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TECHNICAL GUIDELINES AND INSTALLATION MANUAL

Constructed Wetlands

Engineering Constructed Instream Wetland Treatment (CWT) Pilot For isolated rural communities (El-Wahat El-Bahariya), Egypt

(ver. 2)

February 2024

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Project

Improving MEDiterranean irrigation and Water supply for smallholder farmers by providing Efficient, low-cost and nature-based Technologies and practices Project (MED-WET)

Deliverable Leader

Faculty of Engineering

Heliopolis University for Sustainable Development, EGYPT

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Dissemination Level

MED-WET’s partner countries

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Engineering Constructed Instream Wetland Treatment (CWT) Pilot For isolated rural communities (El-Wahat El-Bahariya), Egypt

1. INTRODUCTION

This installation manual (IM) deals with construction phases of the Engineering Constructed Instream Wetlands Treatment (CWT) technology at Sekem Farm in El-Wahat El-Bahariya, EGYPT (Figure 1). This manual is designed to provide clear instructions and guidelines to ensure good understanding of the CWT concept, design and installation. It serves as a comprehensive guide for the proper installation and emergency procedures of CWT. The aim is to explain the installation of CWT so that can be easily replicated in other sites with similar conditions in the Mediterranean Region. The IM is structured to provide detailed information about each component of the CWT, outlining its description, installation procedures, construction stages, control requirements and emergency procedures. By following the guidelines presented in this manual, users can ensure the safe and reliable replication of the CWT. It contains valuable information about its automated components, installed specifically for Sekem as a large land reclamation agricultural scheme, but not for smallholder farmers in rural areas.

Keywords: Nature-based Solution, Low-cost Technologies, Rural Wastewater Treatment Systems; Sustainable Water Management; Combating Climate Change.

