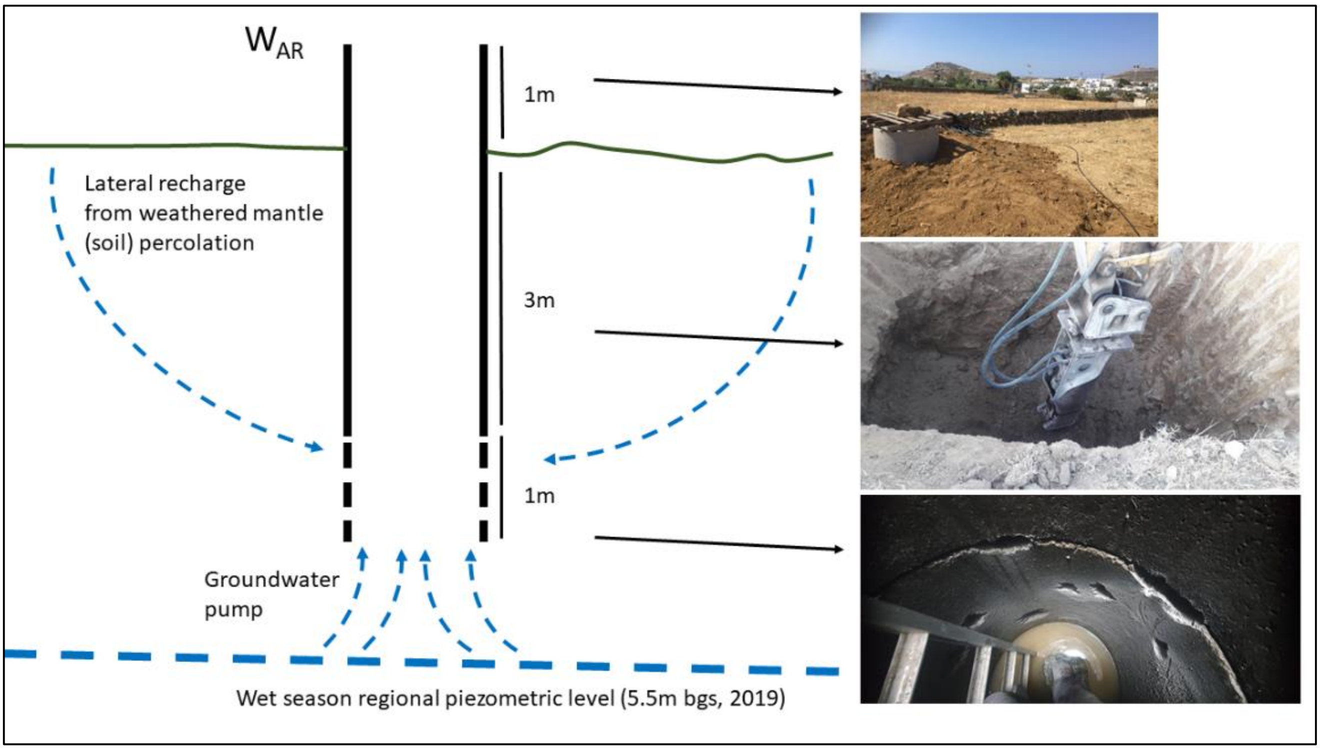


Figure 6.19 Schematic setting of the recharge well W_{AR} and the recharge pathways, supplemented by photographic material of W_{AR} (top), weathered mantle during excavation (middle) & the screens in the lower 1m of the well (bottom)

The surface area that topographically contributes water to HYDRO4 local aquifer is about 3,350 m^2. Based on the geometry and average depths of the sedimentary layers (Zones I and II) derived from the ERT profiles (D2.1), it is postulated that the total volume of sediments within HYDRO4 local aquifer is approximately 7,000 m^3. This rough estimate excludes the thin granitic weathered zone (Zone II) and includes only the weathered mantle (Zone I), which corresponds to the HYDRO4 aquifer unsaturated zone with optimum storage and recovery potential. Taking the most conservative porosity estimates (15%) for weathered mantle sediments of crystalline rocks derived from the literature (Opeyemi Fajana, 2020), the potential volume storage of Zone I, is approximately 1,035 m^3. This volume exceeds the project’s requirements of 500 m^3 to be stored into the aquifer.

In conclusion, Zone I comprises the main layer of the HYDRO4 aquifer recharge and storage with its electrical resistivity values pointing to optimum groundwater potential (Omosuyi et al., 2007), with low hydraulic gradients resulting to longer residence times. Zone I storage capacity is estimated to 1035 m^3, exceeding the goal of the project (500 m^3). Stored water in Zone I recharged either from wet season rainfall, or from artificial injection can be retrieved from Zone II at the base of W_{AR}. Zone II shows hydraulic connectivity with the regional piezometric level and may additionally recharge Zone I during the wet season through groundwater pump.

Monitoring of HYDRO4 aquifer

The monitoring installations of HYDRO4 site included the installation of an Automated Weather Station (AWS) and of an automatic water logger placed in the bottom of W_{AR} to measure the ground water level (GWL). The AWS was set up in one of the roofs of the HYDRO4 site in Ano Mera.

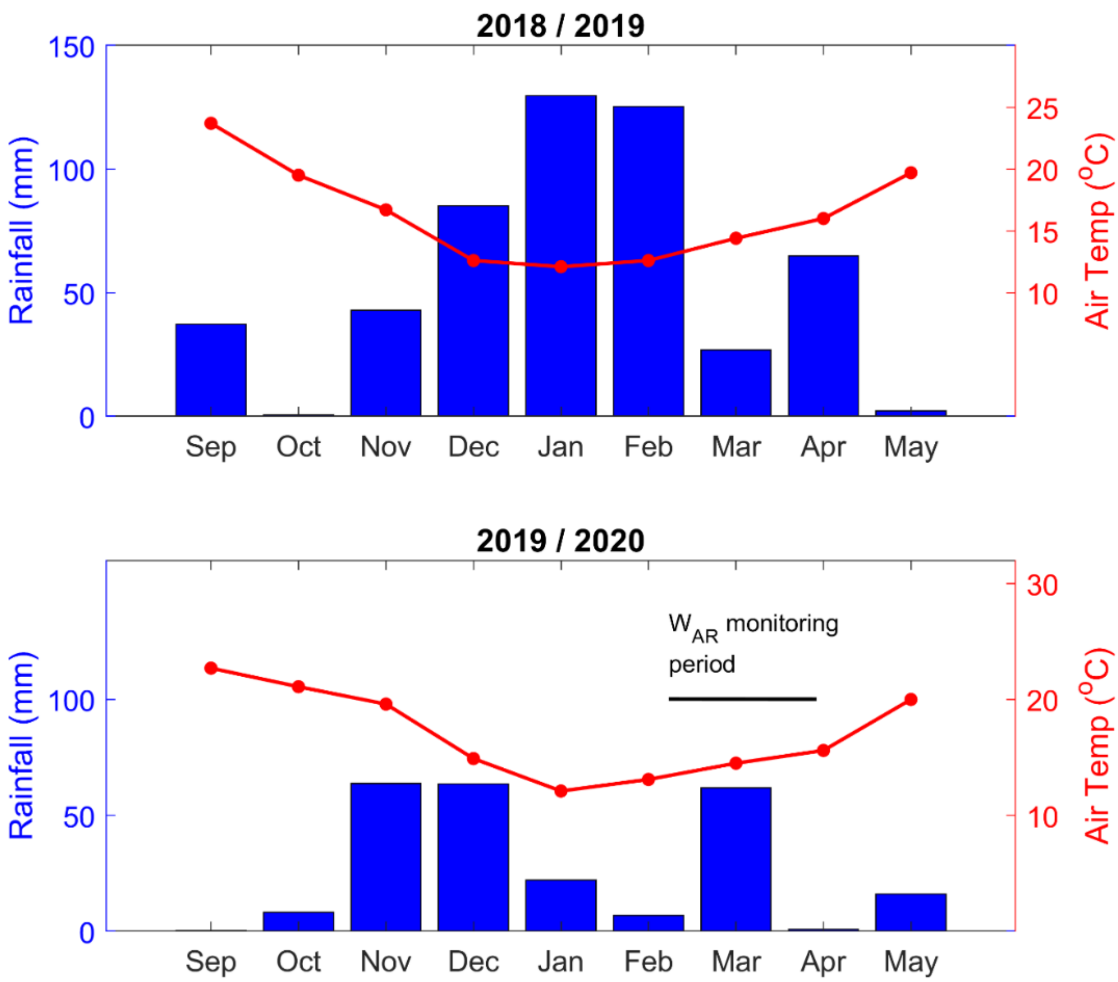


Figure 6.20 Monthly rainfall totals and average air temperatures for the 2018 / 2019 (upper panel) and the 2019 / 2020 (lower panel) wet seasons respectively

Source: Data derived from the National Observatory of Athens (NOA) meteorological station (http://meteosearch.meteo.gr) in Mykonos Chora

The AWS included a rain gauge for recording values of rainfall, air temperature and relative humidity. The measurement steps of the AWS and GWL logger were set to 20 and 10 min intervals respectively.

The data were reduced to hourly means to eliminate noise. The meteorological and water level records were not continuous and span two sub periods of common meteorological and water level data: from February 23 to March 6 and from March 29 to April 21. Continuous monthly and daily meteorological data for Mykonos Island for the 2018/2019 and 2019/2020 wet seasons (September to May), have been derived from the National Observatory of Athens (NOA) station in Chora (Figure 6.20), to provide an overall view of the seasonal and synoptic meteorological conditions.

