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HYDROUSA

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Design of the constructed wetland

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Brief Description	Design of the constructed wetlands (CWs) for the treatment of the UASB effluent from the Lesvos demo sites. A full scale system and some pilot systems are designed with the aim to guarantee the Greek limits for wastewater reuse in irrigation. The full scale system is composed of a hybrid combination of vertical subsurface flow (VF) CWs and treats from 10 to 100 m^3/d. The pilot systems treat 1 m^3/d and is employed to test the possibility to reduce the areal footprint of CWs with innovative solutions, i.e. aerated and bio-electrified CWs.
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EXECUTIVE SUMMARY

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The CW stage consists of a full scale system and some pilot systems, which are designed aiming to guarantee the Greek limits for wastewater reuse in irrigation in terms of total suspended solids (TSS), biochemical oxygen demand (BOD_5), total nitrogen (TN) as well as contributing in disinfection.

The full scale system is composed of a hybrid combination of vertical subsurface flow (VF) CWs and treats from 10 to 100 m^3/d. The full scale system is designed with two stages: 1st stage, saturated downflow VF; 2nd stage unsaturated intermitted load VF CW. Recirculation and by-pass chambers allow to test up to 6 different configurations, investigating the best scheme for Greek and also other Mediterranean conditions (e.g. different water quality standards for TN).

The pilot systems treat 1 m^3/d and aim to test the possibility to reduce the areal footprint of CWs with innovative solutions, i.e. aerated and bio-electrified CWs.

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ABBREVIATIONS

AEW	Aerated wetland (intensified constructed wetlands)
BOD_5	Biochemical oxygen demand
COD	Chemical Oxygen Demand
CW	Constructed wetland
EPDM	Ethylene propylene diene monomer
FWS	Free Water Surface (constructed wetland)
HDPE	High-density polyethylene
HF	Horizontal flow (subsurface flow constructed wetland)
MF	Membrane filtration
MFC	Microbial fuel cell
OD	Oxygen demand
OI	Oxygen input
OLR	Organic loading rate
OTR	Oxygen transfer rate
PVC	Polyvinyl chloride
SAT	Saturated (constructed wetland)
SSF	Sub-surface flow (constructed wetland)
TKN	Total Kjeldahl nitrogen
TN	Total nitrogen
TSS	Total suspended solids
VF	Vertical flow (subsurface flow constructed wetland)
WWTP	Wastewater treatment plant
UASB	Upflow anaerobic sludge blanket
UF	Ultrafiltration (Membrane)
UNSAT	Unsaturated (constructed wetland)
UV	Ultraviolet
VSSF	Vertical Sub-surface Flow (constructed wetland)

1 INTRODUCTION

The aim of the Lesvos pilot site (HYDRO1) is to demonstrate the possibility to treat wastewater produced by a touristic site (high fluctuation in sewage production due to seasonality of touristic activities) and produce an effluent suitable for reuse in irrigation under strict Greek water quality standards. The treatment chain of the Lesvos pilot include: UASB + constructed wetland + ultrafiltration + ultraviolet irradiation. The current document provides the details regarding the design of the constructed wetlands (CWs) for the treatment of the UASB effluent from the Lesvos demo sites.

The CW stage consists of a full scale system and some pilot systems, which are designed aiming to guarantee the Greek limits for wastewater reuse in irrigation in terms of total suspended TSS, BOD_5, TN as well as contributing in disinfection.

The full scale system is composed of a hybrid combination of vertical subsurface flow (VF) CWs and treats from 10 to 100 m^3/d. The full scale system is designed with two stages: 1st stage, saturated downflow VF; 2nd stage unsaturated intermitted load VF CW. Recirculation and by-pass chambers allow to test up to 6 different configurations, investigating the best scheme for Greek and also other Mediterranean conditions (e.g. different water quality standards).

The pilot systems treat 1 m^3/d and aim to test the possibility to reduce the areal footprint of CWs with innovative solutions, i.e. aerated and bio-electrified CWs.

2 CONSTRUCTED WETLANDS

2.1 Technical description (include a separate section for the description of the two pilot CWs)

2.1.1 Full scale system

The full scale system is composed of a hybrid combination of vertical subsurface flow (VF) CWs and treats from 10 to 100 m^3/d of domestic sewage. The full scale system is designed with two stages: 1st stage, saturated downflow VF (VF1 SAT); 2nd stage unsaturated intermitted load VF CW (VF2 UNSAT). Different recirculation options allow to test up to 5 different configurations, investigating the best scheme for Greek and also other Mediterranean conditions (e.g. different water quality standards). The details on 6 configurations modes are reported in section 2.8.

The CW full scale line receives the effluent of UASB digester and is composed of (see Figure 2.1 for plan layout and Figure 2.2 for schematization):

- Bypass manhole, B1;
- 1st stage saturated vertical subsurface downflow CW, VF1 SAT, with a bed of 17.5x14 m (245 m^2);
- Pumping station for VF2 UNSAT, P1;
- 2nd stage unsaturated intermitted load VF CW, VF2 UNSAT, which is divided in 3 beds to accommodate the local orography; the 3 beds host the 4 VF2 UNSAT lines for batch feeding (lines A, B, C, and D); each line sizes 18x8.5 m, i.e. about 150 m^2; the total net surface of VF2 UNSAT is equal to about 600 m^2.
- Recirculation manhole and pumping system towards influent of UASB digester, R1;
- Recirculation manhole and pumping system towards effluent of UASB digester (influent to VF1 SAT), R2.

Recirculation and by-pass manhole are planned to test different configurations, however, the standard configuration includes no recirculation. **The CW system is designed to guarantee the effluent water quality standards without any recirculation.**

As part of the innovation action Horizon2020 HYDROUSA, the Polytechnic University of Marche (UNIVPM), partner of the project, will design and provide membrane filtration and ultraviolet (UV) disinfection system units that will be integrated into the demonstrative wastewater treatment plant at Antissa (Greece).
The units will compose of compact skids, and will be adaptable and flexible to operate on the basis of the type of influent and expected effluent.

With membrane filtration technology it is possible to get a selective barrier that will remove residual particulate and colloidal matter and pathogens from the influent.

On the other hand, the use of UV lamps as a disinfection process will effectively inactivate pathogenic cells through Ultraviolet radiation, while not contributing to the formation of toxic by-products and without using hazardous chemicals. Moreover, it requires short contact time in UV reactors and less space than chlorine disinfection.

Details on wetland technology used for full scale system are reported in Annexes.

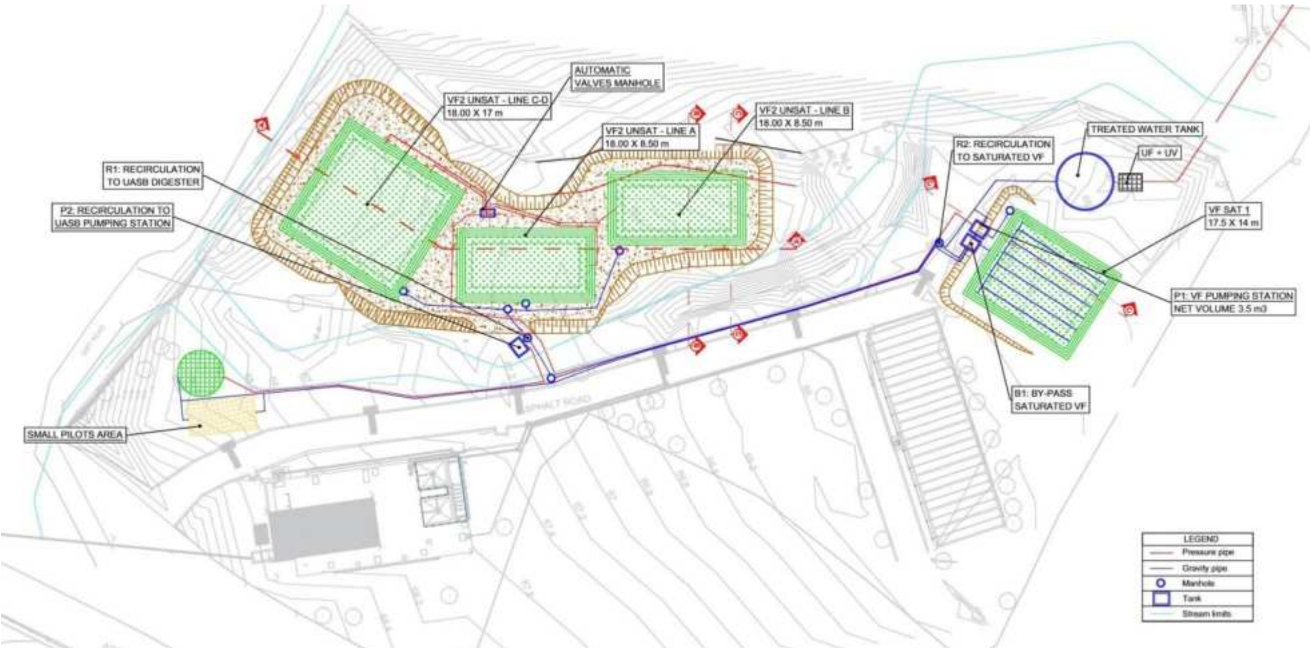

Figure 2.1. Plan layout of Lesvos pilot system

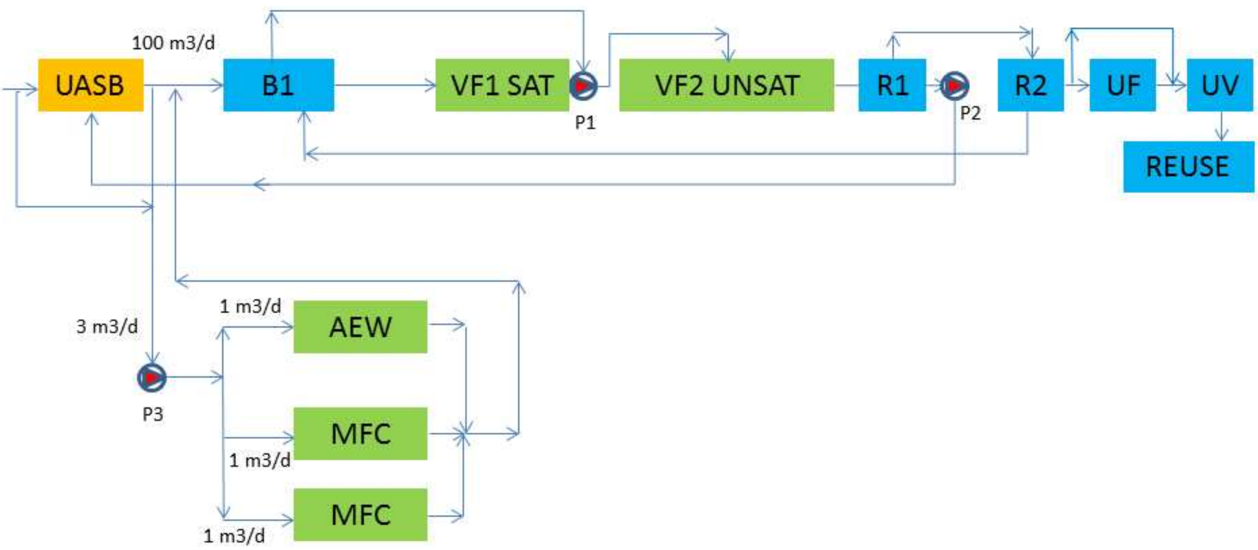

Figure 2.2. Schematization of Lesvos full and pilot scale systems.

2.1.1.1 VF1 SAT unit

The VF1 SAT unit consists of the following characteristics shown in Table 2.1

Table 2.1. VF1 SAT unit construction characteristics

Flow	m^3/d	10-100
Bottom surface area	m^2	250
Size and depth of filter media (starting from bottom) **30-50 mm round washed gravel** **10-20 mm round, washed gravel** **5-10 mm round, washed gravel**	m	 0.80 0.10 0.10
Total Depth of filter media	m	1.00
Free board	m	0.30
Total Depth	m	1.30
Type of plants	-	*Phragmites australis*
Material of construction	-	Excavated in the soil, soil embankments, waterproofed with 1 mm EPDM liner or similar

2.1.1.2 VF2 UNSAT unit

The VF2 UNSAT unit consists of the following characteristics shown in Table 2.2:

Table 2.2. VF2 UNSAT unit construction characteristics

Flow	m^3/d	10-100
Bottom surface area	m^2	600
Size and depth of filter media (starting from bottom) **20-40 mm round washed gravel** **5-10 mm round, washed gravel** **sand 0,4-5 mm** **5-10 mm round, washed gravel**	m	 0.20 0.20 0.40 0.20
Total Depth of filter media	m	1.00
Free board	m	0.30
Total Depth	m	1.30
Type of plants	-	*Phragmites australis*
Material of construction	-	Excavated in the soil, soil embankments, waterproofed with 1 mm EPDM liner or similar

2.1.1.3 Membrane filtration

The membrane filtration technology involves the removal of residual particulate and colloidal matter and even pathogens from wastewater. The high separation yield is achievable thanks to the selective barrier function that carries out the membrane in separating residual TSS, colloidal and dissolved solids.

The separation process can be classified based on several parameters. One of these, which characterizes the removal mechanism, is the nominal size of the separation achieved i.e. microfiltration, ultrafiltration, nanofiltration, reverse osmosis, and electrodialysis. According to this classification, the separation of particles in micro and ultrafiltration is accomplished primarily by physical size exclusion (straining/sieving) of solids with bigger than the membrane porosity whereas in nanofiltration and reverse osmosis, in addition to straining, small particles are rejected by water layer adsorbed on the surface of the membrane. Table 2.3 summarizes the distinguishing characteristic of the membrane processes considered.

Table 2.3. General characteristics of membrane processes (Metcalf & Eddy, 2014)

Membrane process	Membrane driving force	Typical separation mechanism	Typical pore size, μm	Typical operating range, μm	Membrane details: Materials (arranged alphabetically)	Membrane details: Configuration
Microfiltration	Hydrostatic pressure difference or vacuum in open vessels	Sieve	Macropores (> 50 nm)	0.07–2.0	Acrylonitrile, ceramic (various materials), polypropylene (PP), polysulfone (PS), polytetrafluorethylene (PTFE), polyvinylidene fluoride (PVDF), nylon	Spiral wound, hollow fiber, plate and frame
Ultrafiltration	Hydrostatic pressure difference or vacuum in open vessels	Sieve	Mesopores (2–50 nm)	0.008–0.2	Aromatic polyamides, ceramic (various materials) cellulose acetate (CA), polypropylene (PP), polysulfone (PS), polyvinylidene fluoride (PVDF), Teflon	Spiral wound, hollow fiber, plate and frame
Nanofiltration	Hydrostatic pressure difference in closed vessels	Sieve + solution/ diffusion + exclusion	Micropores (< 2 nm)	0.0009–0.01	Cellulosic, aromatic polyamide, polysulfone (PS), polyvinylidene fluoride (PVDF), thin-film composite (TFC)	Spiral wound, hollow fiber, thin film composit
Reverse osmosis	Hydrostatic pressure difference in closed vessels	Solution/diffusion + exclusion	Dense (< 2 nm)	0.0001–0.002	Cellulosic, aromatic polyamide, thin-film composite (TFC)	Spiral wound, hollow fiber, thin film composite
Electrodialysis	Electromotive force	Ion exchange	Ion exchange	0.0003–0.002	Ion exchange resin cast as a sheet	Plate and frame

With a different degree and mechanisms of separation, it is thus possible to remove different types of constituents, as shown in Figure 2.3. In the HYDROUSA demonstration plant, the treated effluent after the wetland will be fed to the membrane under pressure from an equalization tank and the average flow rate fed to the system can be assumed almost constant and equal to 5 m^3/h (100 m^3/d).