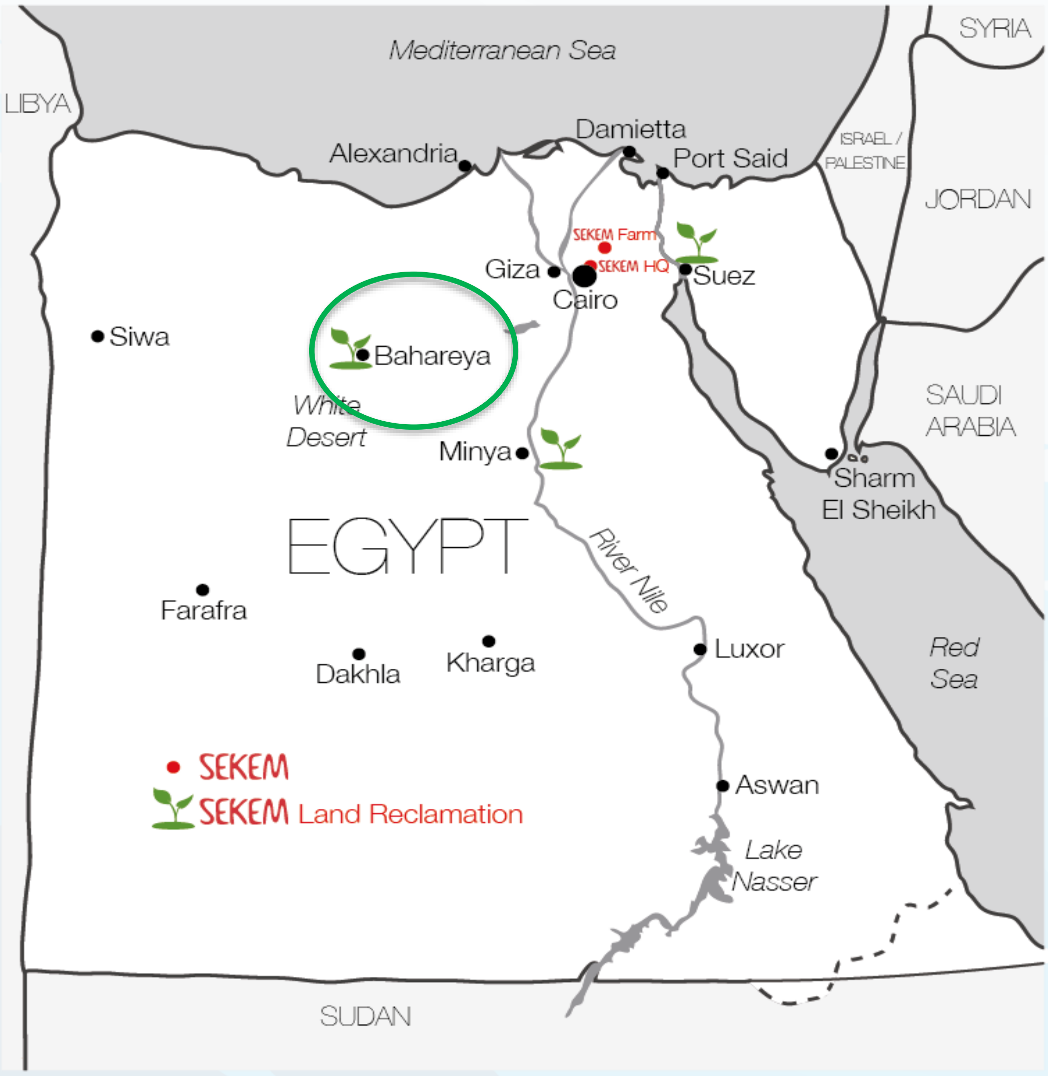

Figure 1. Location of the CWT experimental pilot site in Sekem Farm, El-Wahat El-Bahariya, Egypt

2. AIM

The key objectives of the IM are: 1) the installation of experimental pilot for CWT for the production of suitable irrigation water from wastewater sources (domestic wastewater and agricultural drainage water); 2) equipping the smallholder farmers in isolated areas with the knowledge and skills to install, adapt and operate more efficient and effective irrigation options; 3) increasing the availability of irrigation water from secondary sources; and 4) improving the small farms' profitability and the environmental footprint of pilot farming practices.

The project shall strengthen the farmers' capacity building and urge stakeholder engagement through good linkages with the Egyptian Biodynamic Association (EBDA) as well as Sekem for Land Reclamation (SLR). Upon successful implementation and operation of the pilot experiment; up-scaling and out-scaling shall be targeted to serve the isolated desert communities in El-Wahat El-Bahariya. Afterwards; it is planned to promote the low-cost technology for wastewater treatment in other rural communities in Egypt and beyond in the Med-Wet's partners' countries.

3. CONSTRUCTED-WETLANDS TECHNOLOGY – CONCEPT

Constructed-wetlands (CWT) technology treats wastewater naturally by means of soil filtration, aquatic weeds & micro-organisms uptake, natural aeration and sun penetration effect. The experimental development in Egypt follows a horizontal flow (instream wetland system) with additional integrated weirs and soil filters. Suitable aquatic weeds and submerged plant species are cultivated in natural substrate to extract specific pollutants and release the inflow of wastewater in cleaner condition. The soil filters as well as micro-organisms capture various chemical pollutants from the wastewater. The sun penetration in the shallow and slow flow of water kills significant amount of germs, microbes and viruses. The aim is to "clean" the wastewater and produce reclaimed irrigation water that can be used for agriculture. The climatic conditions are quite different despite the Mediterranean location, so each CWT site should be designed independently according to its physical and climatological conditions.

4. SITE SETTINGS & PILOT SITE IDENTIFICATION AND PREPARATION

With the surface water resources of Egypt currently fully exploited, and the groundwater pumping reaching the maximum limit, the need for alternative non-conventional water resources has never been of more crucial urgency than it is nowadays. Wastewater treatment is listed at the top of those alternatives. Engineering constructed in-stream wetland treatment (CWT) fits well for the rural and desert communities because it is a low-cost (does not need energy nor sophisticated technicians for operation), natural-based, and efficient wastewater treatment technology. In general; CWT technology is known worldwide and applied in several rural areas. It is good for the treatment of various household domestic, agricultural and industrial wastewaters.

Several constraints had been encountered since the start of pilot installation. During the phase of choosing farmers to set-up trials, several farmers from El-Wahat El-Bahariya were contacted and they were reluctant and showed great hesitation, especially because the success of the technique was not guaranteed and might not fit for all planted crops. The HU team managed to install the CWT experimental pilot in a large agricultural scheme called *Sekem Farm for Land Reclamation in El-Wahat El-Bahariya*. This installation manual covers two models of the CWT technology, as follows;

Model (I): Low-cost, nature-based and efficient wastewater treatment technology equipped by automatic operation (sensors, photovoltaic solar cells, batteries, inverter and electrical cables); and

Model (II): Low-cost, nature-based, no energy and efficient wastewater treatment technology with manual operation.