Groundwater level response to rainfall

The seasonal rainfall during the wet season (September 2019 - June 2020), as measured by the NOA station in Chora (243.2 mm), was less than half compared to the previous (2018 /2019) wet season (514.4 mm). These two successive wet seasons were nearly plus and minus one standard deviation value (252.4 mm) from the projected annual precipitation values of 319 mm, as calculated in D2.1. This fact likely had an impact on the regional piezometric level (Figure 6.20) that was 5.5 m bgs (measured in June 20, 2019). However, the inability of accessing the HYDRO4 test site due to the COVID-19 pandemic resulted in no acquisition of piezometric levels by the end of the 2019 / 2020 wet season. Thus, no additional comparison on the overall effects of two “extreme” wet season’s rainfall to the regional piezometric levels can be made.

Monthly rainfall totals for the 2019/2020 wet season measured by the NOA station in Chora, were higher in November and December with 63.8 mm, respectively compared to January (21 mm) and February (6.8 mm). Early spring high rainfall totals in March (61.8 mm), were followed by a dry April (3.8 mm) and the early summer storms of May added another 16 mm (Figure 6.21 lower panel).

Overall, the monthly rainfall measured by the NOA station in Chora and the hourly measurements of the AWS in Ano Mera show similar patterns (Figure 6.20). From the 61.8 mm of rain measured in NOA station in March 2020, 39.4 mm fell in one single rainfall event on 26 and 27 of March (Figure 6.21 upper panel). This rainfall event accompanied by a cold front invasion from the north Aegean Sea and lower air temperatures was not captured by the HYDRO4 station, as its function was interrupted between March 6 and March 29 (Figure 6.21 lower panel). In addition, the rainfall event on April 6 had different values between the NOA (2.8 mm) and HYDRO4 stations (16.4 mm). This is representative of the local character of precipitation in the island of Mykonos, which should be considered when conclusions are drawn by using the NOA station in Chora.

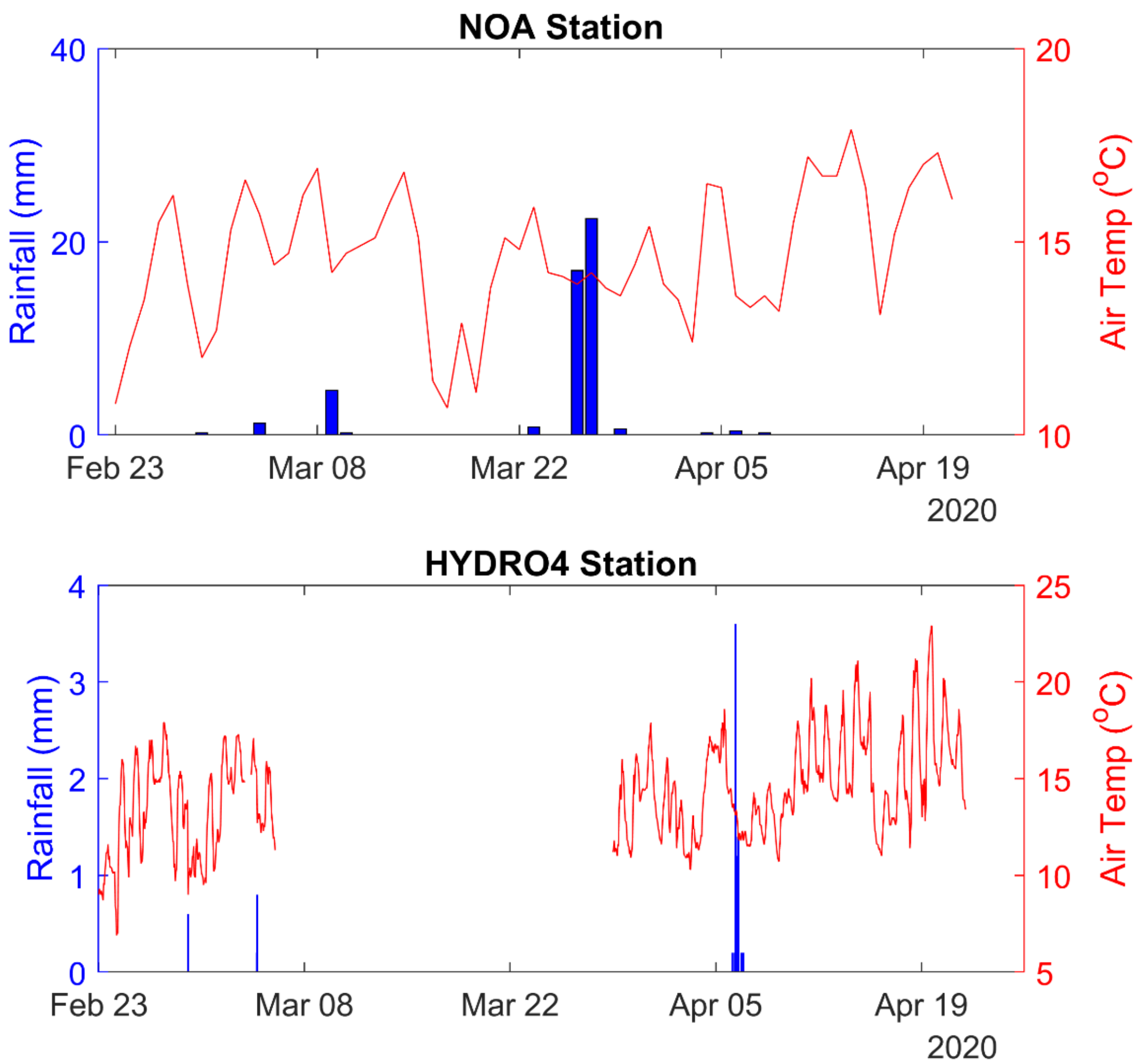


Figure 6.21 Daily rainfall and air temperature observations from NOA Mykonos station in Chora, compared to hourly rainfall and air temperature observations during the two monitoring periods (February 23 to March 06 and March 29 to April 21) of the HYDRO4 test site

Source: http://meteosearch.meteo.gr

In conclusion, the response of the water level in W_{AR} to rainfall measured by the HYDRO4 station is shown in Figure 6.22. All subsequent analyses are based on the condition that all measurements provided by the project partners have been validated and are correct.

For the first part of the monitoring period between February 23 and March 6, the ground water level (GWL) is 3.5 mbgs (0.5 m above the base of W_{AR}) and shows a diurnal variation with a range of 40 mm. Between March 29 and April 21, the GWL demonstrates a dual behaviour over two sub-periods. Along the first part, and after the March 26-27 rainfall event, the diurnal range of the GWL is minimal averaging 0.07 m (Figure 6.22).

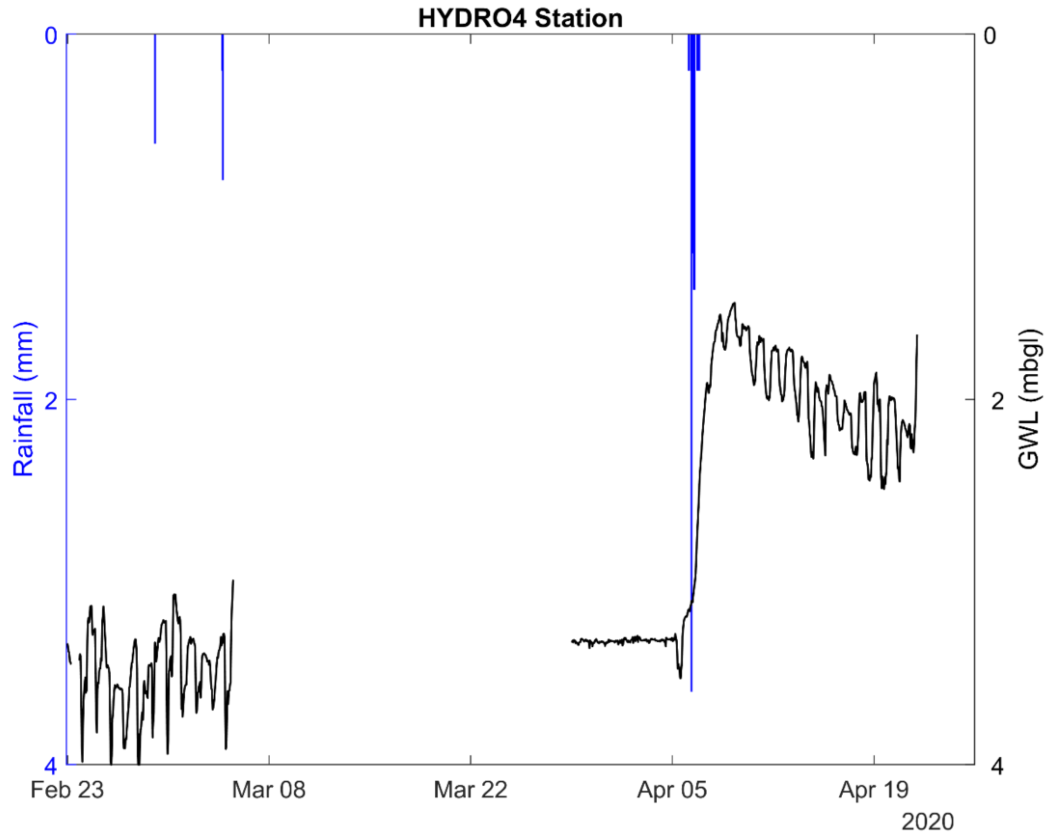


Figure 6.22 Hourly measurements of rainfall and ground water level (GWL) in recharge well W_{AR}

Note: Rainfall axis is reversed for convenience and GWL measurements correspond meters below ground level (mbgl)

Along the second sub-period, the GWL signal shows a 66-hour increase of nearly 1.9 m following the rainfall event on April 6 (16.4 mm) followed by a gradual relaxation of the aquifer, with the drawdown curve characterized by diurnal variations of increasing amplitude (Figure 6.22). In general, diurnal fluctuations of GWL are observed during the rainless periods of the record. Along these drier sub-periods with increasing air temperatures and decreasing humidity (Figure 6.23). 6-8 h time lags in the GWL response to the meteorological variables, such as relative humidity (RH) and air temperature (Air Temp) are likely caused by the low hydraulic conductivity of the aquifer.