Concerning the outflows from the membrane unit, the permeate will be sent to the UV unit and the retentate will be recirculated under pressure at the head of the main plant. Membrane modules will be assembled on a compact skid that which will be preceded and followed by buffer tanks for influent and permeate. Polymeric micro or ultra-filtration membranes will be installed and operated. Periodic membrane cleaning will be carried out mainly with hypochlorite or citric acid or soda, according to the observed fouling. A spare membrane module will be always available to guarantee continuous operation and functionality of the filtration plant.

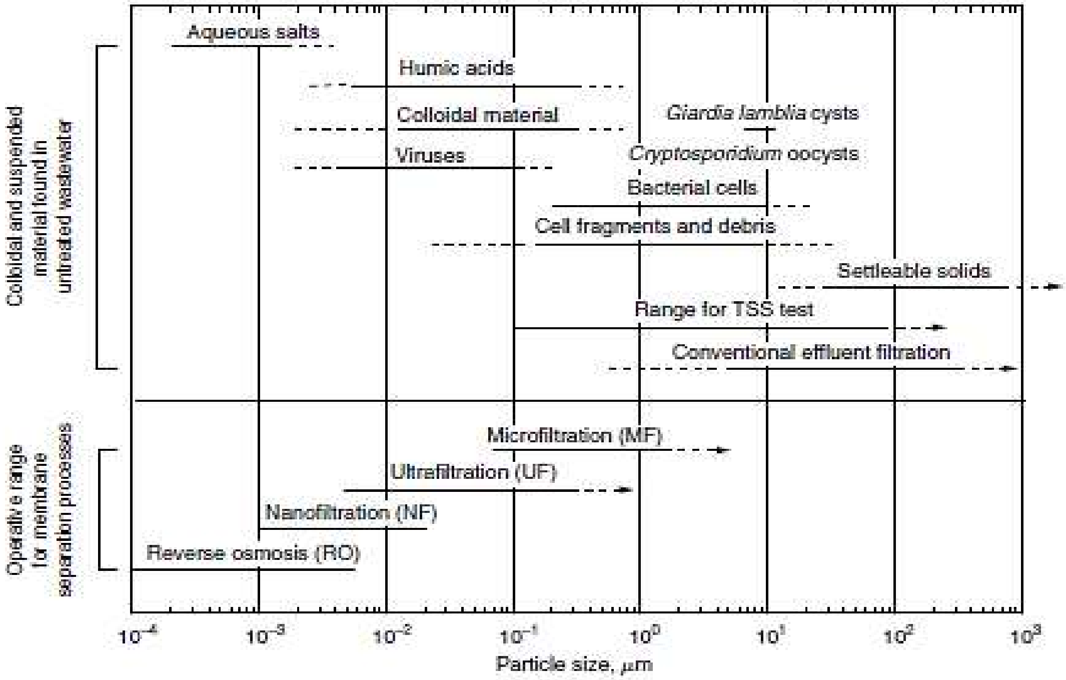

Figure 2.3. Operating size ranges for membrane technologies (Metcalf & Eddy, 2014)

2.1.1.4 UV disinfection

The permeate of the membrane passes to the next step of disinfection which is achieved by UV lamps. The UV disinfection is effective thanks to the photochemical damage to RNA and DNA within the cells of an organism. The UV radiation penetrates the cell wall of the microorganism and it is absorbed by the nucleic acids, responsible for the development of microorganisms, which are damaged in this way. The cells are effectively inactivated and the damage result is a germicidal action. The germicidal portion of the UV radiation band is between about 220 and 320 nm, principally in the UV-C range, as shown in Figure 2.4.

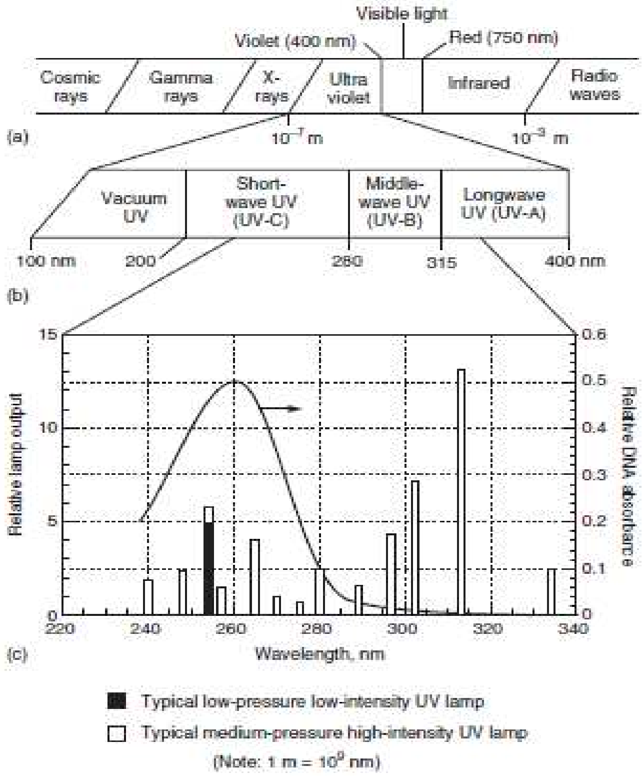

Figure 2.4. Typical operational characteristics for UV Lamps (Metcalf & Eddy, 2014)

2.1.2 Pilot scale system

Three pilot systems are included and are designed to evaluate the possibility to reduce the areal footprint of CWs and in the bio-electrified CWs investigate the potential of energy production through wastewater treatment with intensified innovative solutions (Wu et al., 2014):

- an aerated CW treating the effluent from the UASB, AEW (aerated wetland);
- a bio-electrified CW treating the effluent from the UASB, MFC (microbial fuel cell);
- a bio-electrified CW treating the influent from the UASB (raw wastewater), MFC.

Each pilot system will receive a maximum flow rate of **1 m^3/d**; therefore, a total of 3 m^3/d (max) are diverted to feed the pilot systems.

A brief description of the pilot systems are reported in the following section, while more details on wetland technology used for pilot scale systems are reported in Annexes.

2.1.2.1 Aerated constructed wetland pilot

The aerated constructed wetland pilot system will treat 1 m^3/d effluent from the UASB reactor. The aerated pilot bed will work under saturated condition, i.e. in sub-surface flow mode. An aeration system will be placed under the gravel substrate at the bottom of the bed using the Forced Bed Aeration^{TM} technology, as the patented name, developed by an American constructed wetlands expert Scott D. Wallace. The air is supplied to the aeration system by a blower. The air blown to the system reinforces the oxidation process which creates a very good performance for pollutants removal, reducing 4-5 times areas required for the conventional passive CWs (www.iridra.eu).

2.1.2.2 Bio-electrified constructed wetland pilots

Two bio-electrified CW pilots will be placed, one treating 1 m^3/d effluent from the UASB reactor and the other one treating 1 m^3/d influent from the UASB reactor. The iMETland technology will be tested, which consists of a CW bed working in sub-surface flow conditions and filled with electrically conductive material of selected sizes. The electrically conductive material allows the growth of particular bacterial communities, able to generate electricity from the wastewater treatment as well as to treat the wastewater in an efficient way. The iMETland technology estimates to treat wastewater with an up to 10-fold reduction of required area in comparison to conventional CW technology. The produced electricity will be harvested, investigating potential uses, such as low-voltage sensors.

2.1.3 Construction phases

The realization of VF1 SAT and VF2 UNSAT consist of the following phases:

- Realization of the excavation, according to the project drawings after appropriate regularization of the surface eliminating sharp rocks;
- Along the edges of the bed, realization of a small soil embankments;
- Installation on the bottom and the banks of nonwoven geotextile (minimal density 250 g/m^2);
- Placing on the bottom a sand layer of 10 cm average thickness
- Installation of the waterproofing layer by ethylene propylene diene monomer (EPDM; precast) or High-density polyethylene (HDPE; on site thermo-welded) liner 1 mm
- Realization of outlet pipe passage DN160
- Installation of second layer of geotextile (minimal density 250 g/m^2)
- Fixing of the EPDM/HDPE liner margins below the small soil embankments, protection of the liner with the internal soil embankments and completion of the upper part of the small embankments
- Installation of drainage and aeration pipes constituted by a grid of slotted flexible drainage HDPE or polyvinyl chloride (PVC) pipe DN110 and DN160 as per drawing; on one side the drainage pipes are connected to the main outlet drainage pipe, linked to the outlet DN160 PVC pipe; on the other side the flexible pipe is prolonged vertically until 30 cm above the final gravel surface and closed by a chimney.
- Fill the bed with selected medium gravel and sand layers, as per drawings, until an average height of 1.2 m from the bottom. The final filling surface must be horizontal, i.e. without slope.
- Installation of the distribution system, as per drawing, constituted by PVC pipes DN40 NP10 perforated by hole 5 mm each 0.5 m
- Covering with the ultimate 10 cm of gravel 20 mm.
- Installation of outlet control chamber; the outlet pipe from the basin is inserted in a PVC T90° with elastomeric seal with on the vertical exit the insertion of a vertical trunk pipe that permit to reach a level different operation levels according to the type of the system (unsaturated or saturated) and different operational functioning, from the bottom of the basin and closed with a screw plug with an elastomeric seal.
- Plant the reeds (*Phragmites australis*) in the gravel, with a density of 4 plants/m^2.

2.2 Design data

2.2.1 Climatic conditions

The climatic data of Antissa (the city in which the pilot plant is sited) are used as reference for site (see Figure 2.5 and Table 2.4; https://en.climate-data.org).

The climate is warm and temperate in Antissa; there is more rainfall in the winter than in the summer. The Köppen-Geiger climate classification is Csa. The temperature here averages 15.4 °C. The average annual rainfall is 609 mm. The driest month is August, with 6 mm of rainfall. With an average of 122 mm, December is the month with the higher precipitation. The difference in precipitation between the driest month and the wettest month is 116 mm. During the year, the average temperatures vary by 16.1 °C.

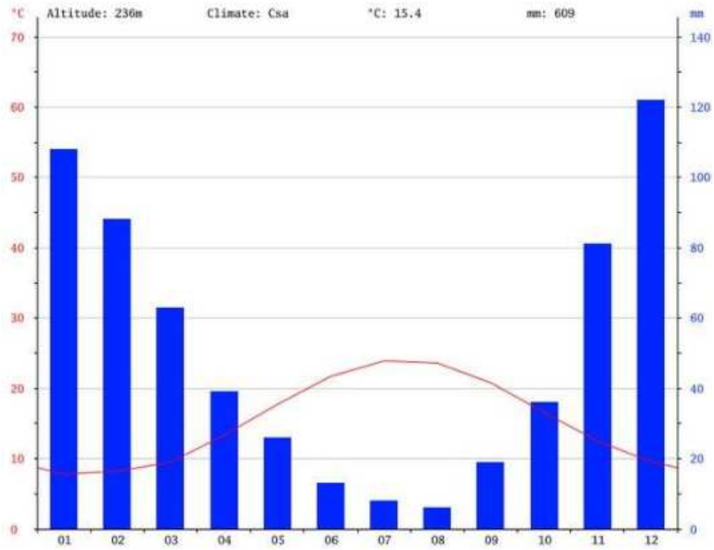

Figure 2.5. Monthly mean temperature and precipitation of Antissa

Table 2.4. Climatic data of Antissa

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Avg. Temperature (°C)	7.8	8.2	9.5	13.3	17.7	21.7	23.9	23.6	20.8	16.6	12.5	9.6
Min. Temperature (°C)	5.1	5.4	6.3	9.4	13.3	17.2	19.6	19.4	16.8	13.1	9.4	6.9
Max. Temperature (°C)	10.5	11	12.8	17.3	22.1	26.3	28.3	27.8	24.8	20.1	15.6	12.4
Precipitation / Rainfall (mm)	108	88	63	39	26	13	8	6	19	36	81	122

2.2.2 Wastewater characterization

The characteristics of the wastewater influent to the UASB + CW system are derived from data provided by the monitoring of the existing WWTP of Antissa from which the wastewater will be diverted towards the HYDROUSA demonstration system. The influent data are from July 2017 to September 2018, and are reported in Table 2.5. A statistical analysis on influent wastewater characteristics is performed and is reported in Table 2.6. The COD/BOD_5 ratio is around 1.8, on the basis of mean values.

Wastewater flow of 10 and 100 m^3/d will be diverted from the inlet of the existing WWTP of Antissa and will be conveyed to the UASB+CW full scale HYDROUSA system during off-season and touristic seasons, respectively.

Table 2.5. Influent wastewater quality of the Antissa WWTP.

Sampling Dates	T °C	pH	Cond. µS/cm	NO_3-N mg/L	NH_4-N mg/L	BOD_5 mg/L	COD mg/L	TSS mg/L	TN mg/L
12/7/17	22.8	7.41	1044	0.2	33.9	354	689	302.8	48.2
22/9/17	26.2	7.35	1712	0.1	39.3	452	672	214.6	55.1
6/11/17	22.3	6.92	1230	0.3	17.6	268	589	231.5	22.8
15/1/18	20.1	7.01	1105	0.2	22.4	313	632	312.3	32.9
1/4/18	21.6	7.25	972	0.1	33.2	270	459	294.4	41.5
9/6/18	23.5	7.86	1114	1.0	36.7	329	541	257.6	49.2
31/7/18	22.9	7.21	1203	0.1	28.9	333	621	299.6	39.8
14/9/18	21.5	7.33	987	0.2	39.9	365	514	227.4	42.5
17/9/18	22.1	7.13	1108	0.1	36.3	298	482	300.9	48.7

Table 2.6. Statistical analysis of the influent wastewater quality

	NO_3-N mg/l	NH_4-N mg/l	BOD_5 mg/l	COD mg/l	TSS mg/l	TN mg/l	TKN mg/l
Mean	0.3	32.0	331	578	272	42.3	42.0
Standard dev.	0.3	7.7	56	83	39	9.8	9.7
Min	0.1	17.6	268	459	215	22.8	22.5
Max	1.0	39.9	452	689	312	55.1	55.0
80° percentile	0.2	37.7	358	648	302	48.9	48.4

2.2.3 Effluent requirements

The target of the UASB + CW treated effluent is the reuse in agriculture. In terms of reuse, the required disinfection limits, strongly vary among different countries (Jeong et al., 2016), with some countries following a "zero-risk approach", i.e. very strict disinfection limits, and other with more flexible regulations considering different type of wastewater reuse (Licciardello et al., 2018). Examples of different disinfection water quality standards for agricultural reuse are reported in Table 2.7. The HYDROUSA system also considers the very recent EU proposal for Regulation on minimum requirements for water reuse. The final effluent produced will meet the criteria set for Class A reclaimed water. These limits are given in Table 2.8 and the different classes are listed in Table 2.9.

As visible from Table 2.7, the Greek limits follow the "zero-risk approach", with very strict pathogen water quality standards. On the other hand, the Greek limit on total nitrogen concentration in the treated effluent (less than 45 mgN/L) is not strict, allowing an effluent rich in nutrients and more suitable for irrigation purposes. To this aim, hybrid constructed wetlands seem a proper solution to meet the effluent targets (Zurita et al., 2014) and provide an effluent suitable for reuse in irrigation in a circular economy view of wastewater management (Masi et al., 2018).