Model (I) CWT fits for the large agricultural scheme and investors farms such as Sekem Farm for Land Reclamation in El-Wahat El-Bahariya. However, Model (II) CWT fits more for the smallholder farmers with low- or moderate-income in remote and isolated communities.

4.1 Pre-Installation Investigation

The pilot site is located in Sekem Farm in El-Wahat El-Bahariya, Egypt (about 450 km distance south west of Cairo). It is desert land with sandy soil currently under reclamation and agricultural cultivation by Sekem Group (Sekem for Land Reclamation, SLR) in collaboration with Heliopolis University (HUSD), located in the Western Desert of Egypt. Table (1) explains the pre-installation set-up of the pilot site in El-Wahat El-Bahariya, Egypt. The implementation site is in El-Wahat El-Bahariya, where land acquisition is easily available as well as the land prices are considerably cheap or fair. Social services, basic utilities such as electricity, water supply and sanitation facility are very poor. The target served community could reach 65,000 capita (first stage).

Table (1): The pre-installation set-up of the pilot site in El-Wahat El-Bahariya, Egypt

Country	Egypt
Number of sites	1
Location	Sekem for Land Development Farm, El-Wahat El-Bahariya, Egypt
Crop type (phase 1)	Bamboo tress and non-fruitful trees for Carbon sequestration
Crop type (phase 2)	Cactus as fruit for low-income communities and for composting manufacturing
Soil filtration type	instream & vertical, 3 filters (gravel, coarse sand and fine sand)
Other treatment segments	Native aquatic weeds, submerged plant species and micro-organisms cultivated in natural substrate
Alternative technology	lagoon constructed wetlands, Trickle Treatment Tower*

The selection of Cactus as initial selected crop to be irrigated by the treated wastewater, because it can survive in dry weather, can tolerate saline irrigation water and less water amounts. Cactus can tolerate water stress more than trees. The projected Cactus area is about 5.0 ha. Other types of trees being cultivated and irrigated with the treated wastewater using the CWT technology in Sekem Farm El-Wahat El-Bahariya are Cacia trees, Neim trees, Tamarisk trees, Desert Willow trees and other indigenous Egyptian trees. Those trees have been adapted to the dry climate, tolerant to salty irrigation water, and can survive in the harsh conditions and in saline soils.

The other possibility (Phase II) is to use the treated water for irrigating productive crops, provided that the quality of that water meets the Egyptian standards for treated wastewater uses. The Egyptian Law for Wastewater Treatment Reuse, (ECP No. 501 for 2015) was developed by the Egyptian Ministry of Housing, Utilities and Urban Communities (MHUUC), adopted in 2015.

The pilot site specifications: The innovative solution adopted and implemented in the MEDWET project in Egypt is Low-cost, energy free, nature-based and efficient technology to transform marginal water with several risks into treated water suitable for irrigating trees and possibly edible crops as well, after examination according to the Egyptian code of Practice for treated wastewater uses (ECP 501 for 2015). The area of the CWT pilot is (100 m X 40 m) = 4000 m^2 (0.4 ha), whereas the area served by the CWT is expected about 12.0 ha. The geographical location of the pilot site is shown in Table 2 and Figure 2.

Table 2: The geographic localization (Longitude N & Latitude E) of the pilot site in El-Wahat El-Bahariya, Egypt

Point #	North	East
Edge (1)	28.2551480	29.1096980
Edge (2)	28.2551920	29.1096280
Edge (3)	28.2550000	29.1095230
Edge (4)	28.2550120	29.1095450
Center point	28.2550420	29.1095670