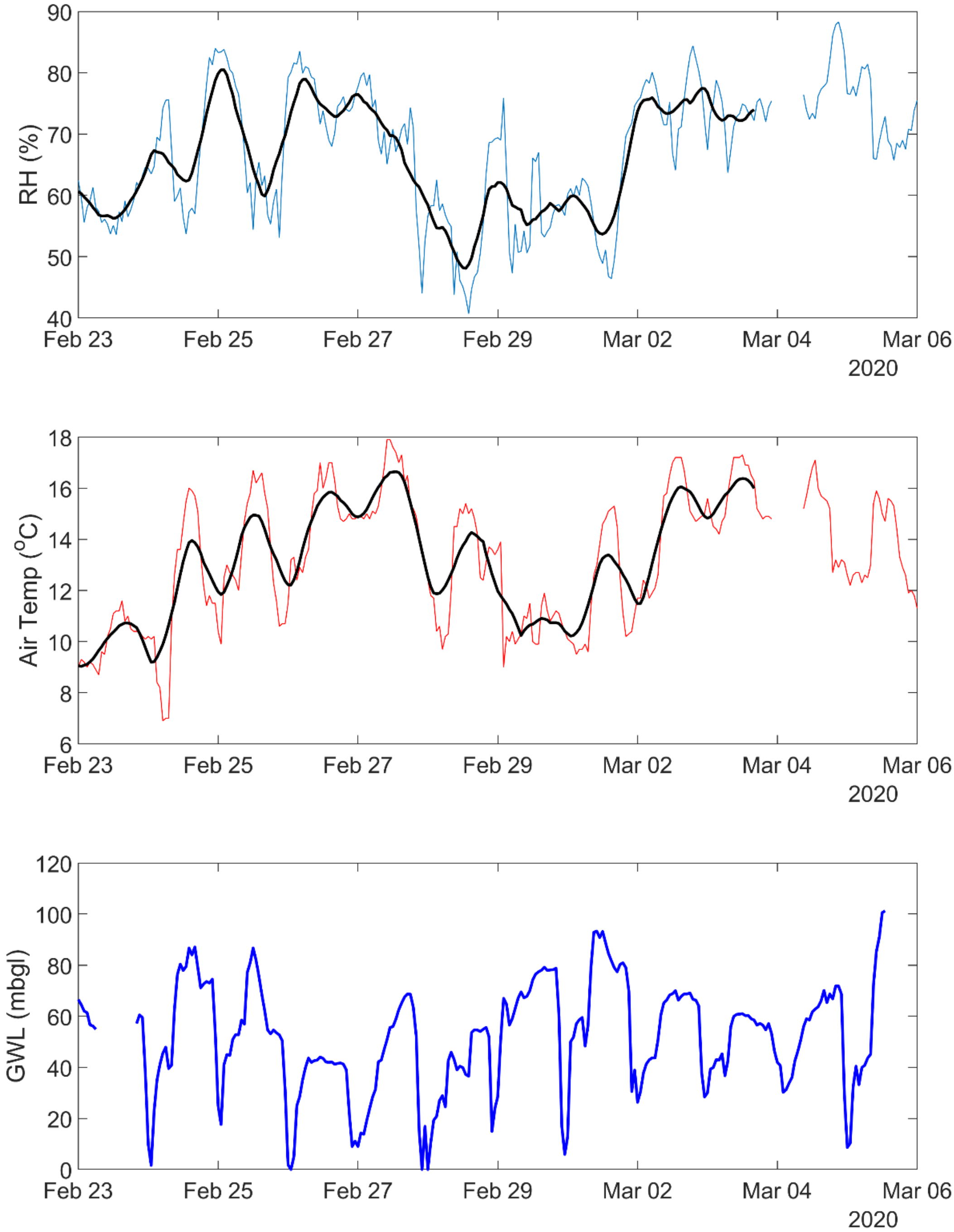


Figure 6.23 Response of HYDRO4 aquifer GWL to the Relative Humidity (RH) and air temperature, during period with minimal rainfall

Note: Black thick lines of RH & Air Temp correspond to the 6 h running means. Periods with higher RH & Air temperature correspond to an overall drop of GWL

The rise of the GWL following the April 6 rainfall event occurred with a 66 h lag. The surface sediments saturated conditions that prevail during the rainfall events of the wet season and the low K values may explain this time lag despite the soil-saturated conditions compared to dry conditions during the sludge injection test (June 20, 2019). Under the consideration that the observed rise in the GWL occurred only from the vertical percolation of water after the rainfall event, the pulse of rainwater to reach the screens of W_{AR} at 3.0 mbgl, with a K value of 1 x 10^{-5} m/s, would be 85 h.

This implies that either K values of the HYDRO4 aquifer Zone I may be slightly higher than $1 \cdot 10^{-5}$ m/s, or that after wet season rainfall events the mechanisms of groundwater pump from Zone II through an elevated regional piezometric level also contributes to the recharge of HYDRO4 aquifer.

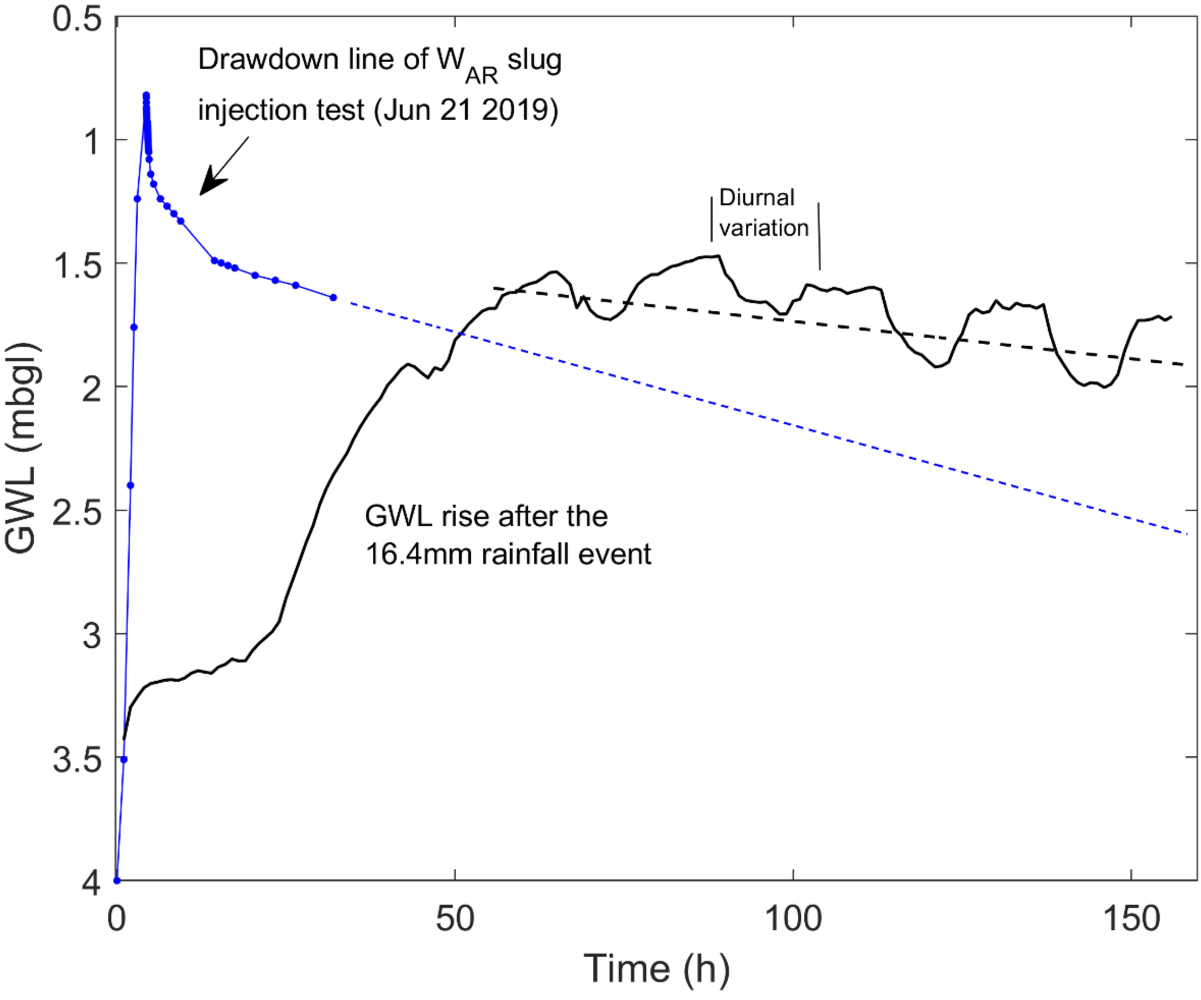


Figure 6.24 Comparison plot of HYDRO4 site aquifer GWL drawdown to the sludge injection test and to the rainfall event (April 6, 2020)

A similar behaviour of the aquifer had been observed during the sludge injection and surface recharge tests of W_{AR} in June 21 2019 (Figure 6.24). During the field tests, the water level in W_{AR} rose immediately with the drawdown continuing despite the continuous surface recharge with 64.5 m^3, within a radius of 25 m from W_{AR}.

During the sludge test, 8.5 m^3 of water were directly injected into W_{AR}, whereas an additional 64.5 m^3 were injected in the surface unsaturated zone of W_{AR} over a radius of 25 m, spanning area of 625 m^2. Dotted lines represent the manually graphical extension of the sludge injection drawdown (blue) and of the drawdown after the rainfall event.