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Table 2.7. Regulations or guidelines disinfection limits for unrestricted agricultural reuse

Regulation	TC/100mL	FC EC, EC/100mL	% samples	Type of Treatment
WHO		200-1000	50	Lagoons
California Title 22	2.2/23		50/max	Secondary/Tertiary/Disinfection
Italy	2		50	
Cyprus		50	80	Secondary/Tertiary/Disinfection
Greece		**5 EC(50 EC)**	**80 (95)**	**Secondary/Tertiary/Disinfection**
JRC Class A		10 (90)	80 (95)	Secondary/Tertiary/Disinfection

Table 2.8. Reclaimed water quality criteria for agricultural irrigation (European Commission, 2018)

Reclaimed water quality class	Indicative technology target	E. coli	BOD_5	TSS	Turbidity	Additional criteria
		cfu/100 mL	*mg/L*	*mg/L*	*NTU*	
Class A	Secondary treatment, filtration, and disinfection (advanced water treatments)	≤ 10 or below detection limit	≤ 10	≤ 10	≤ 5	*Legionella* spp.: ≤ 1,000 cfu/L when there is risk of aerosolization in greenhouses Intestinal nematodes (helminth eggs): ≤ 1 egg/L when irrigation of pastures or forage
Class B	Secondary treatment, and disinfection	≤ 100	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class C	Secondary treatment, and disinfection	≤ 1,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	
Class D	Secondary treatment, and disinfection	≤ 10,000	According to Directive 91/271/EEC	According to Directive 91/271/EEC	-	

Table 2.9. Classes of reclaimed water quality, and the associated agricultural use and irrigation method considered (European Commission, 2018)

Crop category	Minimum reclaimed water quality class	Irrigation method
All food crops, including root crops consumed raw and food crops where the edible portion is in direct contact with reclaimed water	Class A	All irrigation methods allowed
Food crops consumed raw where the edible portion is produced above ground and is not in direct contact with reclaimed water; processed food crops and non-food crops including crops to feed milk- or meat-producing animals	Class B	All irrigation methods allowed
	Class C	Drip irrigation only
Industrial, energy, and seeded crops	Class D	All irrigation methods allowed

The UASB+CW+UF+UV HYDROUSA plant is designed to respect the Greek effluent water quality regulation for unrestricted agricultural reuse, which are reported as follows:

BOD_5 < 10 mg/L for 80% of the samples
Suspended solids < 10 mg/L for 80% of the samples
Turbidity ≤ 2 NTU (median value)
***E. coli* ≤ 5 for 80% of the samples & ≤ 50 for 95% of the samples**

2.3 Design criteria and assumptions

The system is verified considering the functioning of only VF2 UNSAT, i.e. by-passing the VF1 SAT and without any recirculation (MODE 1 as presented in section 2.8).

2.3.1 UASB removal efficiencies

UASB reactors are suitable as a primary treatment stage for CW systems, improving the COD and TSS removal in comparison to conventional septic tanks (Alvarez et al., 2008; de la Varga et al., 2013) as well as allowing the recovery of energy in terms of biogas (Liu et al., 2011). Small pilot systems have the capability to meet treated wastewater reuse criteria with a UASB+CW scheme (El-Khateeb et al., 2003).
The UASB reactor has been designed by considering the possibility of sludge escape from the blanket due to hydraulic load fluctuations typical of touristic areas and therefore the following conservative UASB removal efficiencies have been adopted, for both winter (not-touristic) and summer (touristic) seasons:

- **COD 70%**
- **TSS 70%**
- ***E. coli* 90% (1 $\log_{10}$)** (de Lemos Chernicharo, 2007).
- A negligible contribution of UASB to nutrient removal is assumed.

Based on the above the UASB has been designed to guarantee a treated effluent with the following wastewater quality (deliverable D3_1):

- COD = 173 mg/L;
- TSS= 90 mg/L;

2.3.2 Vertical subsurface flow systems (VF) – unsaturated with intermittent feeding

Sizing procedure for VF beds is mainly based on the nitrification process; in fact, when the treatment goals which are normally required for ammonium concentration are fulfilled, all the other parameters are satisfactory eliminated too.

The oxygen demand (OD) for **nitrification and BOD reduction** is estimated on the basis of BOD_5, following the formula proposed by Kadlec and Wallace (2009):

$$OD = \left(BOD_{5,in} - BOD_{5,out}\right) + 4.6\,(TKN_{in} - TKN_{out})$$

where BOD_5 and TKN (Total Kjeldahl nitrogen) in and out are expressed in g per day. Note that TKN instead of NH_4-N is assumed for OD following a conservative approach, i.e. conserving the need to nitrify the potential ammonia coming from the ammonification of organic nitrogen, as suggested by Kadlec and Wallace (2009), Nivala et al. (2013) and Dotro et al. (2017). Mean values of the influent wastewater characterization are used to estimate the oxygen demand.

The design approach for VF CW relies on empirical observations of the oxygen transfer rate (OTR) from operating systems. Platzer (1999) has measured values of OTR in the range 23-64 g O_2/m^2d. Nivala et al. (2013) reviewed the OTR for the different type of CW systems, reporting values up to 92 g O_2/m^2d for full-scale VF CWs. Following a conservative approach, we calculate the oxygen input (OI) VF systems by presuming a surface aeration rate of 32 g O_2/m^2d.

In terms of **denitrification**, we consider the worst scheme, i.e. no saturation on the bottom and no recirculation to VF1 SAT. Under these assumptions, we consider a denitrification of 10%, as reported by Platzer (1999). Note that, a TN removal of 60-70% can be reached with a saturated bottom and/or with recirculation (Dotro et al., 2017).

Suspended solid removal efficiencies are estimated as a function of solid loading rate, according to the load graph proposed by Kadlec and Wallace (2009), reported in Figure 2.6.

The German Guidelines for domestic wastewater DWA (2006) assume an average organic loading rate (OLR) of 20 $gBOD_5/m^2d$ to avoid clogging and a resting period of 3-6 h, with flushed volumes of 2-4 cm on the top of VF surface.

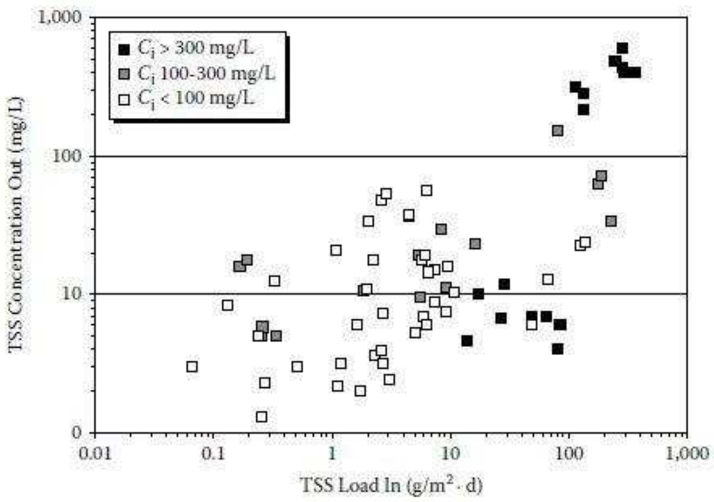

Figure 2.6. Loading graph for TSS removal in VF unsaturated system (Kadlec and Wallace, 2009)

2.3.3 Pathogens removal in subsurface flow constructed wetlands

Domestic wastewater contains human pathogens (bacteria, viruses, protozoa) that may survive pre-treatment and enter the wetland system. These pathogens can be divided into five groups: viruses, bacteria, fungi, protozoan, and helminths.

Measurement of human pathogenic organisms in wastewaters is expensive and technically challenging. Consequently a common practice is the use of indicator organisms that are easy to monitor and correlate with other populations of pathogenic organisms. The EU requirements refer to Faecal Coliform and more recently *Escherichia Coli.* Faecal Coliform are separated from total coliforms by their ability to ferment lactose with gas production in 24 hours at a temperature of 44.5°C. An even narrower group, *Escherichia Coli*, is being used more frequently as an indicator organism, because it can readily be separated from the rest of the faecal group, and because several strains are capable of causing severe human health problems.

Pathogen removal in treatment wetlands is the result of a variety of physical, chemical and biological processes. Physical mechanisms include mechanical filtration, UV exposure and sedimentation. Chemical mechanisms are oxidation, exposure to plant-produced biocides and absorption to organic matter. Biological processes include predation and natural die-off.

Subsurface flow wetlands are considered to be effective for pathogen reduction. For the larger structures (helminth eggs) sedimentation, filtration and interception are dominant removal processes. Adsorption and natural die-off are more important for removal of bacteria and viruses. Typical removal rates are 98%-99% for total and faecal coliforms, 95%-99% for viruses and 93%-99% for helminth eggs (Kadlec and Wallace, 2009).

Considering the vertical sub-surface flow (VSSF) CW contribution to pathogen removal a removal rate up to 99.99% (4 log-reduction) can be achieved (minimum value about 1 log reduction, as reported in many scientific publications). Referring to *Faecal Coliforms*, the final expected concentration is about 1,000 UFC/100mL, (generally the inlet concentration is about 10,000,000 UFC/100mL). European water directives report a final admitted concentration of 5,000 UFC/100mL for a potentiality > 2,000 PE and where the river’s water is used for potable uses.

A variety of other pathogenic bacteria have been assessed in sub-surface flow (SSF) wetlands. These include *Clostridium perfringens*, Enterobacteriaceae, Enterococci, *Salmonella*, *Shigella*, *Yersinia* and faecal streptococcus. Kadlec and Wallace (2009) report that SSF CWs are also effective in the reduction of these pathogenic organisms: for 20 VF systems the mean global removal for these bacteria was 2.63-log reduction. These values are very similar to the reduction observed for faecal and total coliforms, presumably because the same removal mechanisms are operative.

Horizontal flow (HF) CWs are also effective in reducing the number of eggs or oocysts of protozoa and helminths. This is presumably due to a combination of settling, filtration, interception, and predation. Removal percentages reported in the literature range from 79 to 100% (Kadlec and Wallace, 2009). At present, there is not sufficient data to assess the performance of VF wetland for parasite removal, but we can suppose that these systems could be effective in the removal of parasite cysts or eggs. Finally, the reduction of viral organisms occurs in HF systems in the order of 1.47-log; similar virus removal can be expected in VF systems.

Wu et al. (2016) recently reviewed the disinfection capacity of CWs highlighting that:

- generally, horizontal subsurface flow CWs have better capacity than free water surface flow CWs for the removal of *E. coli* (+1.1 log10 CFU/100 mL), faecal coliforms (+0.2 log10 CFU/100 mL), faecal streptococci (+0.9 log10 CFU/100 mL), *Clostridium perfringens* (+0.6 log10 CFU/100 mL) and staphylococci (+0.8 log10 CFU/100 mL), with the exception of total coliforms (−0.9 log10 CFU/100 mL).
- As compared to horizontal flow CWs, the hybrid CWs (i.e. different combination of VF, HF, and FWS) could further improve the removal of *E. coli*, TC and FC by 1.5, 1.2, 0.3 log10 CFU/100 mL, respectively, as visible in Figure 2.7.

The *E. coli* removal efficiency of VF system is estimated according to data reviewed by Kadlec and Wallace (2009), reported in Table 2.10, and is assumed equal to 90-99% (1-2 log_{10}).

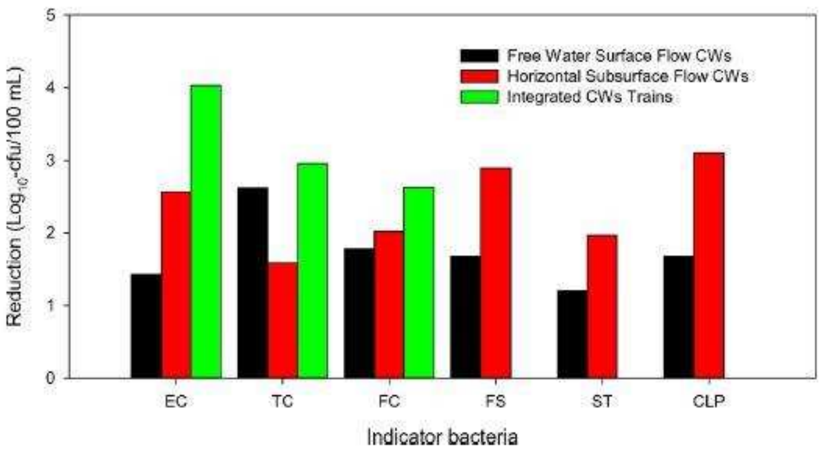

Figure 2.7. Average reduction of indicator bacteria for different CW solutions (TC: total coliforms; FC: faecal coliforms; EC: *Escherichia coli*; FS: faecal streptococci; CLP: *Clostridium perfringens*; ST: staphylococcus) (Wu et al., 2016)

Table 2.10. Reduction of *E. coli* in VF systems collected by Kadlec and Wallace (2009)

System Name and Location	Reference	Media d_{10} *mm*	Vegetation	HLR *m/d*	Organism	Inlet *CFU/100 mL*	Outlet *CFU/100 mL*	log_{10} Reduction
Aurignac, France	Torrents et al. (2007)	River sand (0.25 mm)	*Phragmites*	0.2-0.8	*E. coli*	7.4E+02	-	1.61
Aurignac, France	Torrents et al. (2007)	River sand (0.25 mm)	None	0.2-0.8	*E. coli*	9.7E+02	-	1.49
Aurignac, France	Torrents et al. (2007)	Crushed sand (0.19 mm)	None	0.2-0.8	*E. coli*	8.1E+02	-	1.57
Florence, Italy	Masi et al. (2004)	Sand 0-4 mm	*Phragmites*	0.17	*E. coli*	3.72E+03	2.3E+02	1.20
Langenreichenbach, Germany	Baeder-Bederski et al. (2005)	LECA + Sand	*Phragmites*	0.04	*E. coli*	-	-	2.40
Langenreichenbach, Germany	Baeder-Bederski et al. (2005)	Sand 0-2 mm	*Phragmites*	0.04	*E. coli*	-	-	3.60
Lauwersoog, The Netherlands	Meuleman et al. (2003)	Sand	*Phragmites*	0.4	*E. coli*	5.0E+04	1.9E+01	3.43

2.4 Process design calculations

The process calculations for the parameters are performed according to the methodology and criteria of section 2.3 and are reported in Table 2.11.

Table 2.11. Parameter for process calculation of wetland system

Data	Value	Unit
L VF sector	18	m
W VF sector	8.5	m
n° of sectors	4	
A VF area per sector	153	m^2
A VF total (net)	612	m^2
V pumping station	3.5	m^3
COD/BOD_5 ratio IN – mean measured values	1.74	
OTR	32	gO_2/m^2d
UASB – COD removal efficiency	70%	
UASB – TSS removal efficiency	70%	
UASB – EC removal efficiency	90%	
Flush	2	cm
HLR batch	0.25	m^3/m^2h

The oxygen demand (OD) of the VF system is calculated assuming BOD_5 and nitrification removal efficiencies of **90% and 50%**, respectively. The OD results **18616 gO_2/d**; the calculations are resumed in Table 2.12. The available area of VF2 UNSAT (about 600 m^2) supplies an oxygen input (OI) of **19584 gO_2/d**; **since OI > OD, the assumed removal efficiencies for BOD_5 and nitrification are verified**.