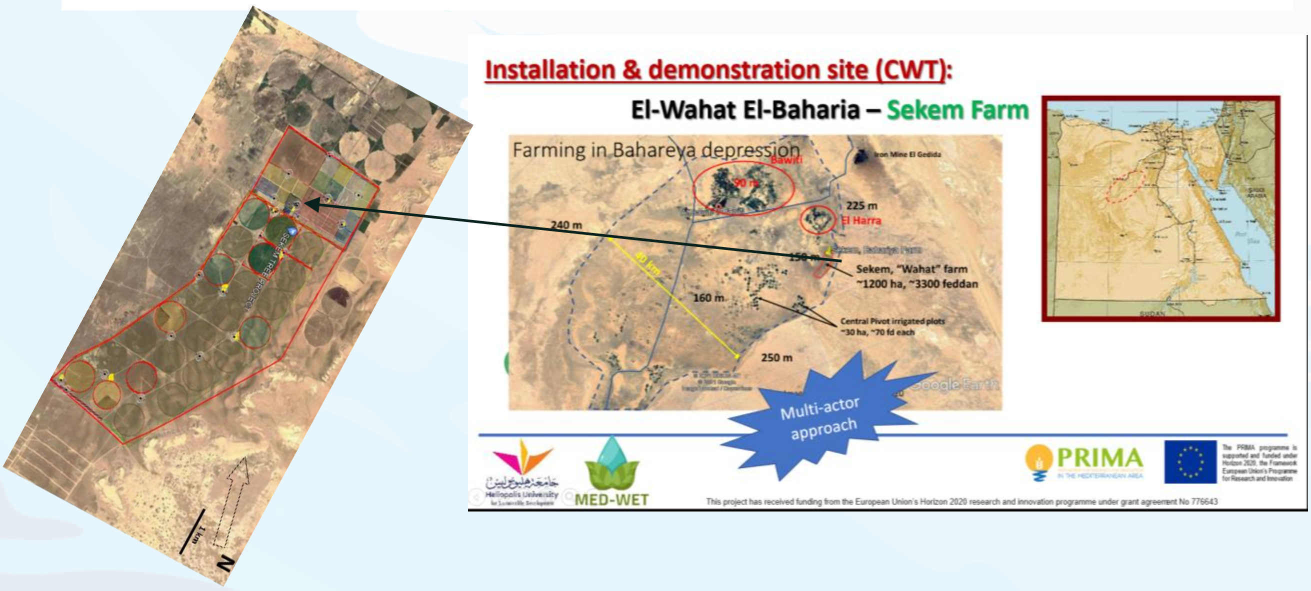

Figure 2. Geographic location of the CWT site within Sekem farm for Land Reclamation in El-Wahat El-Bahariya

4.1 Site Characteristics

Climate data:

The following climate data (Figure 3) represent a typical weather database that is freely available. The weather data of precipitation, average air temperature and average air humidity, among others if possible are recorded every week, if not available we switch to collection of climate data at the end of each month. These data serve as a climate data indicative guide and do not necessarily correspond to measured data during the installation period within the territories of the CWT pilot site

Water quality:

Wastewater from inhabited agricultural localities usually contain a mix of number of chemical and biological compounds. These include physical properties (Temp, pH, EC, TSS, DO, TDS), cations and anions, nutrients, phosphorus and other minor mineral pollutants. This includes determining the concentrations of various ions and metals/metal compounds. The wastewater might also include some nature dissolved metals from the geological formation of the soil in the pilot area (e.g., iron and brass). Detecting the interfering biological and microbial substances (fecal coliform, pathogens, germs, viruses and parasites). The measurement can be done on site or by taking samples to the laboratory. The water used for irrigation must be analyzed for its suitability for plant irrigation. A detailed analysis of the wastewater quality (at inlet of the pilot area) and the reclaimed irrigation water (at outlet of the pilot area) for a large number of trace elements should be carried out in order to estimate the pollutants' removal efficiency.

Soil characteristics:

The nutrient & phosphorus contents as well as the development of micro-organisms in the soils should be examined more closely. Accordingly, soil samples must be taken periodically during the entire test period and analyzed in the laboratory. Conclusions on the effects of the wastewater, the functionality of the soil filtration, aquatic weeds and micro-organism uptakes as well as the resulting plant development are to be drawn by this measure. The soil samples should therefore be analyzed for all their mineral and metal contents (to the possible extent) as well as for excretory products of microorganisms (if necessary). Furthermore, if possible, the composition of the soil filter according to the contents of the mixed substances (e.g. proportion in % compost, proportion in % loam, sand, ...) can be noted before the start of the experimental period.