This is explained by the immediate loss of surface recharge to surface and subsurface evaporation, which during the dry season in semi-arid areas can reach 80% (Balugani et al., 2017) and also by the low hydraulic conductivities (K= 1 x 10^{-5} m/s) of the aquifer. The drawdown line after the sludge injection exhibited a stepwise slope reduction, with a steep slope for the first 6 h that was further reduced over the next 12 h, to taper even more for the last 20 h of the field experiment (Figure 6.24).

The natural recovery of W_{AR} following the GWL rise lasted 280 h and amounted to 0.95 m demonstrating considerable diurnal variation (Figure 6.24). The natural drawdown slope of 0.0034 m/h (Figure 6.24 black dotted line) was almost half, compared to the injection and artificial recharge experiments drawdown slope of 0.0074 m/h (Figure 6.24, blue dotted line).

The difference of HYDRO4 aquifer relaxation and hence effective storage capacity, can be potentially attributed to the degree of Zone I saturation between the wet and dry seasons, but to confirm these conclusions more observations and longer monitoring data are required.

6.3.5 Analytical Technical description of subsystem 3

In subsystem 3 of the configuration (Figure 6.10), rainwater flows from two sources will be recovered (section 2.3.1). These include the **surface runoff** of the private property of the site and from the **bioswale system**; both are recovering rainwater of the wet period to use it in the summer and also to avoid the flooding of the crop.

In the flow diagram of subsystem 3, the aquifer storage and recovery system is illustrated on the topographic map (Figure 6.25).

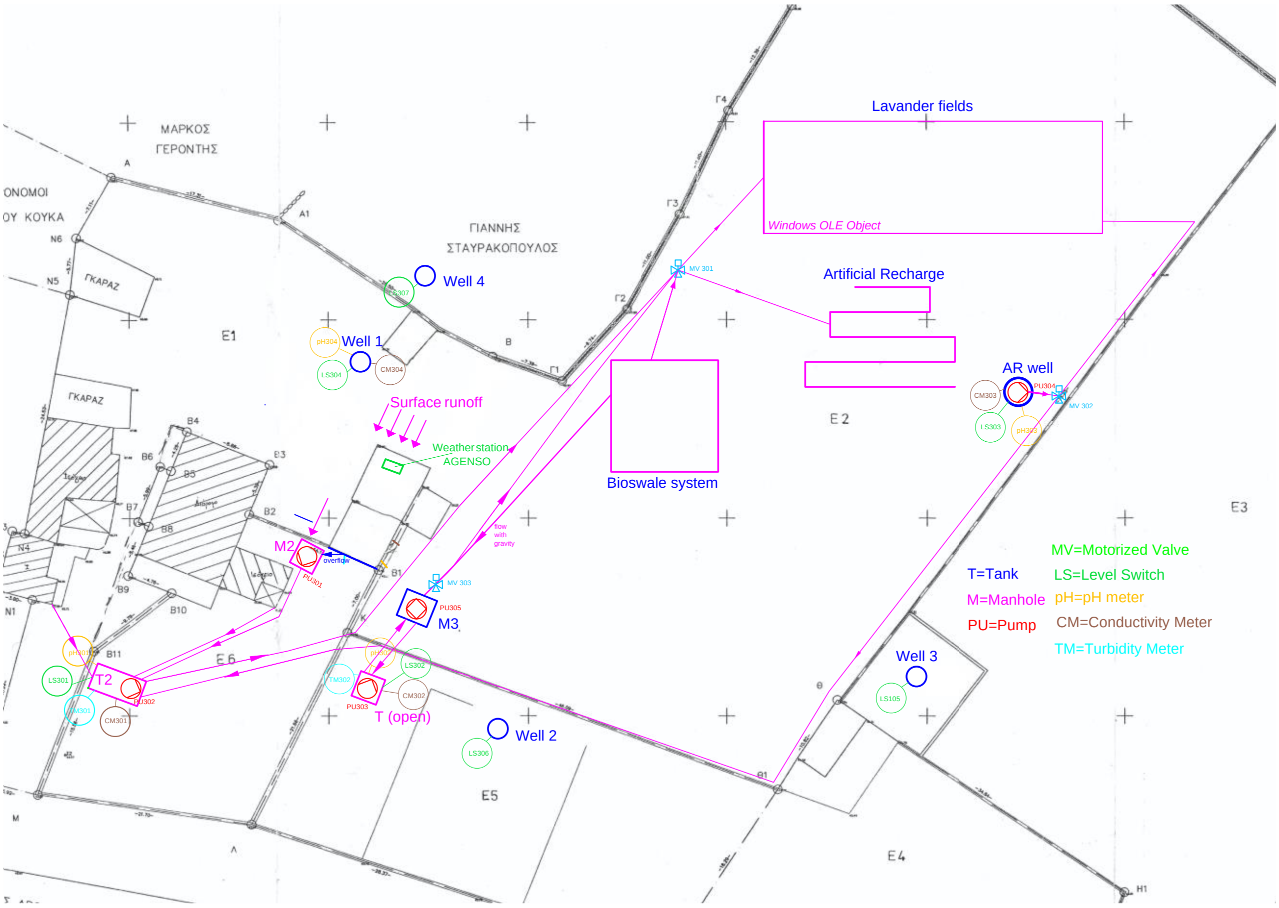


Figure 6.25 Flow diagram of the Aquifer Storage and Recovery System (subsystem 3)

6.3.6. Construction activities of the bioswale system

For the bioswale system, a trapezium shaped dike of 0.65 m on top and 0.4 m on the bottom, 0.65 m height and 46.5 m long has been excavated (Figure 6.27), according to the respective design (Figure 6.26). After the excavation of the dike, a linear layout of geomembrane was installed covering the east side and the bottom of the dike. Additionally, a linear layout of a two (2) layer geotextile has been used to cover the west site of the dike (Figure 6.28). The purpose is to leave the water enter from the west side, retain it inside and lead it south through a water pipe line towards a manhole that acts as a control well, of about 0.65 m x 0.65 m x 0.55 m (L x W x H) (Figure 6.29). For the filtration of the water a drainage system from gravel of 8-16 mm has been constructed (Figure 6.29). The water flows through the pipe line to the well and is sent either to the open tank (with gravity) or to the AR area for recharging the aquifer (with a pump set in the manhole and water pipe lines). A further purpose for this system is to prevent the lavender field from flooding.

Figure 6.26 Excavation work for the construction of the bioswale system

HYDRO4 Drainage and anti-flood stormwater infiltration zone - hybrid "xeriscape bioswale" channel.

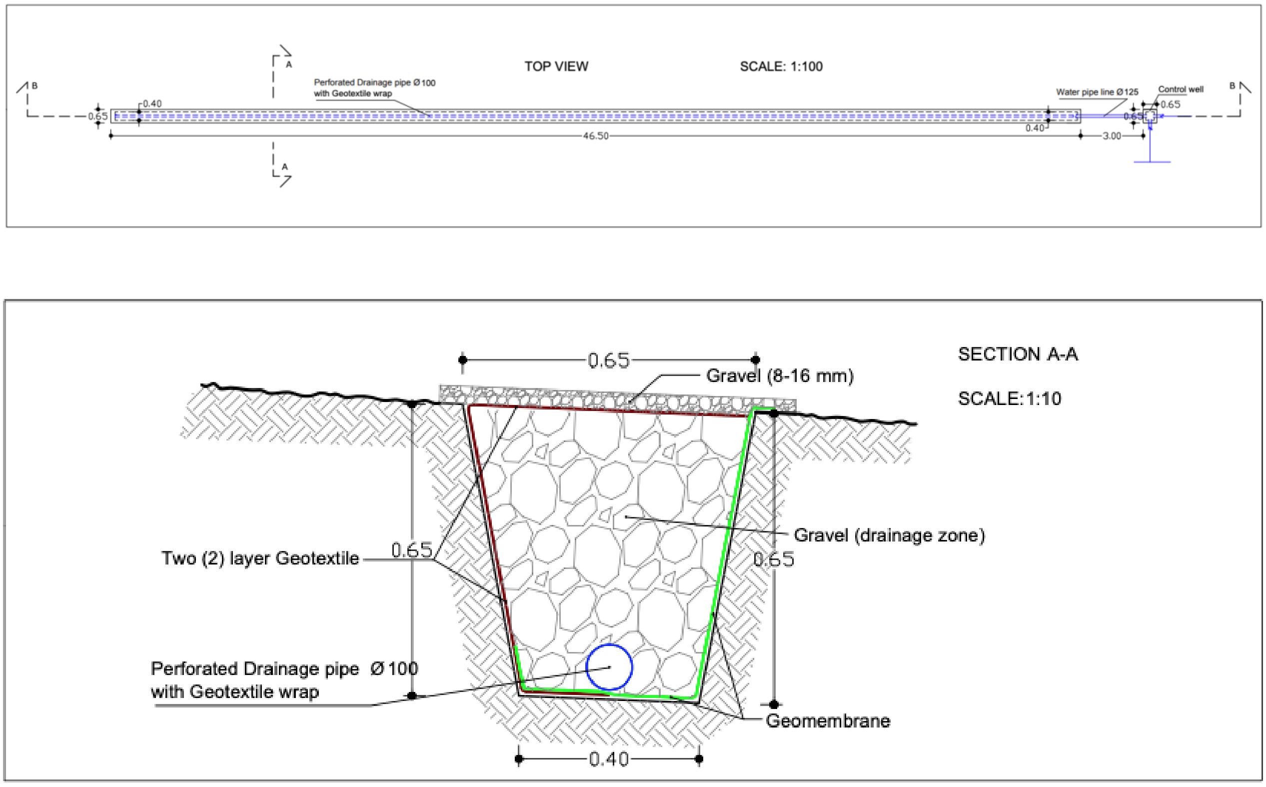


Figure 6.27 Top view & cross section of the bioswale system


Figure 6.28 Installation of the geotextile in the dike of the bioswale system


Figure 6.29 Set up of a drainage system from gravel of 8-16 mm for filtration of water entering the bioswale system. Piping network and manhole M3

Then, the manhole was constructed and the geotextile and the geomembrane was placed in the dyke. Subsequently, the water pipe lines were set, with a geotextile wrap.