Table 2.12. Oxygen demand calculation for VF unsaturated system

		BOD_5	TKN	Total
concentration IN	mg/L	99	42	
concentration OUT	mg/L	9.9	21.0	
load IN	g/d	9940	4204	
load OUT	g/d	994	2102	
load removed	g/d	8946	2102	
Oxygen demand				
OD - Kadlec and Wallace (2009)	gO_2/d	8946	9670.222	**18616**

The characteristics of the designed feeding system are reported in Table 2.13. The minimum volume of the pumping station needs to be 3.1 m^3. The flush time interval of approximately 3 hours is in agreement with German guidelines (DWA, 2006). **The feeding system of the VF2 UNSAT is verified and guarantees a suitable batch feeding, in order to promote removal efficiencies according with literature reported values.**

Table 2.13. VF2 UNSAT designed feeding system characteristics

Parameter	Value	Unit
flush volume - per sector	3.1	m^3
n° of flush per day	9	n°
pump flow rate - per sector	38	m^3/h
	11	L/s
flush duration	4.8	min
flush time interval	2.7	h

The organic load results of **16 g_{BOD5}/m^2d**; **the absence of clogging issues is verified (<20 g_{BOD5}/m^2d)**. The solid loading rate is about **15 g_{TSS}/m^2d**, leading to assume **TSS removal efficiency of 75%** according to the loading graph (Figure 2.6).

The UV irradiation unit is designed to guarantee water quality standard for disinfection according with recent literature (Masotti, 2011; Metcalf and Eddy, 2014) based on UNIVPM laboratory experience.

The estimated treated effluent concentrations as well as the removal efficiencies are summarized in Table 2.14; **the designed VF2 UNSAT stage is suitable to respect the effluent water quality standard for TSS, COD, BOD_5, and TN, with also a significant disinfection. The UV system guarantees the required reclaimed water quality according to the Greek legislation.**

Table 2.14. Removal efficiencies of UASB+VF2 UNSAT system + UV (operation mode 1)

		Mean values						
		IN UASB (raw ww)	OUT UASB (IN UASB)	OUT VF (IN UF)	OUT UV	VF removal efficiency	UASB+VF removal efficiency	UASB+VF+UV
IN flow rate	m^3/d	100	100	100				
TSS conc.	mg/L	301	90	22.6		75%	92.5%	92.5%
COD conc.	mg/L	578	173	17.3		90%	97.0%	97.0%
BOD_5 conc.	mg/L	331	99	9.9		90%	97.3%	97.3%
TKN conc.	mg/L	42	42	21.0		50%	50.0%	50.0%
NO_3^--N conc.	mg/L	0.2	0.2	19.1		10%	Negative	Negative
TN conc.	mg/L	42.3	42.3	40.2		5%	5.1%	5.1%
EC	MPN/100 mL	1.0E+06	1.0E+05	1.0E+03 - 1.0E+04	<5	90-99%	99-99.9%	>99.9999%

The design parameters of the CW system are summarized in Table 2.15.

Table 2.15. Design parameters of VF2 UNSAT

Parameter	Value	Unit
specific surface of total CW (VF1 SAT + VF2 UNSAT)	1.7	m^2/PE
specific surface of only VF2 UNSAT	1.2	m^2/PE
OLR of total CW (VF1 SAT + VF2 UNSAT)	11.8	$gBOD_5/PE$
OLR surface of only VF2 UNSAT	16.7	$gBOD_5/PE$
HLR of total CW (VF1 SAT + VF2 UNSAT)	0.12	m^3/m^2d
HLR surface of only VF2 UNSAT	0.17	m^3/m^2d

2.5 List of operation units – specifications of electro-mechanical equipment

This Specification is intended to indicate the minimum standard of design, workmanship and materials acceptable in this project. The itemized specific requirements are given in the Particular Electro-Mechanical Specifications.

2.5.1 General requirements and workmanship

All supplied parts shall be designed and constructed for the maximum stresses occurring during fabrication, erection and continuous operation. All materials shall be new and both workmanship and materials suitable for the service the units are to be subjected and shall conform to all sections of the Specifications.

The general mechanical and electrical design of the Works and particularly that of the bearings, contacts, and other such wearing parts shall be governed by the need for a long period of service without frequent maintenance and attention. Unless otherwise specified, all items of the Works shall be rated for continuous service at the specified duties under the prevailing atmospheric and operational conditions of the Site. All parts subject to wear shall be readily accessible. Provision shall be made for taking up wear in all bearings and other wearing parts or for easy replacement if adjustment is not practicable.

Wherever practical MINAVRA shall ensure the maximum interchangeability of similar items from alternative suppliers. Suitable packers, shims, adjustment and the like shall be fitted for ease of adjustment and realignment of all machinery units with particular attention given to combined sets. All pipes shall be checked for alignment and mating of connections before being secured and pipes shall be in straight line and grade. Pumps shall be designed to meet the operational duties under the Site conditions as specified. Pumps shall be designed to keep constant performance. Waterways through the pump and impeller shall be smooth and free from recess and projections.

2.5.2 Submersible pumps

2.5.2.1 General

The pumping station for VF2 UNSAT loads the bed in a batch mode, controlled by timer and time switch to program pump start and duration of pumping (or alternatively by switch level regulators), ensuring a resting period between every flush of approximately 3-6 h. Flush volume will be 3100-4600 L.

The pumps are 4 (one per reed bed) and they are centrifugal submergible with cast iron open channel impeller; flow 10 L/s Head 10 m, Nominal power 3 kW, motor 400 V 50 Hz 3-phase.

The pumps shall be easily removable for inspection or service, requiring no bolts, nuts, or other fastenings to be disconnected.

Each pump will be equipped with:

- check valve
- PVC ball valve

Pumping equipment shall be constructed as shown on the Drawings with all the necessary equipment for installation and operation. Each pump shall be capable of operating on its own or in parallel with one or all of the pumps in a particular group. Performance curves shall be continuously rising from maximum discharge to shut off head and free of any unstable points. Pumps shall be selected so that their capacity at the design points is less than or equal to the capacity at the best efficiency point.

2.5.2.2 Motor

Close couple, dry type, squirrel cage induction motor, class F insulation suitable for operation on a 400 V AC 3 phase 50 Hz supply, maximum rotation speed 1,500 rpm. The motor shall be effectively grounded. Motors shall have a thermal rating to allow at least 12 starts per hour under specified conditions. Rotor/stator clearances shall take into effect possible short circuits during shock loading. The pump housing shall be arranged to provide an easy removal and re-locating the stator.

2.5.2.3 Casing

Casings shall be cast iron, castings shall be pressure tested before assembly. The overall height of the pump casing shall be limited where possible to allow pumping station operating levels to be set as low as possible.

2.5.2.4 Shaft

Shafts shall be stainless steel. Composite metal shafts will not be accepted. The shaft must be fully protected along its whole length, i.e. it must be totally enclosed within the pump casing. A good allowance of shaft length shall be made for the fixing of the impeller.

2.5.2.5 Seals

The pumps shall be sealed from the motor by two mechanical face seals working independently and in contact with the oil chamber between the pump and the motor. Face seals shall be tungsten carbide. Static seals shall be of neoprene or similar approved. Seals must be reusable. Rotating seals shall be easy to locate and shall not make contact with 0-rings. Seals shall be protected.

2.5.2.6 Bearings

The bearings shall be able to take up the forces, radial and axial, in such a way that no harm shall be transmitted elsewhere. The bearing housing shall not form part of the main casing. The whole assembly shall be arranged for ease of removal for maintenance. High thermal rating lubricants shall be used. The grease life shall be at least that of the bearings. Anti-friction rolling element bearings shall be used, the race being securely locked to prevent movement. The top bearing shall be combined thrust and journal type, designed to prevent any thrust loads being transmitted to the driver motor.

2.5.2.7 Impeller

The impeller shall be keyed to the shaft and be securely locked on with a lock nut which shall be fitted with a removable protective cap. The impeller shall be of cast iron. If a cutting plate is fixed to the bottom of the pump as a standard design feature to prevent the impeller from ragging - up, then this part must be adjustable, reusable and constructed from hardened steel.

2.5.2.8 Cables

Cable insulation shall be rated for a minimum of 600 V AC. Cable entries shall be located at one point of the pump casing, i.e. not spread around the case. The cables shall be of at least 14m length from cable gland to free ends, which will be terminated at a cable box. Suspension loops shall be made in the cables using stainless steel fittings, the cables will be hung on stainless steel brackets located immediately below the access manhole opening, allowing a safe and easy access for pump lifting.

The cable entry sealing system shall be flexible, hard setting resins shall not be used. Cable glands shall be of good quality being arranged to place the minimum stress on the cables at point of entry to the pump casing. The cable terminals shall be sealed from the motor winding to prevent ingress of water. A terminal bonded to the pump casing shall be provided for earth fault protection.

2.5.2.9 Lifting and Locating Pump

The pump shall be fitted with a neoprene or similar approved sealing ring to mate with the duckfoot bend/ pump pedestal and provide a positive seal without using mechanical locking. Smooth mating surfaces shall be provided. Guide rails and lifting chains shall be stainless steel. Lifting chains shall have an automatic locking device at each end to attach to the pump and lifting device during a pump lifting/ lowering operation. The chain shall be fitted with at least two lifting eyes suitable spaced along the full length of the lifting chain. Guide rail clamps shall be of a robust heavy duty pattern.

2.5.2.10 Painting

Pump pedestal and casing shall be finished with a non-solvent epoxy paint, DFT not less than 250 μm.

2.5.2.11 Testing of Pumping Equipment

The pumps shall be tested in the factory as follows: The pump casings and/or column and head assemblies shall be subject to a hydrostatic test pressure of twice the maximum operating head or 1.5 times the shut off head, whichever is the greater. Certified pump test performance curves shall be submitted.
MINAVRA shall conduct non-witnessed performance tests on each pump.

2.5.2.12 Installation of Pumping Units

Installation of pumping units shall be in strict accordance with the manufacturer's instructions.
Equipment installation and required connections shall be made by skilled tradesmen to the best standard. The work shall be accurately carried out to produce a neat, accurate, secure, functional installation. Under no

circumstances will there be allowed any stress to be imposed on any pump flanges or equipment. Under no circumstances will “springing” of piping to correct misalignment be allowed. The anchor bolts and concrete bases for the pumping units cast iron or steel bases shall be prepared in advance. The pump and motor bases shall be set in place and shimmed to correct elevation. The bases shall be grouted in place with non-shrink grouting.

Upon completion of installation of the pump equipment, checking of equipment requiring oils, coolants, greases etc. will be implemented. The types and amount used shall be in strict accordance with the manufacturer’s instructions.

2.5.2.13 Installation of Submersible Pumps

Installation of all pumps shall be in strict accordance with the manufacturer's instructions. Each submersible pump shall be carefully installed down into its well. Proper attention shall be given to the pressure flange that the pump is set to in order to ensure that the pump submergence conforms to the manufacturer's recommendations. The waterproof power and control cables shall be securely attached to the discharge pipe free of kinks.

2.5.2.14 Control panel

The pump is controlled by a control panel comprehensive of:

- Electrical protection and automatic or manual command of no. 1 pump 1 Kw three phase
- Type of custody: Cabinet in SMC (fiberglass-reinforced plastic) in protected execution IP44 with hinge door. Type of custody: For internal installation.
- Installation: wall
- Motoring start-up: Star/Triangle
- The Local switchboards shall meet the requirements of degree of protection index IP55.
- Power supply: 400 V - 50 Hz.

The panel will contain mounted and connected the following materials:

- n°1 Rotary knife, lockable door blocking manoeuvre
- n°1 Fuse 3 pole with fuse to feature delayed
- n°1 Complete thermal relay contactors
- n°1 Selectors man-o-aut (manual position not stable) for each equipment
- n° 2 Beamers with lamps for each equipment
- 1 lights (pump marching) for each equipment
- 1 lights (pump stopped) for each equipment
- n° 1 single-phase transformer for auxiliary circuits adequate power - q.s. relay shutter operation (alternation)
- Programmable timer
- Control unit for pump switching

2.5.3 Valves

2.5.3.1 General

All valves shall be designed to the minimum working pressure as shown on drawings and/or detailed in Particular Specification. Flanges for valves shall comply with EN 1092-2:1997 for cast iron flanges, or equivalent. Unless otherwise specified, all valves shall be anti - clockwise opening and operated by hand wheel for up to 300 mm, above 300 mm geared actuators shall be used.

The maximum effort required to be applied at the circumference of the hand wheel to operate the valves against the maximum unbalanced head shall not exceed 200 Nm. Unless detailed otherwise all hand wheels shall have the words “open” and “close” in English with arrows indicating the direction of rotation cast on. All hand wheels shall be of a solid cast type.

Valves of all types shall be capable of withstanding corrosion in the ambient conditions and any parts manufactured from a material which is not itself corrosion-resistant must be protected. Works tests will not normally be witnessed except where so specified or required by the Engineer. A certificate from manufacturers for shop testing shall be provided for the approval of the Engineer.

2.5.3.2 Gate valves

Gate Valves shall be resilient seated with smooth straight through bore. Body and bonnet shall be of cast iron with non-rising stem of stainless steel spindle. The wedge shall be of ductile iron, inside and outside fully rubberised with vulcanised elastomer, the wedge guide of wear resistant plastic with high gliding features both suitable for potable water.

2.5.3.3 Butterfly Valves

The butterfly valves shall be manufactured according to the ISO 5752, or equivalent. The seepage free shut-off pressure difference of the valve shall be 10 bar against atmospheric pressure.

The body shall be made of cast iron and rubber lined. The disc shall be of cast iron and the shaft of stainless steel. Removal and replacement of seals without removing the valve shaft shall be possible.

2.5.3.4 Pressure Gauges

Gauges shall be provided having mounting arrangements, scale ranges, designation and alarm contacts as required. Gauges shall be of the Borden tube type with isolating diaphragm, brass case with flanged neck and stainless steel bezels. They shall have removable backplate to facilitate inspection and adjustment. Diameter of dial shall not be less than 100 mm. The dial shall be calibrated in kPa. Pressure range shall not exceed system working pressure more than 1.5 times.

Each gauge shall be fitted with a stainless steel isolating cock.

Pump delivery pressure gauges shall be mounted direct on to the pressure tapping in the delivery mains and be corrected to show actual pressure at the delivery flange of the pump.

2.5.4 Membrane and UV lamp

The membrane filtration and UV lamps will be equipped with the following electromechanical components consisting of permeation, backwash and wastewater transfer pumps and electromechanical valves with same specifications followed in section 2.5. Pressure and flows meters will be integrated into the membrane filtration system to support the operation of the membrane process unit. Logger controller will be installed in the filtration unit to set the filtration phases and to acquire the main operative data during the experimental activities.

2.6 List of sensors – meters – automation/control strategy

The automation and control strategy of the CW systems is selected aiming to:

- Monitor effluent water quality of the CW stages, both at full and pilot scale
- Control and manage the functioning of electro-mechanical equipment (pumps)
- Measuring and monitoring of wastewater quantity delivered to CW system

- Provide automation to the recirculation options, allowing to manage the switch between different feeding modes (see section 0) by a PLC
- Monitoring the aeration efficiency of the aerated pilot system

The sensors installed for the automation and control strategy of the CW systems are reported in Table 2.16.

Table 2.16. List of sensors for automation and control

Type of on-line sensor	Process monitored	Point of installation	Parameter(s) monitored	System output
Level sensor	Influent pumping from UASB to the equalization tank	equalization tank	Level	Digital output
Pressure sensor	pressure of n°4 pumps in EQ	equalization tank	Pressure	Analogical output
Flow meter	extra-organic available for the CW process	derivation upstream UASB	Flow	Analogical output
Flow meter	Wastewater recirculation line	Recirculation pipeline	Flow	Analogical output
Level sensor	recirculation tank	recirculation tank	Level	Analogical output
Pressure sensor	pressure of n°1 pump in recirculation tank	recirculation tank	Pressure	Analogical output
Pressure sensor	Aeration	blower pilot n°1	Pressure	Analogical output
Quality sensors	WWTP treatment performances	inlet from WWTP	e.g. COD, NH_4-N, NO_3-N	Digital output
Quality sensors	WWTP treatment performances	output from WWTP	e.g. COD, NH_4-N, NO_3-N	Digital output
Flow meter	UF membrane proper functioning	Influent UF	Flow	Digital output
Turbidity/TSS probe	UV lamp proper functioning	Influent UV	Turbidity	Digital output

2.7 Benefits and limitations

Benefits and limitations of different adopted CW solutions are summarized in:

- Table 2.17 for saturated VF CW (VF SAT 1);
- Table 2.18 for unsaturated VF CW (VF UNSAT 2);
- Table 2.19 for UF membrane;
- Table 2.20 for UV lamp;
- Table 2.21 for intensified CWs (AEW and MFC).