Treatment efficiency:

The efficiency of CWT can be determined by measuring the amount of wastewater pollutants (all types as lump sum) supplied and the residual amount in the reclaimed irrigation water as a function of the unit volume, concentrations or loads. Water discharge meters or alternatively measuring scales can be installed and used for control and measurements. Depending on the measuring technology installed, a weekly/monthly rejection should be aimed for average quantity/week or month.

climate data: retrieved 24.01.23 from https://de.climate-data.org/

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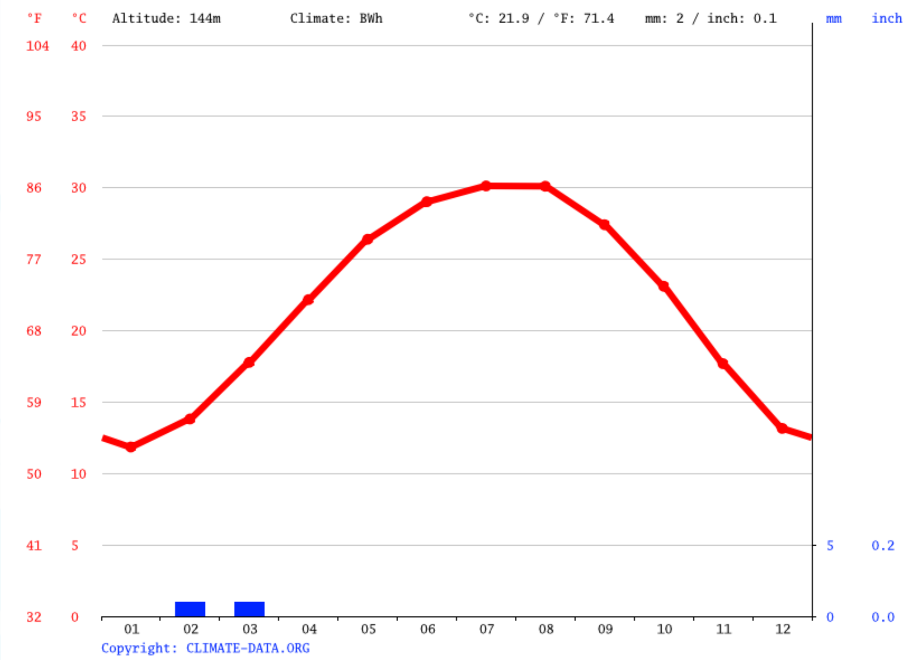

	January	February	March	April	May	June	July	August	September	October	November	December
Avg. Temperature °C (°F)	11.9 °C (53.3) °F	13.8 °C (56.9) °F	17.8 °C (64) °F	22.2 °C (71.9) °F	26.4 °C (79.5) °F	29 °C (84.3) °F	30.1 °C (86.2) °F	30.1 °C (86.2) °F	27.4 °C (81.4) °F	23.1 °C (73.6) °F	17.7 °C (63.8) °F	13.2 °C (55.7) °F
Min. Temperature °C (°F)	5.6 °C (42.1) °F	6.9 °C (44.5) °F	10.1 °C (50.1) °F	13.9 °C (57.1) °F	18 °C (64.4) °F	20.7 °C (69.2) °F	21.9 °C (71.3) °F	22.2 °C (71.9) °F	19.8 °C (67.7) °F	16.3 °C (61.3) °F	11.3 °C (52.3) °F	7.3 °C (45.1) °F
Max. Temperature °C (°F)	17.6 °C (63.6) °F	19.9 °C (67.7) °F	24.3 °C (75.7) °F	28.9 °C (83.9) °F	33 °C (91.5) °F	35.5 °C (96) °F	36.4 °C (97.6) °F	36.3 °C (97.4) °F	33.8 °C (92.8) °F	29.1 °C (84.4) °F	23.6 °C (74.5) °F	18.9 °C (66) °F
Precipitation / Rainfall mm (in)	0 (0)	1 (0)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Humidity(%)	50%	41%	32%	26%	24%	26%	28%	31%	36%	43%	49%	55%
Rainy days (d)	0	0	0	0	0	0	0	0	0	0	0	0
avg. Sun hours (hours)	8.7	9.7	10.7	11.5	12.1	12.5	12.3	11.8	11.0	10.2	9.3	8.8

Data: 1991 - 2021 Min. Temperature °C (°F), Max. Temperature °C (°F), Precipitation / Rainfall mm (in), Humidity, Rainy days. Data: 1999 - 2019: avg. Sun hours

Figure 3: The climate data of the pilot site in El-Wahat El-Bahariya, Egypt

Crop development:

The development of plants and seasonal crop yield using the reclaimed water from CWT technology must be precisely documented. It is noted that the CWT pilot shall be mainly used for irrigating Bamboo tress, Cactus and non-fruitful trees for Carbon sequestration. Various measurement methods can be used to draw conclusions about the growth and changes in the plants caused by environmental and ecological influences. Physical, thermal, electrochemical and biochemical analyses can be used in the evaluation. Possible complications should be noted with date. In addition, photographic documentation is desirable.