6.3.6 Construction activities of the surface runoff system

For the surface runoff system, the main activities that took place are described below:

- Upgrade of the rainwater collection surfaces in the private property.
- Increase of impermeable areas to about 596 m^2.
- Cleaning and restoring of the water tank T2.
- Construction of water channels to collect surface rainwater and guide it to the tank (Figure 6.30).
- Construction of a rectangular manhole as a control well of about 1m x 1m x 0.70 m (L x W x H) (Figure 6.31).
- Installation of appropriate water pipe lines (about 25 mm diameter – 6 atm) and pumps to transfer water from the manhole to the tank and to the AR site.

Figure 6.30 Water pipes and channels to collect surface rainwater and guide it to the tank

Figure 6.31 Construction of a rectangular manhole to collect the surface runoff

6.3.7 Construction activities of the AR site

In the area of the maximum storage capacity, a small piezometric well was constructed to be used, as the recovery path for using water that has been stored during the wet months to irrigate the lavender in the dry period. The new well has a depth of 5 m (4.5 m to the ground level) and a diameter of 1m (Figure 6.32).

Regarding the construction of this, all previous research and assessment to evaluate the characteristics of the system, in terms of the geological structure, the geophysical characteristics and the subsurface conditions described in section 6.3 was taken under consideration, in order to provide a thorough understanding of the hydraulic behaviour of the aquifer of the site and assess the potential to implement aquifer storage and recovery (ASR) schemes. Once the optimum location with the maximum storage potential was identified, excavation work took place and the installation of five (5), concrete cylinders of 1 m diameter and 1 m high were stacked on top of each other. Additionally, a pump and water pipe lines for recovering water for irrigation purposes were installed. Finally, an area of 0.2 ha was identified to be planted with lavender seeds, not near the AR location, in order to avoid flooding the crop.

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

Figure 6.32 Construction of the small piezometric well (W_{AR})

6.3.8 Deviations from the design deliverable for Subsystem 3

The operation of the subsystem 3 has started. However, there are some pending activities to complete that will facilitate the monitoring of the aquifer storage and recovery system and will allow the more effective use of recovered water:

- Plantation of lavender (0.2 ha)
- Implementation of the automation plan at the site for the control of the system (linked with WP5).
- Installation of sensors for online monitoring of certain parameters. The probes which are pending to be installed include the conductivity and the turbidity of water (quality) in Tank 2 and in the wells (linked with WP5) as well as the measurement of the water level inside the wells. These are currently measured manually at regular time intervals.

These activities were planned to be completed in 2020; however, due to the COVID-19 there was a deviation from the initial planning. The activities will be concluded within the first months of 2021.

7. EQUIPMENT OF HYDRO4

To monitor the subsystems and for enabling controlling and automating capabilities of HYDRO4, a series of equipment are to be set in the site. This section focuses on describing this equipment within the framework of HYDROUSA, in order to gather the necessary demo site data to optimize the systems as well as to control the operation of the configuration. In particular, sensors are to be installed for monitoring important parameters including: water quantity and quality parameters required for producing, collecting, storing and managing water and weather data parameters. In addition, controllers and actuators will be deployed at the demo sites for ensuring the smooth operation of the setting and for preventing unexpected events.

Sensor data gathering and controlling is achieved using both industrial and low-cost solutions for comparing their performances. Presently, only the low-cost solutions have been installed (weather station, pH, temperature, level meter, pH) in the site and the industrial sensors are expected to be set shortly.

Figure 7.1 Initial weather station installed in June 2019

In Table 07.1 the monitoring equipment is described, including the industrial sensors along with the weather station.

Table 07.1 Monitoring equipment for HYDRO4

Type of sensor	Process monitored	Installation point
Tank level sensor	Monitor the water level of tanks	Installed in the existing tanks (3)
Water level sensors	Monitor the water level of wells/aquifer	Installed in the wells (5)
Portable water level sensor	Portable water level sensor to monitor before installing the industrial sensors and calibrate sensors in set up	Portable to all the wells before installing the sensors and when calibrating.
Turbidity meters	Monitor turbidity of water stored in tanks	Installed in the existing tanks (3)
Conductivity meters	Monitor conductivity of water stored in tanks and in the wells	Installed in the existing tanks (3) & in the wells (2)
pH meter	Monitor pH of water stored in tanks and in the wells	Installed in the existing tanks (3) & in the wells (2)
Weather station	Monitor meteorological parameters online in real time (www.ardefsi.gr)	HYDRO4 demo site (set in a roof)
Controller for HYDRO4	Controlling and automating capabilities of HYDRO4	HYDRO4 demo site

Figure 7.2 Sensors installed in wells and tanks

With regard to the SSF System, the list of materials is described below:

- Reservoir Tank 1 (System 1)
- Filter body, the SSF tank
- Storage tank for the filtered water - pending
- HDPE pipes - installed,
- HDPE and brass connectors and fittings
- Float valve
- Flushing valve

- Sensors to configure HYDROUSA’s ICT system - pending
- Pump, optional
- Sieves - developed on site, three different types of DYI sieves based on resources available on the island
- Fine sand - sieved on site
- Fine gravels - sieved on site
- Coarse gravels - sieved on site

8. START-UP

HYDRO4 system is currently running and is collecting water for the dry period. The configurations of the parts are tested and monitoring has already started. Measurements are taken by the meteorological station as well as the water levels of the well and the tanks to monitor the system behaviour throughout all the wet period, in order to make any adjustments and optimization interventions. In addition, water quality is monitored in NTUA lab by sampling procedure.

For subsystems 1 and 3, certain challenges must be addressed as follows:

- Continuing operation testing of the subsystem individually and the whole configuration.
- Operate the configuration in a semi-automatic way before the fully automated configuration is implemented.
- Calibration of the monitoring equipment can be performed by comparing measurements of the low-cost sensors with the ones of the industrial sensors.
- Record time series for all the important parameters to monitor the system, to quantify the water collected and valorised and provide optimization schemes. The data should be credible and in a continuing format.

The SSF upcycling version is a system which can be easily developed with low cost materials. Following this approach, a SSF was built at the premises of ALCN Austria in late summer 2020 based on upcycled available materials. All the components apart from the sand could be sourced from inside and around an average family home.

Given the priority to use available material, some constraints arose and there were few minor issues about the SSF development in terms of deviations from the elements used in the calculations and technological drawings. For example, there were some challenges to connect the underdrain pipe inside the tank. The underdrain pipe (PVC) is installed under drain under the gravel to avoid clogging at the port. The pipe has 3 mm (diameter) holes that are about 5 cm apart along the entire pipe along 3 axial lines. The drainage pipe is connected to a lead-through at the bottom of the barrel, which means that the angle between the pipe and the cylinder wall is fixed at 90°. The challenge arose due to fact that the barrel that was used is not perfectly cylindrical but rather has slightly conical walls towards both ends. Therefore, the pipe would have pointed upwards if installed too close to the bottom, and to avoid that the outlet was placed slightly higher than planned to achieve a horizontal position. Other challenges are the SSF material where to source sand and gravel. The material required should be sourced locally, and shall be natural and cleaned.

Figure 8.1 DYI Sieves developed

Figure 8.2 Sand sieved

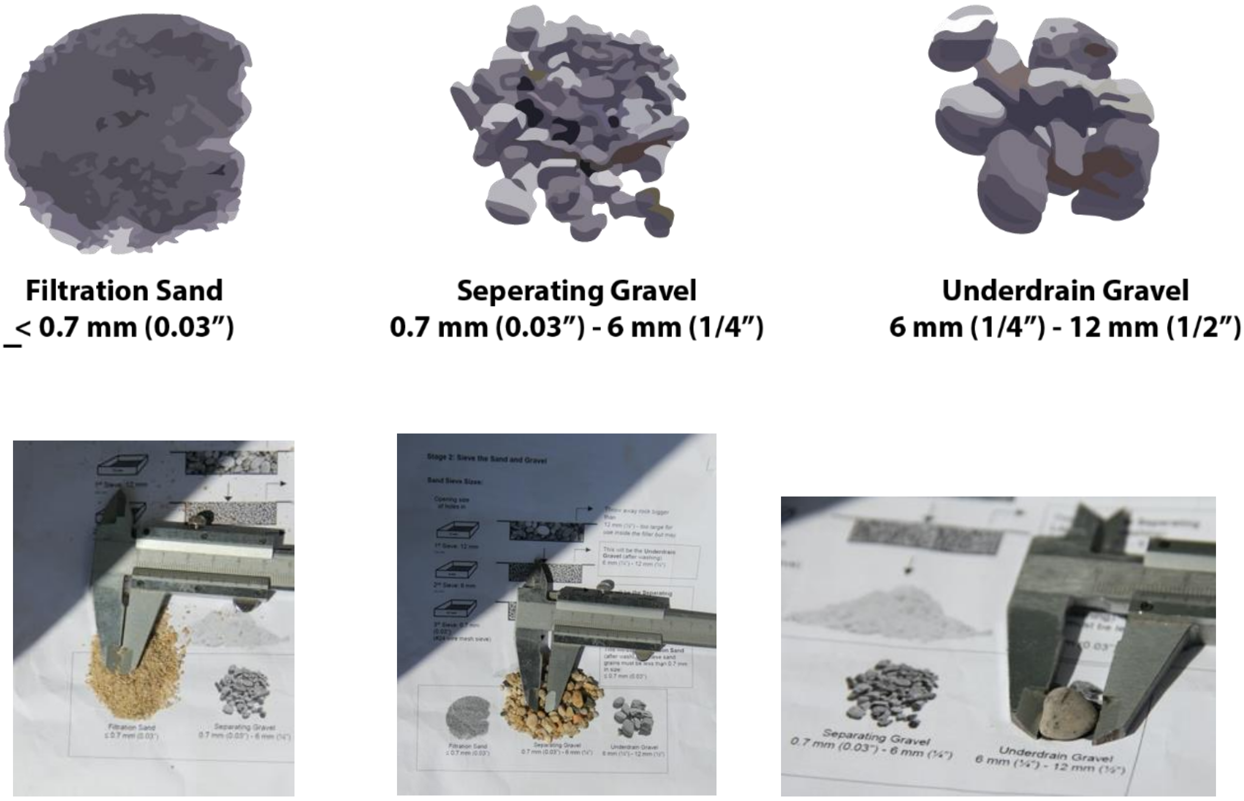


Figure 8.3 Size of sand and gravels for the different lays in SSF and the sieved ones