Table 2.17. Benefits and limitations for VF SAT 1 (full scale system)

Saturated VF CW (VF SAT 1)	
Benefits	**Limitations**
• Low operation and maintenance – process available materials • It can be built and repaired with locally available materials • Utilization of natural processes • No chemicals required, construction and repair with local materials and local labourers • Limited energy input due only to feed the beds – no energy in case of possible gravity feeding • Efficient removal of suspended and dissolved organic matter, nutrients and pathogens • High reduction in BOD, suspended solids, nitrates and pathogens	• Permanent higher space requirement in comparison to technological solutions • Moderate capital cost depending on land, liner, fill, etc.; low operating costs • Pre-treatment is required to prevent clogging • Limited nitrification and P removal

Table 2.18. Benefits and limitations for VF UNSAT 2 (full scale system)

Unsaturated VF CW (VF UNSAT 2)	
Benefits	**Limitations**
• Low operation and maintenance – process stability • It can be built and repaired with locally available materials • Utilization of natural processes • No chemical required, construction and repair with local materials and local labourers • Limited energy input due only to feed the beds • Efficient removal of suspended and dissolved organic matter, and pathogens • Efficient nitrification • High reduction in BOD, suspended solids and pathogens • It does not present issues as mosquitos proliferation as compared to the free-water surface constructed wetlands • Lower footprint in comparison to saturated constructed wetlands (but higher in comparison to intensified CWs, such as aerated CWs)	• Permanent higher space required in comparison to technological solutions • Moderate capital cost depending on land, liner, fill, etc.; low operating costs • Pre-treatment is required to prevent clogging • Feeding system requires more complex engineering (and therefore higher O&M) in comparison to gravity-fed saturated CWs • limited denitrification and P removal

Table 2.19. Benefits and limitations for UF membrane (full scale system)

UF membrane	
Benefits	**Limitations**
• High quality level of final effluent • Sanitation level • Elevated performances in the separation of TSS	• Operative costs • Higher electromechanical complexity of the unit • Use of reagents for the washing phases

Table 2.20. Benefits and limitations for UV disinfection (full scale system)

UV disinfection	
Benefits	**Limitations**
• Physical disinfection without use of reagents • No secondary compounds formation	• Disinfection level is related to the transmittance of the influent flow • Possible fouling/scaling of UV lamp • Substitution of the lamp

Table 2.21. Benefits and limitations for intensified CWs (pilot systems)

Intensified CWs (AEW and MFC)	
Benefits	**Limitations**
• Minimization of area footprint for CW solutions • Operation and maintenance lower than technological solutions – process stability • It can be built and repaired with locally available materials • Utilization of natural processes • No chemical, construction and repair with local materials and local labourers • Efficient removal of suspended and dissolved organic matter, and pathogens • High reduction in BOD, suspended solids and pathogens • Efficient nitrification • Bio-electrochemical CWs permit to recover small amount of energy, which can be used for low-voltage equipment (e.g. sensors)	• Permanent higher space required in comparison to technological solutions, but of the same order of magnitude • Aerated CWs requires energy input higher than classical CWs, but lower than technological solutions • Moderate capital cost depending on land, liner, fill, etc.; moderate operating costs • Feeding system requires more complex engineering (and therefore higher O&M) in comparison to gravity-fed saturated CWs • Aeration and bio-electrochemical systems requires more complex engineering (and therefore higher O&M) in comparison to classical CWs • Pre-treatment should be required (raw feeding of bio-electrified CW needs to be confirmed by the monitoring results) • Limited denitrification

2.8 Description of operation

The CW stage consists of a full scale system and some pilot systems, which are designed aiming to guarantee the Greek limits for wastewater reuse in irrigation in terms of TSS, BOD_5, TN as well as contributing in disinfection. The full scale system is designed with two stages: 1st stage, saturated downflow VF (VF1 SAT); 2nd stage unsaturated intermitted load VF CW (VF2 UNSAT). Recirculation and by-pass chambers allow to test up to 3 different configurations, investigating the best scheme for Greek and also other Mediterranean conditions (e.g. different water quality standards for TN). The possible operational modes are:

- MODE 1: UASB + VF2 UNSAT + UV (no recirculation, nitrification, no denitrification):
- MODE 2: UASB + VF2 UNSAT + recirculation to UASB + UV (recirculation, nitrification, partial denitrification)
- MODE 3: UASB + VF1 SAT + VF2 UNSAT + recirculation to UASB + UV (recirculation, nitrification, partial denitrification)
- MODE 4: UASB + VF1 SAT + VF2 UNSAT + recirculation to VF1 SAT + UV (recirculation, nitrification, partial denitrification)
- MODE 5: UASB + UF + UV (no recirculation, nitrification, no nitrogen removal)
- MODE 6: Full treatment scheme: UASB + VF1 SAT + VF2 UNSAT + recirculation to VF1 SAT + UF + UV (recirculation, nitrification, partial denitrification)

2.8.1 Operation MODE 1: UASB + VF2 UNSAT + UV

Operation MODE 1 (Figure 2.8) can be selected in case only the nitrification would be required. To this aim, no recirculation is provided, not using any denitrification stages, neither to UASB nor to VF1 SAT. The anaerobically treated wastewater flows by gravity towards by-pass manhole B1. The UASB effluent by-passes the VF1 SAT stage and is diverted from B1 towards the pumping system serving VF2 UNSAT stage, where the liquid is uniformly distributed on the whole surface by a feeding system constituted by pressure pipes developed along the entire VF2 UNSAT surface. The feeding of VF2 UNSAT is in batch, feeding alternatively the four lines (either A, B, C, or D) according to the batches and resting periods defined in section 2.3.2. The liquid drains under the unsaturated bed and is collected at the bottom of the bed by the VF2 UNSAT drainage system, which delivers the liquid towards the next stages. The treated effluent by-passes both recirculation towards UASB R1 and towards VF1 SAT R2 and is conveyed by gravity to a treated wastewater tank. Finally, the treated effluent is sent from the treated wastewater tank by pressure to the final UV stage for disinfection before it is used to irrigate the agroforesty system (i.e. HYDRO2).

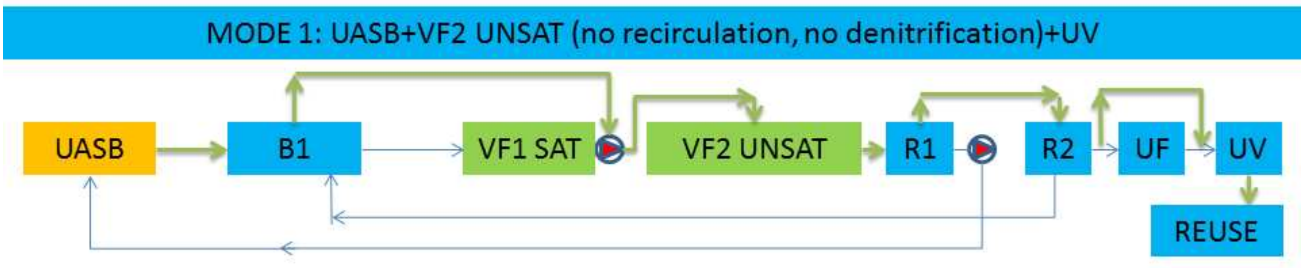

Figure 2.8. Schematization of MODE 1 operation modes of full scale Lesvos system of HYDRO 1: green arrows represent the functioning treatment chain, while the blue arrows the turned off options within the operational mode.

2.8.2 Operation MODE 2: UASB + VF2 UNSAT + plus recirculation to UASB + UV

Operation MODE 2 (Figure 2.9) can be selected in case both nitrification and denitrification would be required. To this aim, recirculation towards the UASB is selected. The anaerobically treated wastewater flows by gravity towards by-pass manhole B1. The UASB effluent by-passes the VF1 SAT stage and is diverted from B1 towards the pumping system serving VF2 UNSAT stage, where the liquid is uniformly distributed on the whole surface by a feeding system constituted by pressure pipes developed along the entire VF2 UNSAT surface. The feeding of VF2 UNSAT is in batch, feeding alternatively the four lines (either A, B, C, or D) according to the batches and resting periods defined in section 2.3.2. The liquid drains under the unsaturated bed and is collected at the bottom of the bed by the VF2 UNSAT drainage system, which delivers the treated effluent towards the next stages. Part of the treated wastewater by-passes the recirculation pumping station (recirculation R1) and another portion is conveyed by gravity to a treated wastewater tank. Therefore, part of the VF2 UNSAT effluent is recirculated by pressure to the UASB reactor. Finally, the treated effluent is sent from the treated wastewater tank by pressure to the final UV stage for disinfection before it is used to irrigate the agroforesty system (i.e. HYDRO2).

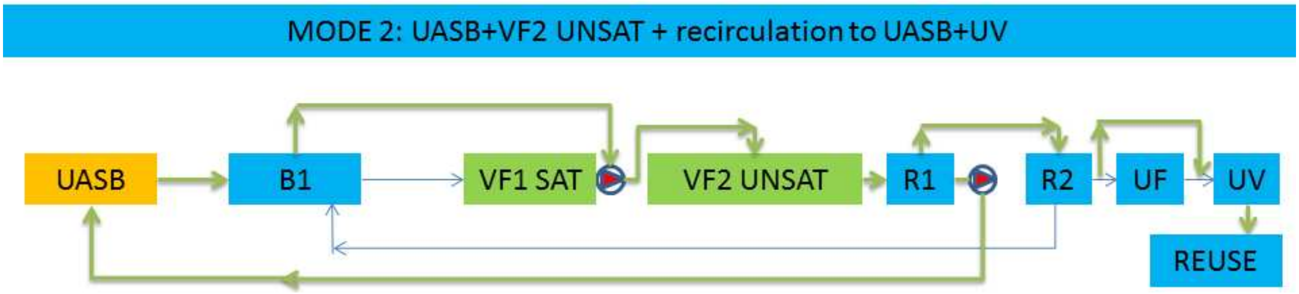

Figure 2.9. Schematization of MODE 2 operation modes of full scale Lesvos system HYDRO1: green arrows represent the functioning treatment chain, while the blue arrows the turned off options within the operational mode.

2.8.3 Operation MODE 3: UASB + VF1 SAT + VF2 UNSAT + plus recirculation to UASB + UV

Operation MODE 3 (Figure 2.10) can be selected in case both nitrification and denitrification would be required. To this aim, recirculation towards the UASB is selected. Differently from MODE 2, this option exploits the VF1 SAT as an additionally saturated bed for TSS and COD removal. In this case, VF1 SAT functions as "safety" stage before the VF2 UNSAT stage, which is filled by sand and is more sensitive to potential sludge escaping from the UASB reactor. The anaerobically treated wastewater flows by gravity towards by-pass manhole B1. The UASB effluent is conveyed by gravity from B1 to the VF1 SAT stage, where it is uniformly distributed on the whole surface by a feeding system constituted by gravity pipes developed along the entire VF1 surface. The feeding of VF1 SAT is continuous. The liquid drains with a downward plug functioning under saturated conditions and is collected at the bottom of the bed by the VF1 SAT drainage system, which delivers the liquid towards the pumping system serving VF2 UNSAT stage. The liquid is taken from the VF2 UNSAT pumping station and is uniformly distributed on the whole surface by a feeding system constituted by pressure pipes developed along all the VF2 UNSAT surface. The feeding of VF2 UNSAT is in batch, feeding alternatively the four lines (either A, B, C, or D) according with the batches and resting periods defined in section 2.3.2. The liquid drains under the unsaturated bed and is collected at the bottom of the bed by the VF2 UNSAT drainage system, which delivers it towards the next stages. Part of the treated effluent by-passes to the recirculation pumping station (recirculation R1) and another portion is conveyed by gravity to a treated wastewater tank. Therefore, part of the VF2 UNSAT effluent is recirculated by pressure to the UASB reactor. Finally, the treated effluent is sent from the treated wastewater tank by pressure to the final UV stage for disinfection before it is used to irrigate the agroforesty system (i.e. HYDRO2).

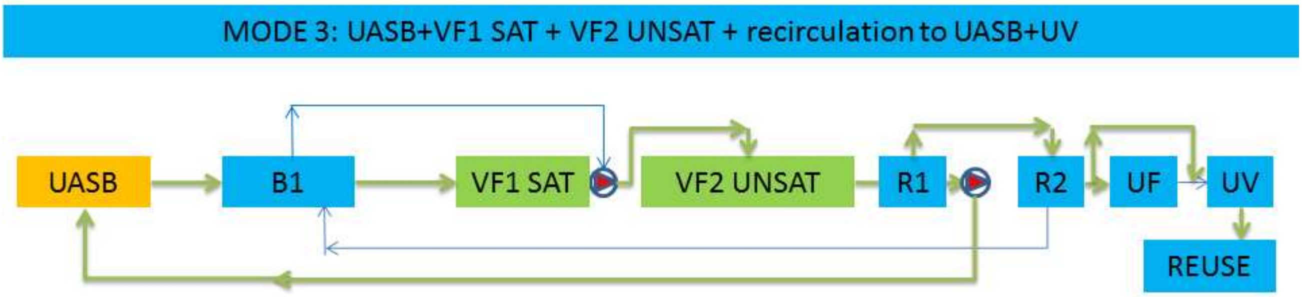

Figure 2.10. Schematization of MODE 3 operation modes of full scale Lesvos system HYDRO1: green arrows represent the functioning treatment chain, while the blue arrows the turned off options within the operational mode.

2.8.4 Operation MODE 4: UASB + VF1 SAT + VF2 UNSAT + UV plus recirculation to VF1 SAT

Operation MODE 4 (Figure 2.11) can be selected in case both nitrification and denitrification would be required. To this aim, recirculation towards the VF1 SAT is selected. Differently from MODE 3, this option exploits the VF1 SAT both as denitrification stage and as an additionally saturated bed for TSS and COD removal. In this case, VF1 SAT functions also as "safety" stage before the VF2 UNSAT stage, which is filled by sand and is more sensitive to potential sludge escaping from the UASB reactor. The anaerobically treated wastewater flows by gravity towards the by-pass manhole B1. The UASB effluent is conveyed by gravity from B1 to the VF1 SAT stage, where it is uniformly distributed on the whole surface by a feeding system constituted by gravity pipes developed along the entire VF1 surface. The feeding of VF1 SAT is continuous. The liquid drains with a downward plug functioning under saturated conditions and is collected at the bottom of the bed by the VF1 SAT drainage system, which delivers the liquid towards the pumping system serving VF2 UNSAT stage. The liquid is taken from the VF2 UNSAT pumping station and is uniformly distributed on the whole surface by a feeding system constituted by pressure pipes developed along all the VF2 UNSAT surface. The feeding of VF2 UNSAT is in batch, feeding alternatively the four lines (either A, B, C, or D) according to the batches and resting periods defined in section 2.3.2. The liquid drains under the unsaturated bed and is collected at the bottom of the bed by the VF2 UNSAT drainage system, which delivers it towards the next stages. The treated effluent by-passes the recirculation pumping station serving the UASB (recirculation R1), but it is sent to the recirculation VF SAT 1 stage (R1). Therefore, part of the VF2 UNSAT effluent is recirculated by gravity to VF SAT 1 and another portion is conveyed by gravity to a treated wastewater tank. Finally, the treated effluent is sent from the treated wastewater tank by pressure to the final UV stage for disinfection before it is used to irrigate the agroforesty system (i.e. HYDRO4).