4.2 Tools and Equipment

Gather all required tools, equipment and materials beforehand. Basic installation tools like tractor, excavator, driller, lorry, construction materials, bricks, and poly ethylene lining materials are well-stocked. Also small construction toolbox like shovels, hoses, hand excavator, ladders will be needed. Ensure all water measuring and control (meters and gages) equipment, as well as pumps, are available and in working condition.

4.3 Safety Measures

- Electricity: always ensure that any electrical connections are made under the supervision of a certified electrician. Ensure that the power is turned off when working with electrical components.
- Handling: handle all components, especially sensitive ones like sensors with care.
- Avoid submerging sensors or other components that are not water-resistant. Keep them as clean and dust free as possible.
- Protective Gear: wear appropriate protective gear, especially when handling saline water. Basic protection like gloves is recommended.
- Chemical Exposure: always be cautious when working with or near chemicals, ensuring that they are stored and handled safely.

4.4 Technical Assistance

The design of a well-functioning engineering constructed instream wetland pilot is not familiar for the HU team. Therefore, HU contracted an expert who is qualified in the field of "wastewater treatment using low-cost technologies“ to do the field surveys, select the appropriate conceptual design and execute the detailed CWT design with all details.

On the other hand, while some aspects of the installation can be managed by general personnel, certain components might require specialized skills. It is recommended to have access to builders, plumbers, botanists, and electricians during the installation process. Always follow guidelines or instructions provided by technicians or experts when installing specific components (e.g., pumps and solar systems). Sekem Company for land reclamation gave the HU team the due and needed technical support during the installation time in El-Wahat El-Bahariya.

5. THE ENGINEERING CONSTRUCTED INSTREAM WETLAND (CWT) - DESIGN STAGES

During the CWT's experimental pilot installation in Egypt, three design stages were executed. HU team started by the reconnaissance survey works, followed by selecting the best fit CWT prototype, and finally the detailed design including all supplementary and auxiliary works were accomplished.

5.1 CWT's Prototype Selection

For rural smallholder farmers and remote communities comes the low-cost technology of wetland treatment as a suitable alternative that does not need energy or sophisticated equipment to operate, yet provides the smallholder farmers with sufficient treated water suitable for irrigating their local crops and trees while maintaining the human health and environmental safeguards according to the Egyptian code. Figure (4) illustrates a physical layout of an engineering constructed wetland, as a natural-based, low energy and efficient technology for wastewater treatment in remote communities. For every four households (20 persons in average) in rural communities, an engineering constructed instream wetland site of 100 m × 40 m (two cells) could be enough to treat their domestic and agricultural drainage waters, resulting in a daily treated wastewater of about 35-40 m3/day, good to irrigate their local crops and trees (or to be used as supplementary irrigation). The cost of constructing and operating such a nature-based CWT site will be affordable by the rural communities because its components are from the native environment, with no electrical or mechanical parts used in the CWT at all.