Figure 8.4 Sand sieved on site ready for setup

9. ANNEX

9.1 Raw data & graphs illustration of the experimental activities conducted (June 2019)

Table 9.1 Initial water levels of the wells – 20.06.2019

Wells	Water levels (m)
W1	3
W2	5.14
W3	5.32
W4	1.38

Table 9.2 Recharge of W_{AR} with a flow of 2.7 m^3/h and water levels of W3 & W2

time (min)	W3 (m)	W2 (m)	time (min)	W_{AR} (m)
0	5.23	5.14	0	4.88
30	5.23		60	3.51
60	5.23		120	2.4
90	5.23		150	1.76
120	5.23		180	1.24
150	5.23			
180	5.23			
260	5.23			
340	5.23			
550	5.25			

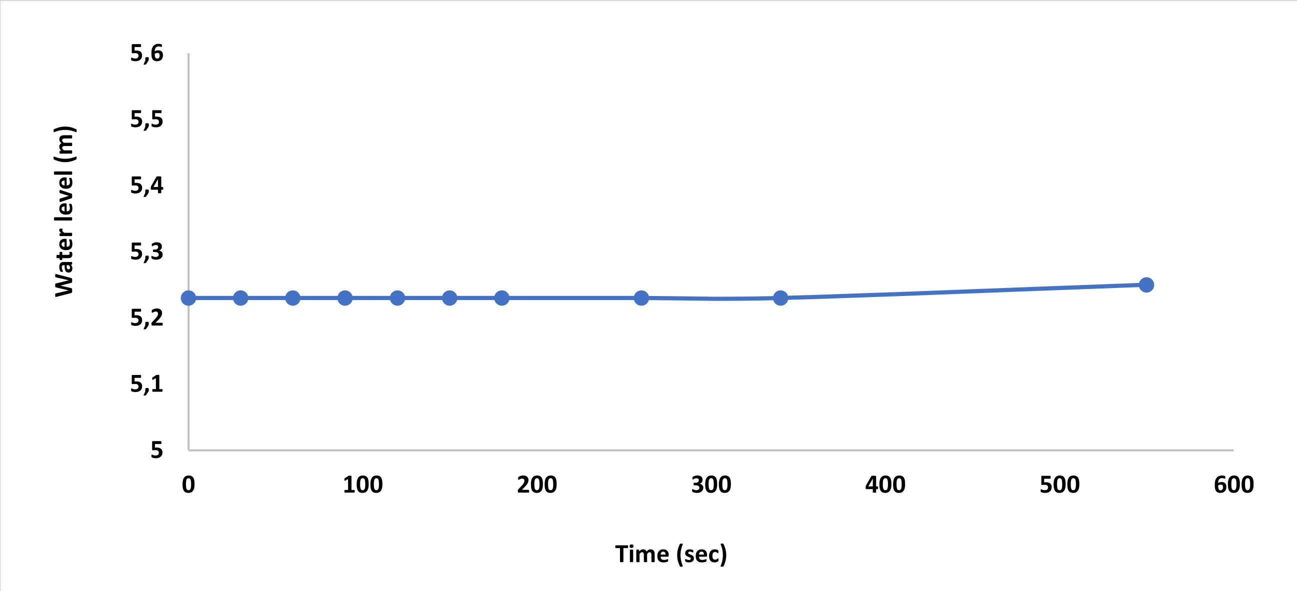


Figure 9.1 Recharge inside W_{AR} to test the behaviour of W3

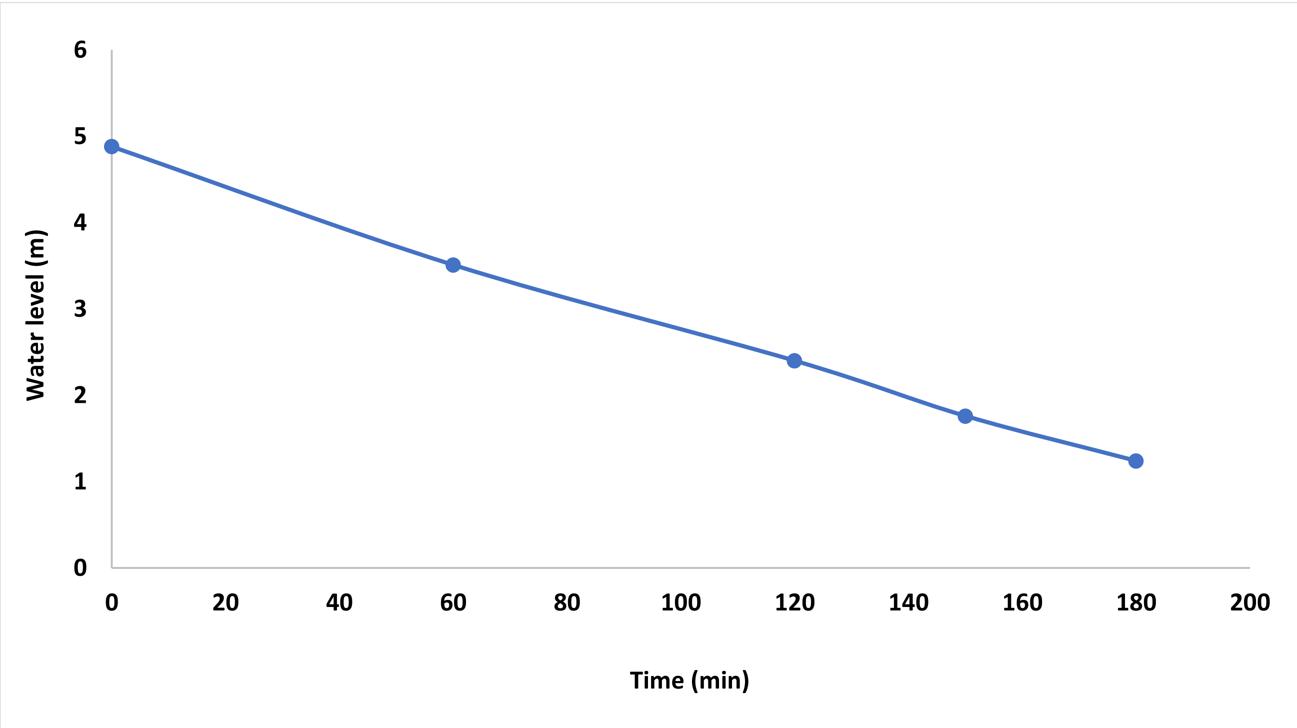


Figure 9.2 Recharge inside W_{AR}

Table 9.3 Return rate of well W_{AR}

time (sec)	water level of W_{AR} (m)
0	82
15	83
30	85
45	85
60	85
75	87
90	87
105	87
120	88
135	88
150	89
165	89
180	90
195	90
210	91
225	91
240	92
255	92
270	92
285	93
300	93
315	93
330	94
345	94
360	94
375	94
390	95
405	95
420	95
435	96
450	96
465	96
480	97
495	97
510	98
525	98
540	98.5
555	99

570	99
585	99.5
600	100
615	100
630	101
645	101
660	102
675	103
690	103
705	104
720	105
735	108
750	114
765	118
780	124
795	127
810	130
825	133