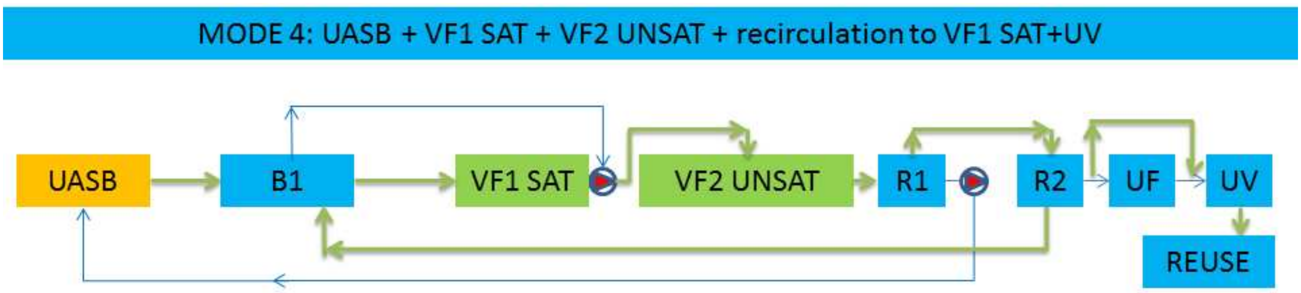

Figure 2.11. Schematization of MODE 4 operation modes of full scale Lesvos system HYDRO1: green arrows represent the functioning treatment chain, while the blue arrows the turned off options within the operational mode.

2.8.5 Operation MODE 5: UASB + UF + UV

Operation MODE 5 (Figure 2.12) can be selected to test the possibility to have neither nitrification nor denitrification, and to reuse anaerobically treated wastewater after only ultrafiltration (UF) and UV disinfection stages. To this aim, no recirculation is provided, not using any denitrification stages, neither in UASB nor into VF1 SAT. Moreover, all the CW stages are by-passed. The anaerobically treated wastewater flows by gravity towards by-pass manhole B1. The UASB effluent by-passes both the VF1 SAT and VF2 UNSAT stages and is diverted from B1 by gravity to a treated wastewater tank. Finally, the treated wastewater is sent from the treated wastewater tank by pressure to the UF and final UV stage for disinfection before it is used to irrigate the agroforesty system (i.e. HYDRO2).

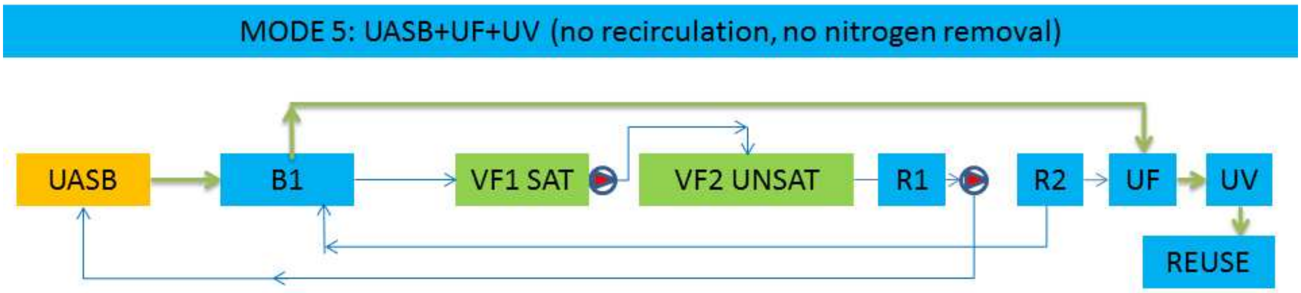

Figure 2.12. Schematization of MODE 5 operation modes of full scale Lesvos system HYDRO1: green arrows represent the functioning treatment chain, while the blue arrows the turned off options within the operational mode.

2.8.6 Operation MODE 6: UASB + VF1 SAT + VF2 UNSAT + recirculation to VF1 SAT + UF + UV

Operation MODE 6 is equivalent to the full treatment scheme available. It can be selected in case both nitrification, denitrification and full suspended solids removal would be required. To this aim, recirculation towards the VF1 SAT and treatment through the UF are selected. This option is similar to option 4 with the addition of UF for compete suspended solids removal. The anaerobically treated wastewater flows by gravity towards by-pass manhole B1. The UASB effluent is conveyed by gravity from B1 to the VF1 SAT stage, where the liquid is uniformly distributed on the whole surface by a feeding system constituted by gravity pipes developed along the entire VF1 surface. The feeding of VF1 SAT is continuous. The liquid drains with a downward plug functioning under saturated conditions and is collected at the bottom of the bed by the VF1 SAT drainage system, which delivers the liquid towards the pumping system serving VF2 UNSAT stage. The liquid is taken from the VF2 UNSAT pumping station and is uniformly distributed on the whole surface by a feeding system constituted by pressure pipes developed along all the VF2 UNSAT surface. The feeding of VF2 UNSAT is in batch, feeding alternatively the four lines (either A, B, C, or D) according to the batches and resting periods defined in section 2.3.2. The liquid drains under the unsaturated bed and is collected at the bottom of the bed by the VF2 UNSAT drainage system, which delivers it towards the next stages. The effluent by-passes the recirculation pumping station serving the UASB (recirculation R1), but it is send to the recirculation to VF SAT 1 stage (R1). Therefore, part of the VF2 UNSAT effluent is recirculated by gravity to VF SAT 1 and another portion is conveyed by gravity to a treated wastewater tank. Finally, the treated effluent is sent from the treated wastewater tank by pressure to the UF and final UV stage for disinfection before it is used in the agroforesty system (i.e. HYDRO2).

2.9 Safety instructions

2.9.1 CW stages

The objective of the next step is to identify functional bottlenecks of the (planned) treatment system. These bottlenecks are referred to as “hazards” and “hazardous events, with:

- "hazards" being specifically defined as "failure modes of treatment units and supporting units" (e.g. pumps, monitoring devices, etc.), and
- "hazardous events" being defined as "circumstances favouring these mal-functions or failure modes"

The identification and understanding of these bottlenecks represents the centrepiece of the "safety" thinking – and builds the basis for systematically identifying relevant prevention and monitoring measures.
Hazards need to be identified for each system component. Here, we distinguish between hazards and hazardous events that are linked to the design, construction and operation phase.
Once potential hazards are listed, the risk of each hazard can be assessed taking into account its probability and severity. Based on the risk assessment, the criticality of each hazard can be evaluated.
A semi-quantitative risk scoring approach is used, which was developed under the NaWaTech project (material available on NaWaKit, 2015) not only takes into account the criteria of probability (P) and severity (S), but also the detectability (D) of each hazard. Each identified hazard was assessed using the semi-quantitative risk-scoring matrix shown in Table 2.22. Once the risks are assessed, risk ranking helps prioritising risks, giving safety indication of the system. The ranking is based on calculating risk scores (R) with R = P*D*S. Results of the risk scoring were then grouped in two ranking classes indicating the criticality of the estimated risk. A risk is considered critical if R > 7, P = 3, or S = 3 (adapted from Mayr et al., 2012).

Table 2.22. Semi-quantitative risk score matrix for risk scoring

Score	**Probability (P)** ***(of the hazardous event)***	**Detectability (D)** ***(of the hazard)***	**Severity (S)** ***(of the consequence of the hazard)***
1	Occurs less than once in 5 years	Hazard is detected based on visual inspections	Will not result in major system degradation and will not produce system functional damage
2	Occurs once a month to once a year	Hazard detection requires stepwise analysis (e.g. sampling required)	Will degrade system performance but can be counteracted or controlled without major damage
3	Occurs more often than once a month	No detection in normal operation; problem analysis is stepwise and complex	Will (severely) degrade system performance by substantial damage (component failure), interrupt system feeding, requiring immediate corrective action for system survival.

The risk score matrix is applied to a CW system, resulting in the selected hazards and the risk assessment is reported in Table 2.23. General hazards are hazards that do not concern a system component specifically, but the whole system. The column "project phase" indicates whether the respective hazard is controllable during the design, construction or operation phase. For hazards controlled during design or construction phase, no likelihoods are assessed.

Table 2.23. Selected hazards and risk assessment applied; Project phases: (1) design (2) construction (3) operation.

CW Hazards and their effects				Risk Assessment			
Component	**Project Phase**	**Hazardous Event (Failure cause)**	**Hazard (failure mode)**	**P**	**S**	**D**	**R**
Screen	3	Insufficient cleaning of screen, build-up of solid material	Reduction of flow; eventually choking; overflow of screen chamber	3	1	1	3
Pump	3	Malfunction of lower floating valve	Pump doesn't stop after reaching the minimum level	2	3	2	12
Anaerobic Settler	3	Insufficient removal of sludge	Reduction of effective volume; non-adequate removal of SS	2	1	2	4
CW	2	Use of low-quality or unwashed filter material	Uneven distribution of WW in wetland; clogged zones in filter bed	-	2	2	-
General	3	Frequent staff rotations	Knowledge management impeded; Loss of experience; temporary/long-term understaffing	2	3	1	6

2.9.2 UF membrane and UV disinfection

Operation of the UF system is performed by use of controls, valves, and instruments. The devices have to be set and work at the conditions suggested in the operation and maintenance manual. The user should be familiar with these devices – their location and function - before operating the UF system. Periodic cleaning of the membrane can improve system performance and is the most important maintenance procedure required. In normal operation, mineral scale, biological matter, colloidal particles, and organic substances can foul the membranes and must be removed to restore performance. Cleaning procedures and chemicals vary depending on the type of fouling to be removed. The system will be carefully inspected before start-up. All plumbing, electrical connections and instruction will be checked for the starting filtration phase.

For the UV system proper maintenance will ensure to sustain the system's effectiveness during the time. A pre-filter will protect the UV unit and ensure that it functions properly. Wastewater chemistry and contaminants can change over time and can affect the quality of the final effluent. Furthermore, changes in operating conditions can change the quality of the treated effluent. Usually the UV systems are equipped with light intensity meters or sensors that indicate the penetration of UV light. These sensors provide a warning signal when the UV dose is too low to provide adequate disinfection and indicate when it is time to clean the quartz sleeve and/or replace the UV lamp. If a UV system does not have a sensor, it is best to follow the manufacturer's recommendation for cleaning and replacement.

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4 ANNEX

4.1 Description of adopted CW systems

4.1.1 Vertical subsurface flow systems (VF) – unsaturated with intermittent feeding

Unsaturated vertical subsurface flow (VF) CW (Figure 4.1) is fed through the main bed in discontinuous flow from pumps or self-priming siphons and infiltrate vertically within the inert material. The unsaturated type of VF wetland in this case study will be based on the German system. The bed which is usually filled by a combination of both sand and gravel layers will be filled by coarse sand that has a high rate of filtration and is easy to provide in the case study location.

Saturated wetlands have a limited ability to oxidize ammonia due to the limited oxygen transfer. Unsaturated VF wetland with an alternate feeding system generating unsaturated condition, allows the transfer of large quantities of oxygen inside the main bed filled with coarse sand (Nivala et al., 2013). The high oxygen transfer is suitable to remove the organic matter and perform nitrification satisfactory. The hydraulic retention time (HRT) of unsaturated VF wetland is few hours which is more rapid compared to saturated wetland that needs generally few days. The good adsorption by the inert material, including the grown biomass, drives the phosphorous removal processes and performs minimal denitrification. However, denitrification of unsaturated VF systems can be improved by implementing a saturated layer at the bottom of the VF bed (Silveira et al. 2015).

The capacity of VF CWs to oxidize ammonia has brought them to be applied in the treatment of effluents characterized by high ammonia concentrations. This configuration is used as well for landfill leachate and food processing wastewater treatment, which can have over 1000 mgN/L of ammonia concentration (Kadlec & Wallace, 2009).

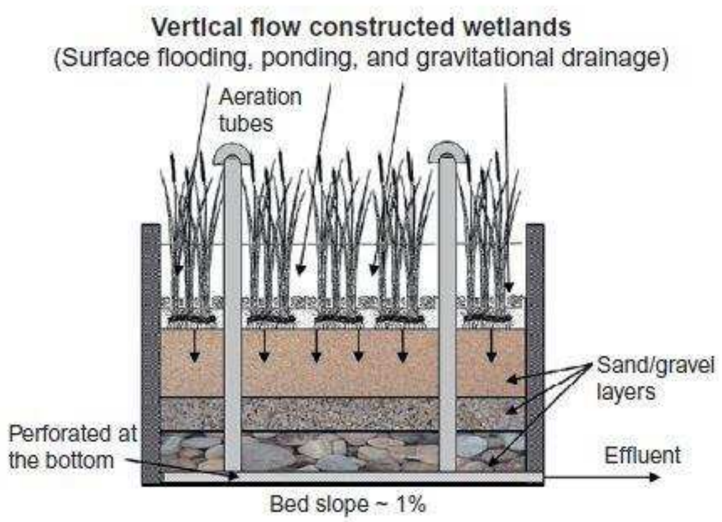


Figure 4.1. VF CW with intermittent loading (unsaturated) (Stefanakis et al., 2014)

4.1.2 Vertical subsurface flow systems (VF) – saturated with downflow feeding

Saturated VF (Figure 4.2) is continuously fed on the top of the bed and for the whole surface, maintaining saturated conditions and developing anaerobic/anoxic conditions (Stefanakis et al., 2014). In comparison to the common horizontal flow saturated systems, VF downflow solution increase the available feeding surface area, limiting the risk of clogging. Saturated VF wetlands consist of inert materials such as gravel beds planted with wetland vegetation. *Phragmites australis* (reed) and *Typha latifolia* (bulrush) are common plant species used in saturated wetlands. The basin is excavated and covered by liners which are made out of PVC, HDPE, or EPDM and sometimes concrete. The wastewater is intended to stay beneath the surface of the gravel bed and flows through the roots and rhizomes of the plants while the inert material is maintained water saturated. The plant root system helps in creating aerobic, anaerobic, and anoxic zones which are beneficial to develop highly various microbial populations which increase the rate of purification against pollutants and pathogens. Due to the water within the process, the system is not exposed to the air and therefore the risk of pathogenic exposure to human and wildlife is low; this makes it suitable to be adopted in urban areas (Kadlec and Wallace, 2009). This solution is suitable to remove organic and suspended solid loads, as well as to provide denitrification.