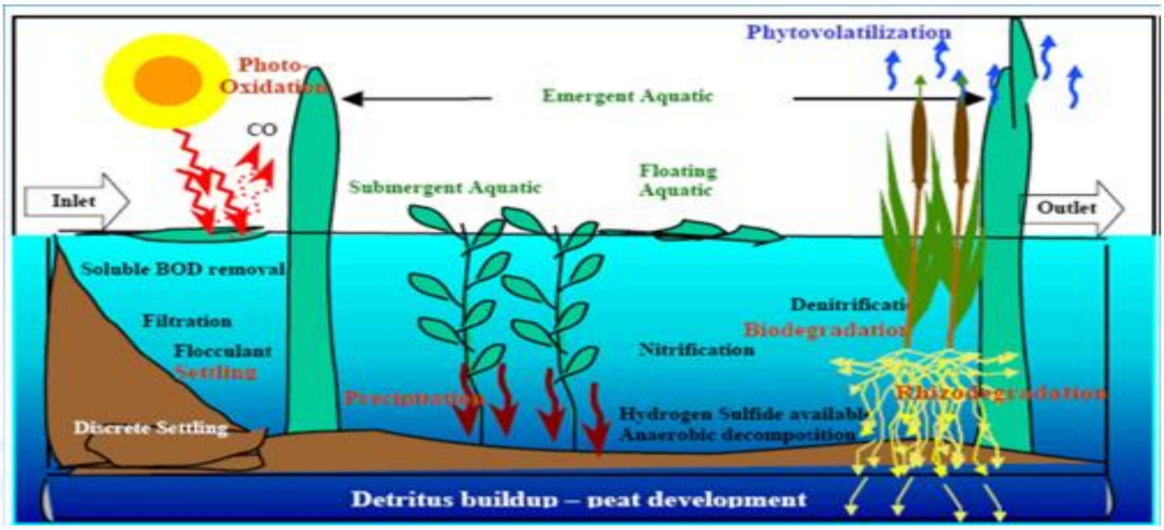

Figure 4. The physical layout of an engineering constructed wetland, as a cheap, low energy and efficient technology for wastewater treatment in remote communities

In such engineering constructed instream wetlands, the aerobic and anaerobic re-actions occur without energy (cheap technology) as well as sedimentation, filtration, and plants abstraction, to efficiently treat almost all pollutants (removal of biological load, fecal coliform, E. coli bacteria, pathogens, complex nutrients and phosphorus compounds, and metals). Advantages of such engineering constructed in-stream wetland treatment technology system are as follows:

- Efficient and cheap technology for treating domestic wastewater and agricultural drainage water;
- Increases the available water resource (non-conventional water) in scarce water regions;
- Reclaims nutrient-rich effluent for irrigation purposes;
- Preserves the groundwater and surface ponds from pollution, leading to reduction of the environmental impacts;
- Useful for safe sludge management and on-site reuse with zero waste;
- Good application of the circular economy concept for the smallholder farmers; and
- Supports the local business creation and smallholders' irrigation in remote communities.

According to the installation plan, the conceptual design of the system includes three soil filters, two concrete weirs and aquatic weeds segment on clay and sandy soils substrate. In addition, a segment for micro-organism treatment using green Azolla algae is also added to the pilot. The system contains also vertical-flow process for more aeration and cleaning of the wastewater. HU team, throughout the MED-WET Project, desires to develop a sustainable CWT in-stream wetland system that combines several segments of plants placed for de-pollution and high nutrient uptake from the inflow wastewater. This treatment technology results in safe reuse of treated water with useful nutrients levels that contributes positively to the circular economy.

5.2 CWT's Conceptual Design

Figure (5) below shows the conceptual design of the best CWT prototype fit explained in Figure (4) above. The conceptual design of the engineering constructed wetland treatment pilot is famous for its natural, cheap and efficient components that are used for the construction of the wetlands pilot. It consists of two treatment cells with its segments made of local nature of the experiment site. The mechanical and electrical parts have been purchased from the Egyptian market. The CWT segments are low-cost and nature-based exist in the native desert area of El-Wahat El-Bahariya. There are no components need to be purchased from abroad.

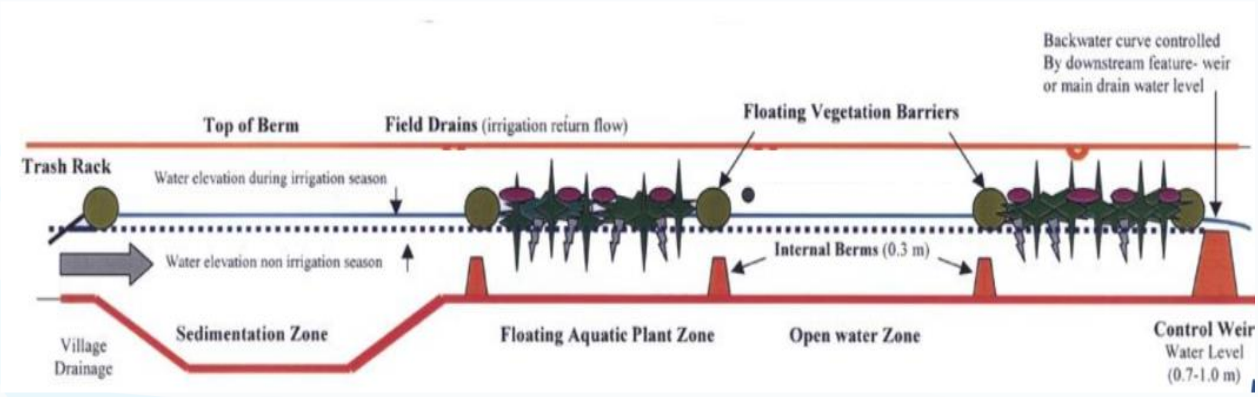

Figure 5. Conceptual design of the engineering constructed wetland treatment pilot