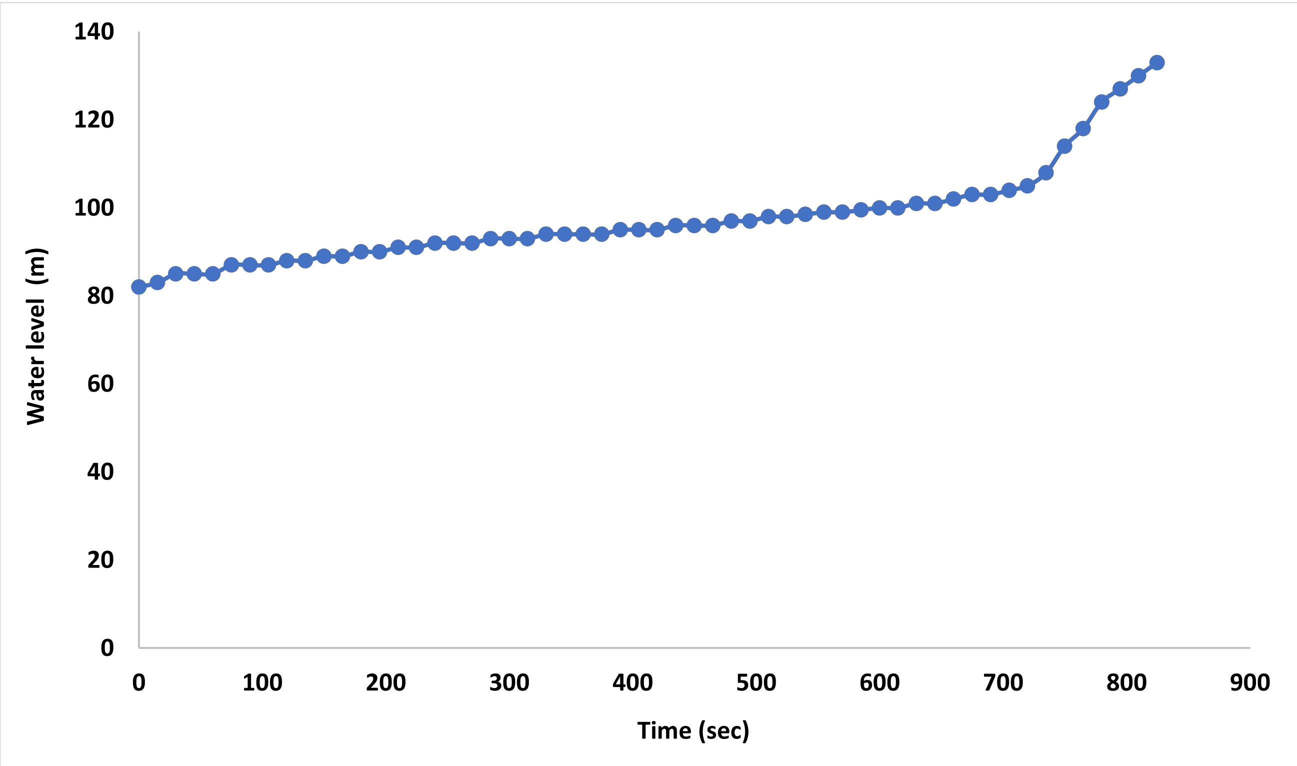


Figure 9.3 Return rate of well WAR

Table 9.4 Recharge of well W1 with a flow of 2.7m^3/h & water level of W4

time (min)	water level of W1 (m)	water level of W4 (m)
0	3	
2	2.95	
4	2.91	
6	2.88	
11	2.79	
16	2.71	
21	2.61	
26	2.52	
31	2.44	
36	2.34	
41	2.25	
51	2.08	1.37
61	1.88	
71	1.7	
81	1.52	
91	1.34	
101	1.16	
111	0.97	
121	0.82	1.38

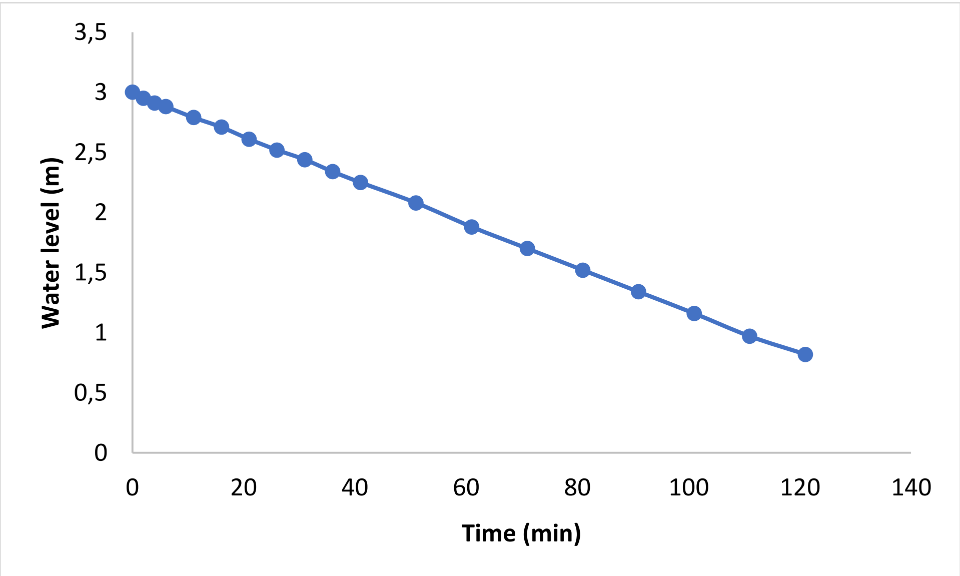


Figure 9.4 Recharge of well W1 with a flow of 2.7 m^3/h

Table 9.5 Return rate of well W1

time (min)	water level of W1 (m)
0	3
2	2.95
4	2.91
6	2.88
11	2.79
16	2.71
21	2.61
26	2.52
31	2.44
36	2.34
41	2.25
51	2.08
61	1.88
71	1.7
81	1.52
91	1.34
101	1.16
111	0.97
121	0.82

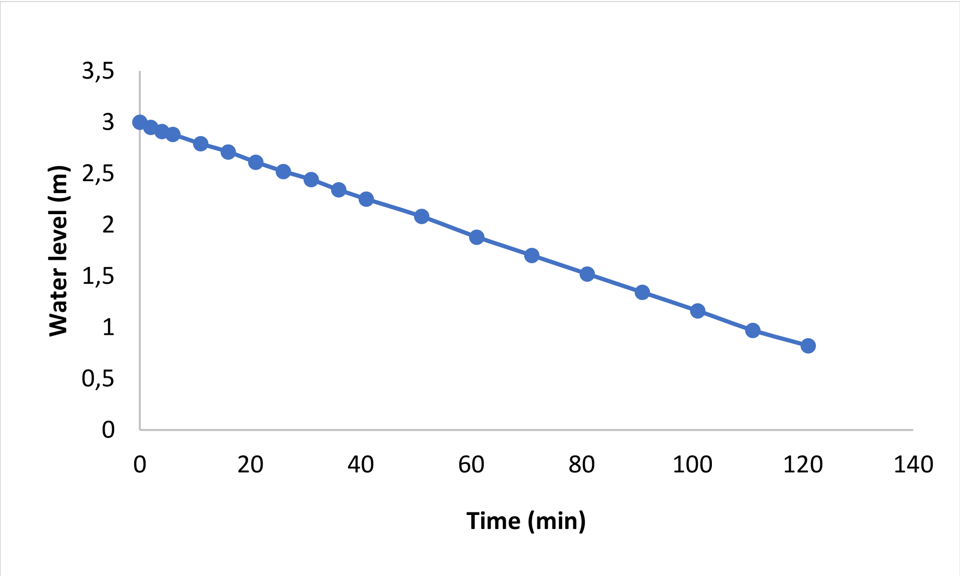


Figure 9.5 Return rate of well W1

Table 9.6 Pumping of well W1 with a flow of 1.1 m^3/h

time (sec)	water level of W1 (m)
0	0.82
15	0.83
30	0.83
45	0.84
60	0.84
90	0.85
120	0.85
180	0.86
240	0.87
360	0.89
480	0.9
600	0.92
900	0.94
1200	0.96
1500	0.975
1800	0.99
2400	1.01
3000	1.025
3600	1.03

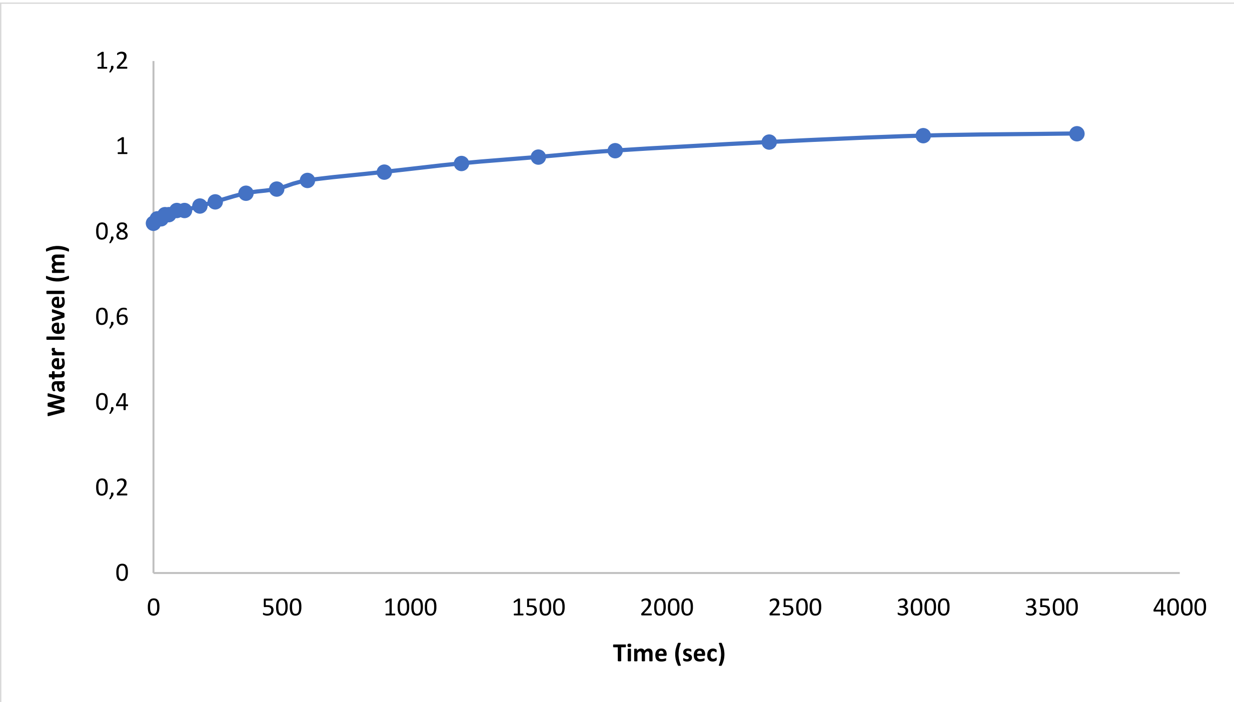


Figure 9.6 Pumping of well W1 with a flow of 1.1 m^3/h

Table 9.7 Initial water levels – 21.06.2019

wells	water levels (m)
W1	6.58
W2	1.4
W3	5.28
W4	5.28
W_{AR}	1.49

Table 9.8 Recharge in the ground around the WAR with a flow of 2.7 m^3/h

time (h)	water levels (m)
0	1.49
1	1.5
2	1.51
3	1.52
6	1.55
9	1.57
12	1.59
24	1.64
36	
60	
84	
108	
132	