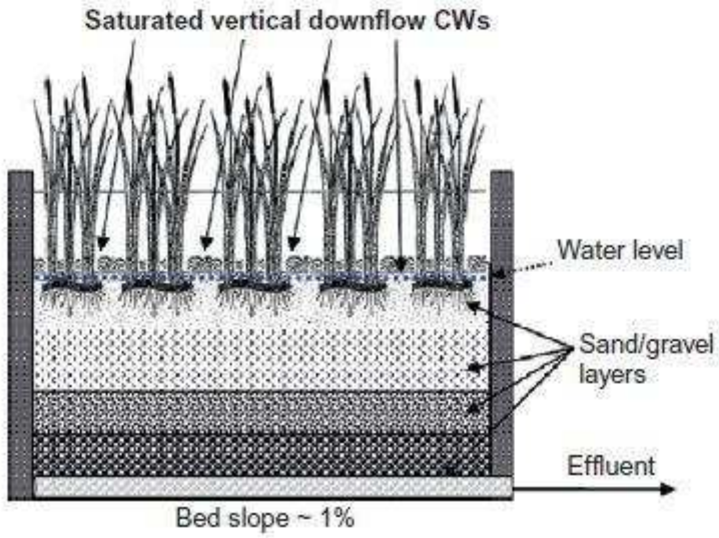


Figure 4.2. VF CW with downflow loading (saturated) (Stefanakis et al., 2014)

4.1.3 Aerated constructed wetland systems

Aerated wetland or Forced Bed Aeration™ (Figure 4.3) as the patented name, developed by an American constructed wetlands expert Scott D. Wallace, is a new wastewater treatment technology which enhances the performances of the constructed wetland. Aerated CW is under the so called "intensified CWs" field, i.e. CWs in which innovative solutions are included to improve the treatment performances and reduce the footprint (Wu et al., 2014).

Aerated CW consists of one or more basins with the horizontal (HF) or vertical flow system (VF). This CW is usually applied as secondary treatment after the primary treatment that generally operates for gravity settling and sedimentation. The coarse bubble aeration network is placed under the gravel substrate of a sub-surface flow wetland basin and air is supplied to it by blowers. It allows a more efficient removal of the contaminants due to the higher availability of oxygen. This system is ideal for treating wastewater with high loads of BOD and COD and for minimizing the footprint (Masi and Bresciani, 2013). The air blown to the system reinforces the oxidation process which creates a very good performance for pollutants removal, reducing 4-5 times areas required for the conventional passive CWs (Figure 4.4; www.iridra.eu).

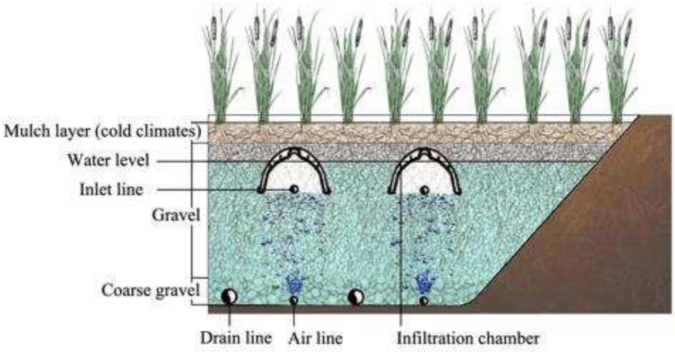


Figure 4.3. Aerated CW (NaWaTECH project)

This technique allows a considerable increase in performance with regard to the degradation of organic compounds and nitrification. There are particular types of wastewater that can be treated by the aerated wetland (Nivala et al., 2013a):

- Water contaminated by hydrocarbon from oil installation
- Airports runoff water (ethylene glycol contaminated)
- Polluted groundwater by chemicals (POPs)
- Mining drainage waters
- High organic load wastewater from wineries, dairies, and other agricultural or food processing facilities.
- High ammonia content (slurry from livestock, manure, digestate)

Aeration CW has various advantages for the treatment of wastewater:

- Aerated CWs may nitrify wastewater almost completely
- The system can be deeper than the conventional reed beds which consumes 4-5 times or 50% less space than the passive system
- Plants develop well due to the abundant amount of oxygen which prevents the toxic product which can be an obstacle for the growth in strongly anaerobic, passive systems
- Aerated CWs can be divided into aerobic and anoxic zones to both nitrify and denitrify
- Ideal for treating fluctuating loads and locations with variable occupancy
- Study indicates that this system has reduced clogging rate extending operational life of the system

Aerated CWs may be retrofitted to the existing passive CWs as an improvement which prolongs the lifetime of the bed. It can be applied in a CW that has issues such as overloads.

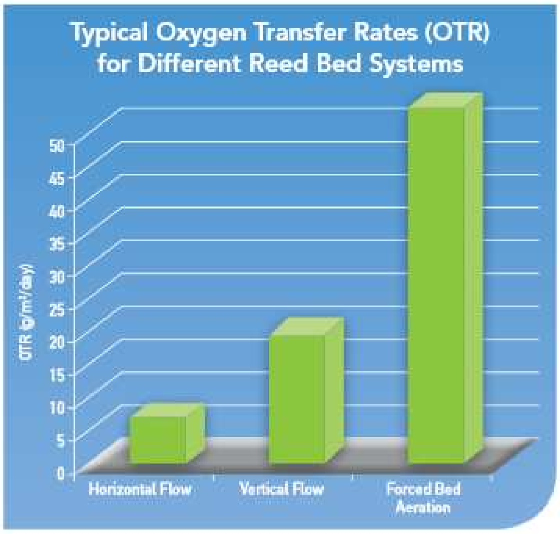


Figure 4.4. Comparison of the oxygen transfer rate of passive constructed wetland with aerated CWs (www.iridra.eu)

4.1.4 Bio-electrified systems (IMET)

iMETland aims to develop decentralized water management technologies, which are integrated into the natural environment. The iMETland bio-electrified wetland is an innovation combining water, energy, ICT and land resources. The iMETland bio-electrified wetland can tackle the small communities wastewater treatment needs in a cost effective, energy efficient and environmental friendly manner.

The envisaged bio-electrified wetland has the following advantages:

- **Offers a new tool** that maximizes water reuse in small or isolated communities
- **Decreases cost** for wastewater treatment for small and centralized communities (ca. 200 PE)
- **Optimizes the use of land**: iMETland reduces up to ten times the extension of land need for natural wastewater treatment and integrates the treatment system into the landscape
- **User autonomy**: iMETland enhances end-user autonomy and satisfaction, making use of user-friendly technologies for monitoring

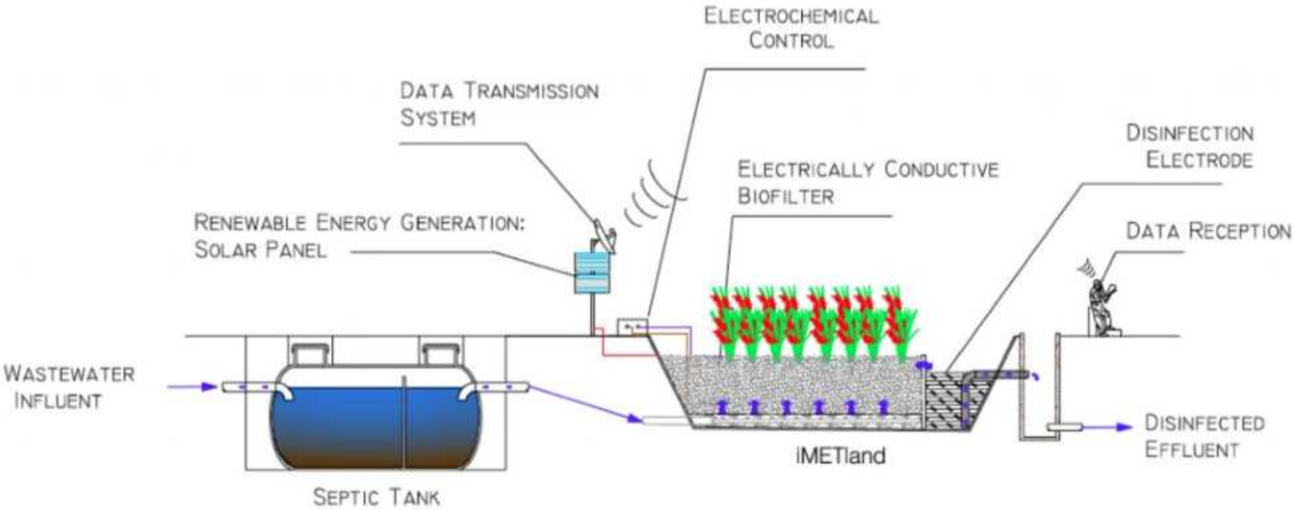


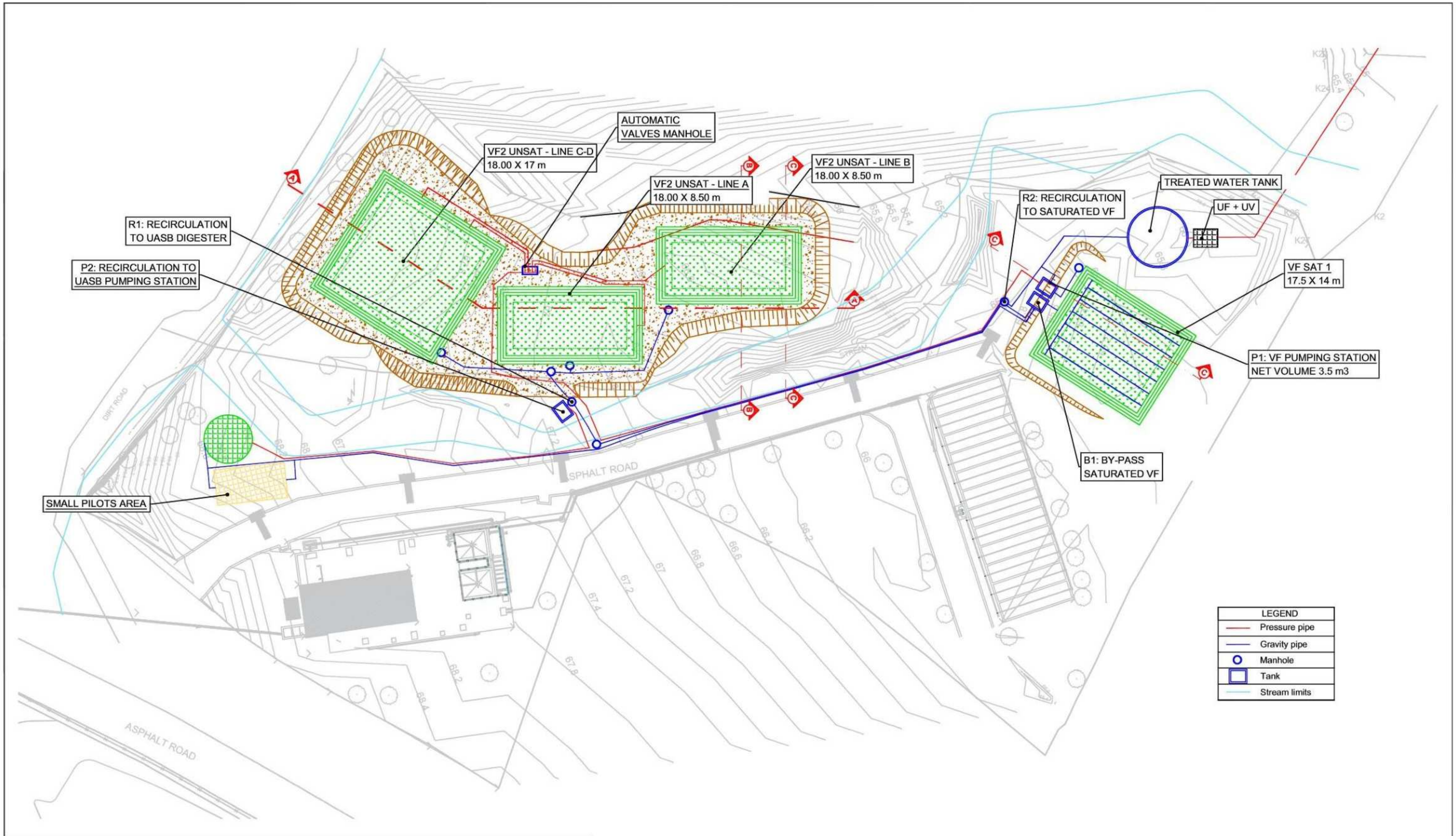
Figure 4.5. Schematization of IMET bio-electrified CW (www.imetland.eu)

4.2 Drawings

In the following pages the following drawings are reported:

- **Drawing n° 1**: Plan layout
- **Drawing n° 2**: Section A-A (from point 1 to 17)
- **Drawing n° 3**: Section A-A (from point 17 to 21)
- **Drawing n° 4**: Section B-B and C-C
- **Drawing n° 5**: Section D-D
- **Drawing n° 6**: Typological sections

Drawings are reported in A3 layout and all (expect typological sections) in scale.



Lesvos (Greek)

HYDROUSA - D3.2

Design of the constructed wetland

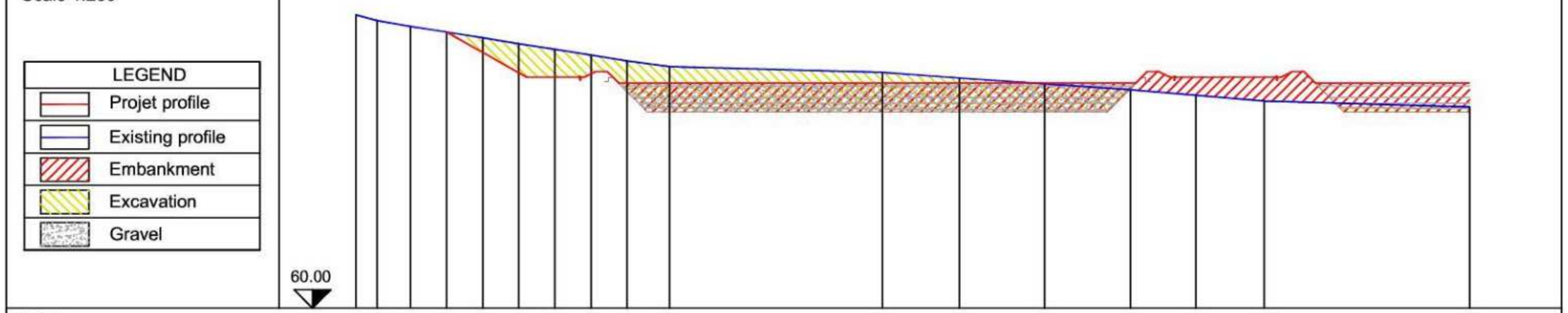
IRIDRA S.r.l.
Via A. La Marmora, 51 - 50121 Firenze Tel. 055-470729 - Fax. 055-475593

Elaborated by:
Ivano Filippini Surveyer

Supervioson:
Fabio Masi PhD

N° 1	Drawings	
Date: November 2018	Descriprion: Plan layout of proposed CW systems	Scale: 1:500

SECTION A-A
from point 1 to 17
Scale 1:200



Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Partial distance	0.74	1.17	1.26	1.26	1.26	1.26	1.26	1.26	1.48	7.41	2.68	2.96	2.98	2.28	2.38	7.15	
Progressive distance	0.00	0.74	1.91	3.16	4.42	5.67	6.93	8.18	9.44	10.92	18.33	21.01	23.97	26.95	29.23	31.61	38.76
Ground elevation	70.20	70.00	69.80	69.60	69.40	69.20	69.00	68.80	68.60	68.40	68.20	68.00	67.80	67.60	67.40	67.20	67.00
Design ground elevation				69.60	68.89	68.18	68.03	68.14	67.83	67.83	67.83	67.83	67.83	67.83	68.03	68.03	67.83
Bottom of the excavation										66.83	66.83	66.83	66.83				66.83

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HYDROUSA - D3.2
Design of the constructed wetland

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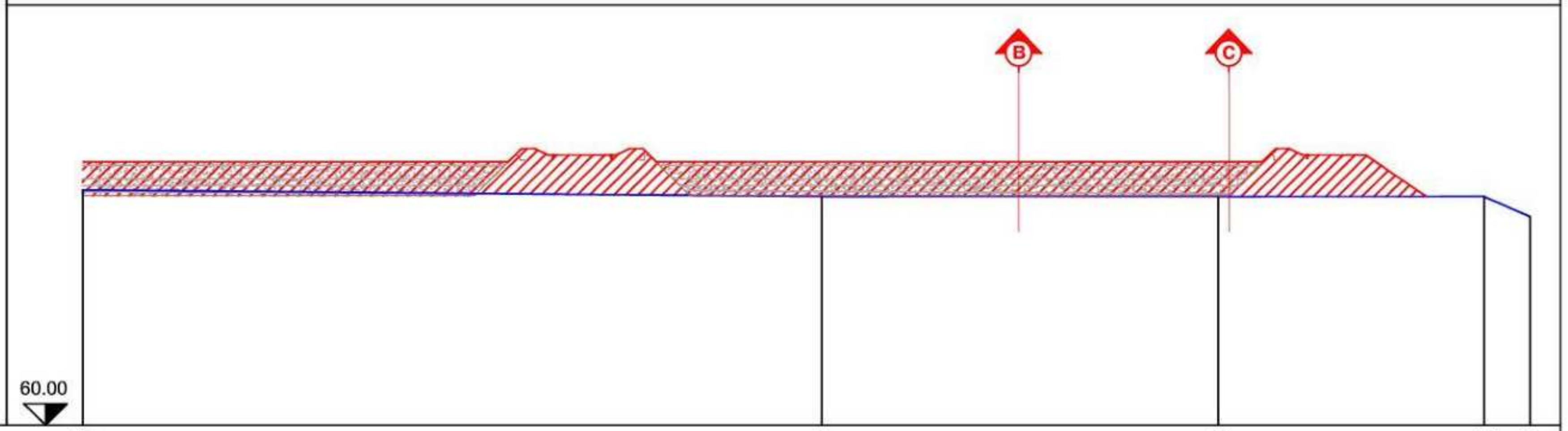
Elaborated by:
Ivano Filippini Surveyer

N° 2	Drawings	
Date: November 2018	Descriprion: Section A-A (from point 1 to 17) of proposed CW systems	Scale: 1:200

Supervioson:
Fabio Masi PhD

SECTION A-A
from point 17 to 21
Scale 1:200

LEGEND
Projet profile
Existing profile
Embankment
Excavation
Gravel



Point	17	18	19	20	21
Partial distance		21.94	11.78	7.90	1.37
Progressive distance	0.40	21.54	33.32	41.22	42.58
Ground elevation	67.00	66.80	66.80	66.80	66.20
Design ground elevation	67.83	67.83	67.83		
Bottom of the excavation	66.83	66.83	66.83		

Lesvos (Greek)

HYDROUSA - D3.2
Design of the constructed wetland

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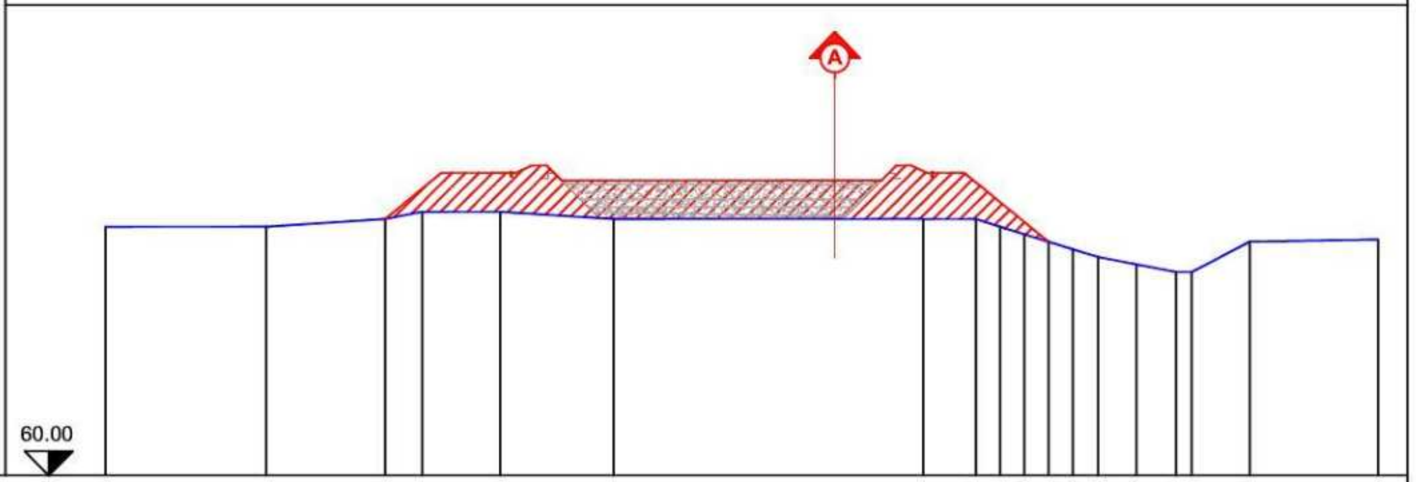
N° 3	Drawings		
Date: November 2018	Description: Section A-A (from point 17 to 21) of proposed CW systems	Scale: 1:200	

Elaborated by:
Ivano Filippini Surveyer

Supervioson:
Fabio Masi PhD

SECTION B-B
Scale 1:200

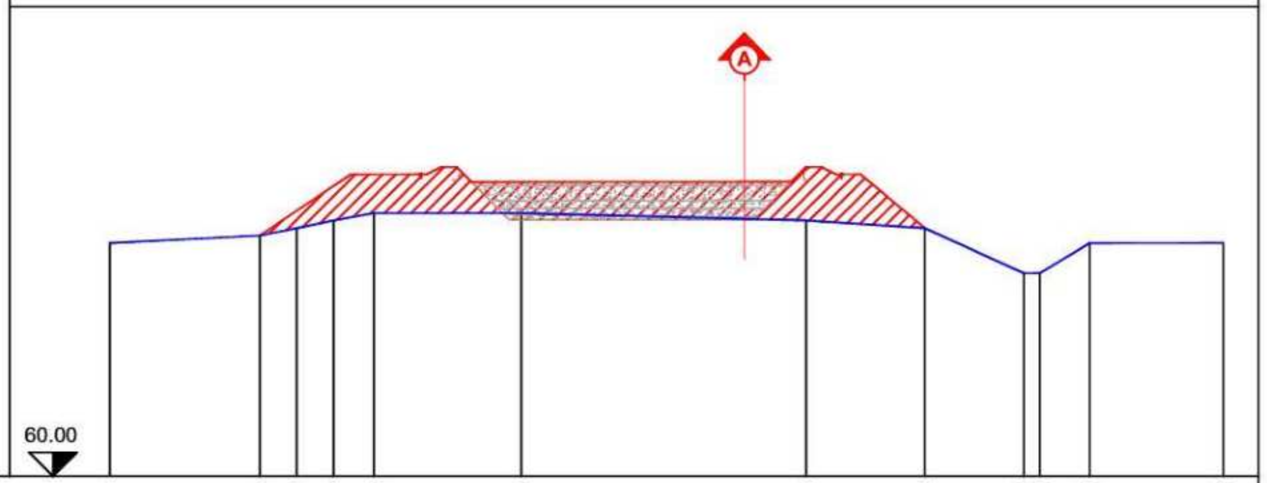
LEGEND	
Projet profile	
Existing profile	
Embankment	
Excavation	
Gravel	



Point	Partial distance (to next point)	Progressive distance	Ground elevation	Design ground elevation	Bottom of the excavation
1	4.28	0.00	66.60		
2	3.16	4.28	66.60		
3	0.98	7.43	66.80	66.80	
4	2.07	8.41	67.00	67.70	
5	3.02	10.49	67.00	68.03	
6	8.23	13.51	66.80	67.83	66.83
7	1.40	21.73	66.80	68.07	
8	0.64	23.13	66.80	67.77	
9	0.64	23.78	66.60	67.25	
10	0.64	24.42	66.40	66.73	
11	0.64	25.06	66.20	66.20	
12	0.67	25.71	66.00		
13	1.03	26.38	65.80		
14	1.05	27.40	65.60		
15	0.42	28.45	65.40		
16	1.55	28.87	65.40		
17	3.40	30.41	66.20		
18		33.81	66.26		

SECTION C-C
Scale 1:200

LEGEND	
Projet profile	
Existing profile	
Embankment	
Excavation	
Gravel	



Point	Partial distance (to next point)	Progressive distance	Ground elevation	Design ground elevation	Bottom of the excavation
1	3.99	0.00	66.20		
2	0.99	3.99	66.40	66.40	
3	0.98	4.97	66.60	67.06	
4	1.07	5.95	66.80	67.71	
5	3.92	7.02	67.00	68.03	
6	7.58	10.94	67.00	67.83	66.83
7	3.16	18.51	66.80	68.23	
8	2.63	21.67	66.60	66.60	
9	0.42	24.31	65.40		
10	1.33	24.73	65.40		
11	3.54	26.06	66.20		
12		29.60	66.20		

Lesvos (Greek)

HYDROUSA - D3.2
Design of the constructed wetland

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Elaborated by:
Ivano Filippini Surveyer

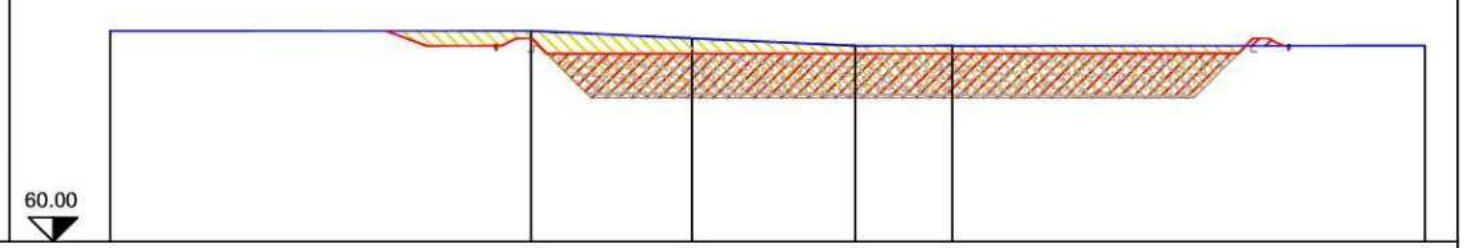
Supervioson:
Fabio Masi PhD

N° 4 — **Drawings**

Date: November 2018
Descriprion: Section B-B and C-C of proposed CW systems
Scale: 1:200

SECTION D-D
Scale 1:200

LEGEND
Projet profile
Existing profile
Embankment
Excavation
Gravel



Point	1	2	3	4	5	6
Progressive distance	0.00	11.19	15.48	19.83	22.40	34.97
Ground elevation	65.60	65.60	65.40	65.20	65.20	65.20
Design ground elevation	65.60	65.40	65.00	65.00	65.00	
Bottom of the excavation			63.81	63.81	63.81	

Partial distance	11.19	4.28	4.35	2.57	12.57

Lesvos (Greek)

HYDROUSA - D3.2
Design of the constructed wetland

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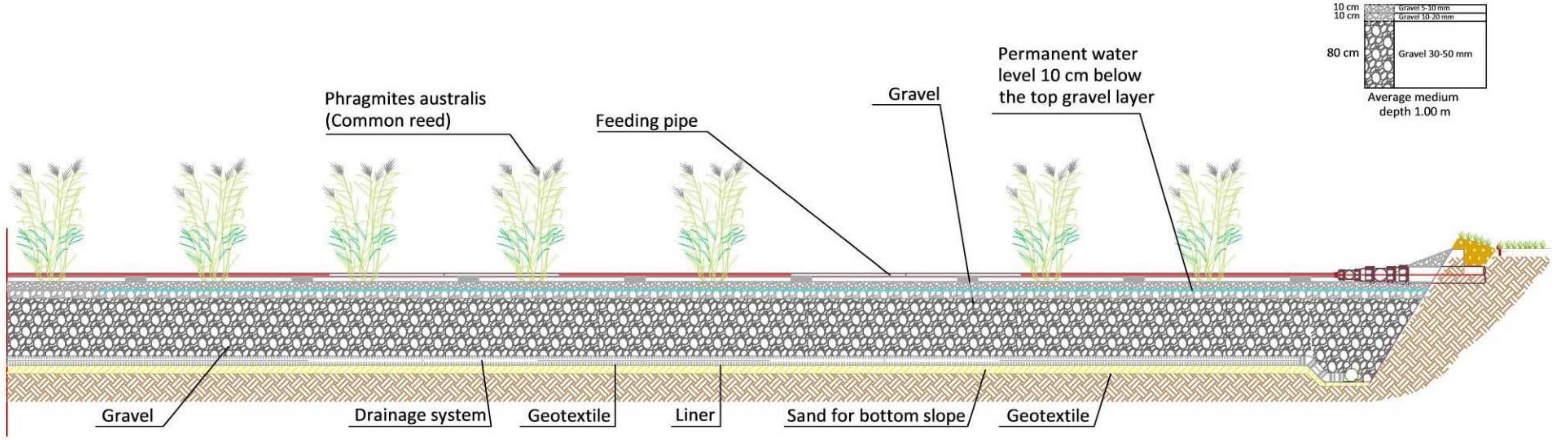
N° 5	Drawings	
Date: November 2018	Descriprion: Section D-D of proposed CW systems	Scale: 1:200

Elaborated by:
Ivano Filippini Surveyer

Supervioson:
Fabio Masi PhD

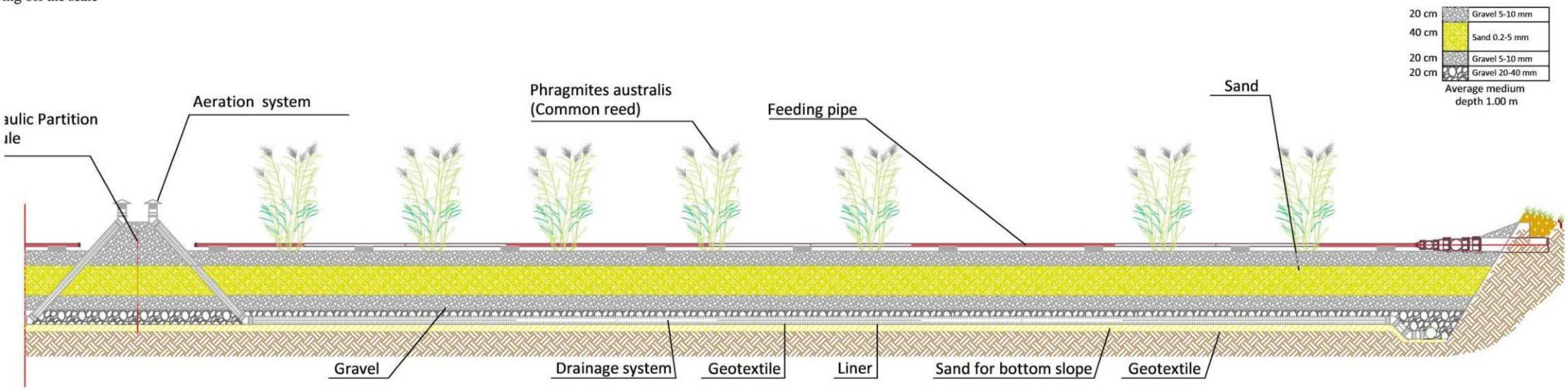
Saturated Vertical subsurface flow constructed wetland (SAT VF1)

Drawing off the scale



Unsaturated Vertical subsurface flow constructed wetland (UNSAT VF2)

Drawing off the scale



Lesvos (Greek)

HYDROUSA - D3.2

Design of the constructed wetland

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Elaborated by: Ivano Filippini Surveyer

Supervioson: Fabio Masi PhD

N° 6	Drawings	
Date: November 2018	Descriprion: Typological sections of proposed CW systems	Scale: Off scale