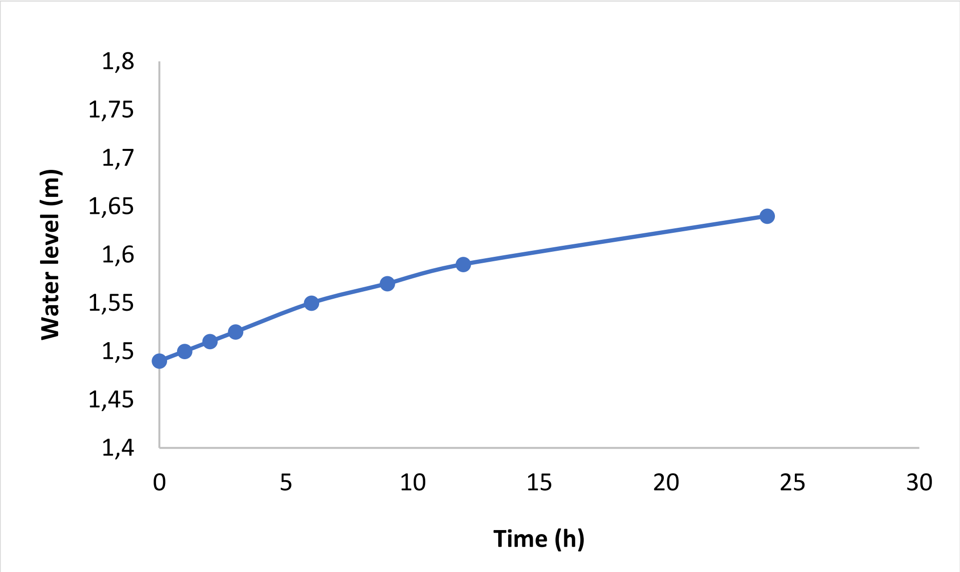


Figure 9.7 Recharge in the ground around the WAR with a flow of 2.7 m^3/h

Table 9.9 Natural water recharge of W1

time (h)	water level (m)
0	6.58
1	6.57
2	6.57
3	6.57
6	6.57
9	6.55
12	6.55
24	6.54

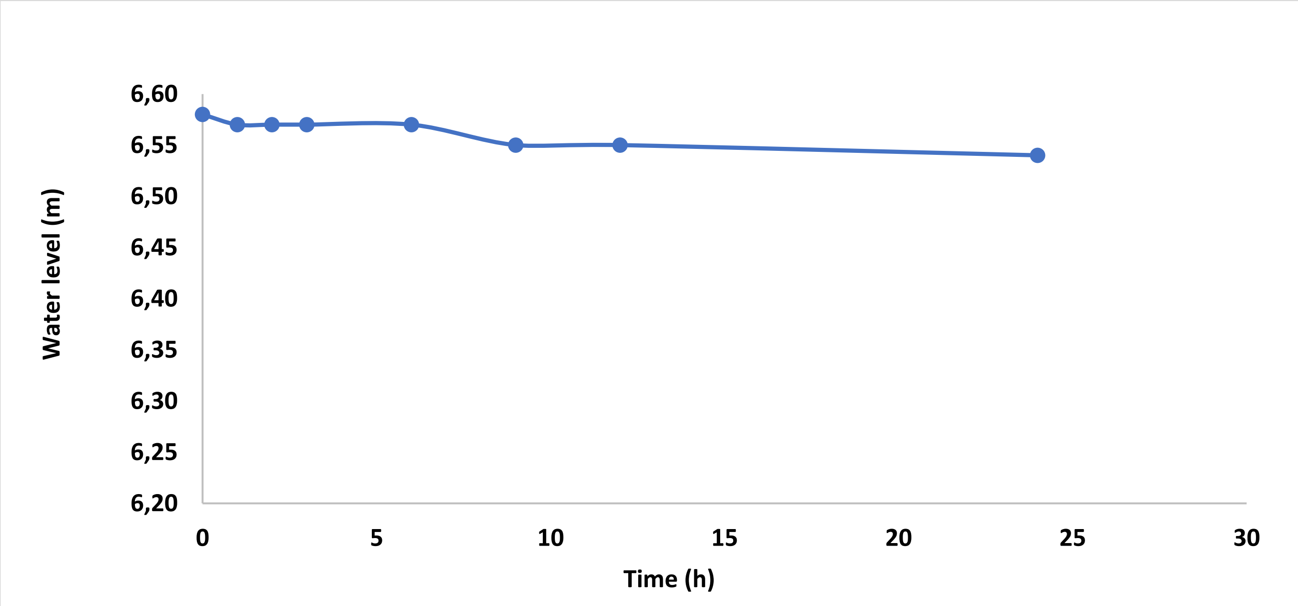


Figure 9.8 Natural water recharge of W1

Table 9.10 Natural water recharge of W3

time (h)	water level (m)
0	5.28
1	5.28
2	5.28
3	5.30
6	5.29
9	5.3
12	5.31
24	5.33

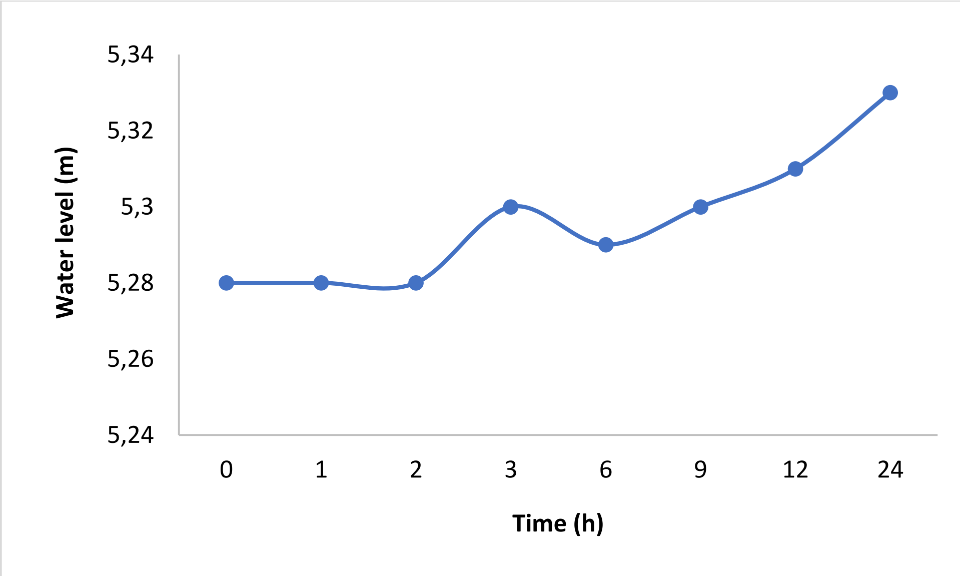
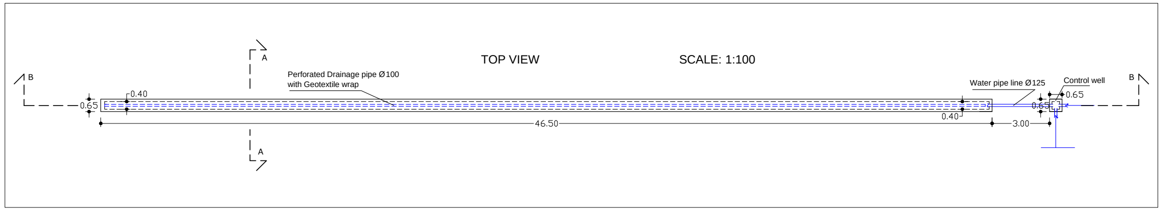
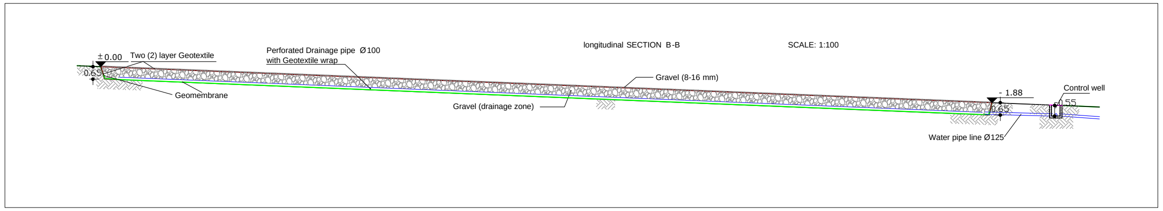


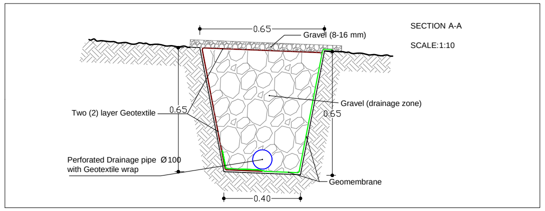
Figure 9.9 Natural water recharge of W3

9.2 Top view and two cross sections of the bioswale system

HYDRO4 Drainage and anti-flood stormwater infiltration zone - hybrid "xeriscape bioswale" channel.







HYDROUSA - WP2 - HYDRO4

hybrid "xeriscape bioswale" channel.

DRAWING No: **1**

Ioannis T. VASILAKOS
CIVIL ENGINEER NTUA
WATER RESOURCES SCIENCE & TECHNOLOGY NTUA

+30 6978 776 424
vasilakos@hydraspis.gr

SCALE:

DATE -YEAR: **NOV 2019**

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