The engineering constructed instream wetland treatment pilot (CWT) includes upstream wastewater tanks (above the ground surface), downstream treated water tanks (below the ground surface), two lined treatment cells, gravel and sand filters, treatment substrate, aquatic and floating weeds, micro-organisms, pipes, valves and discharge meters. The main modification made is relative to the daily rate of treated water has been adjusted and increased to 35-40 m^3/day from the two treatment cells. The two upstream overland tanks of the two cells and the two downstream underground tanks are constructed to maintain gravity flow with a hydraulic gradient thus no-energy consumption at all in the CWT system. The following is the configuration of the CWT's configuration and dimensions:

- The CWT's length is 50 m (2 cells)
- The CWT's longitudinal slope is 1:1000
- The CWT's geometric depth is 1.5 m
- The CWT's side slope is 1:3
- The CWT's bottom width is 0.8 m
- The CWT's top width is 5.0 m
- The CWT's hydraulic depth is 0.6 m
- Lining: heavy duty poly ethylene synthetic sheets of 1 mm thickness
- Flow (Q) = 20 m^3/day per each cell
- The Hydraulic Retention Time (HRT) is 2.78 approximated to be 3 days for easy operation.
- Two upstream tanks are 2X2X2 m (above ground surface)
- Two downstream tanks are 2X2X2 m (underground surface)

The treatment cells are provided with gravel and sand filters, sharp crested weirs, and substrate medium to support rooted aquatic plants. Each cell consists of plants, biofilms, soil, and micro-organisms (floating green algae) to naturally treat and remove the majority of the physical, chemical and biological water pollutants. Figure (6) shows the installed design of the engineering constructed instream wetland experimental pilot (CWT) installed in Sekem Farm, El-Wahat El-Bahariya, Egypt.

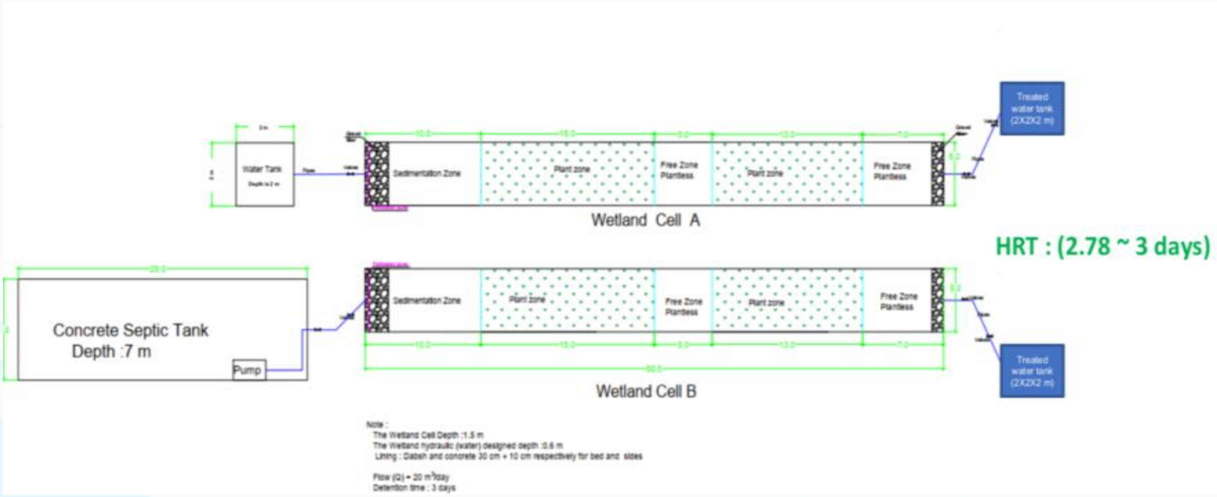

Figure 6. The initial installed design the engineering constructed instream wetland experimental pilot (CWT) installed in Sekem Farm, El-Wahat El-Bahariya, Egypt

The following Figure (7) shows the cross sectional area of the trapezoidal treatment cells, with all its dimensions. It explains also the estimation of the hydraulic retention time (HRT) of the CWT processes.

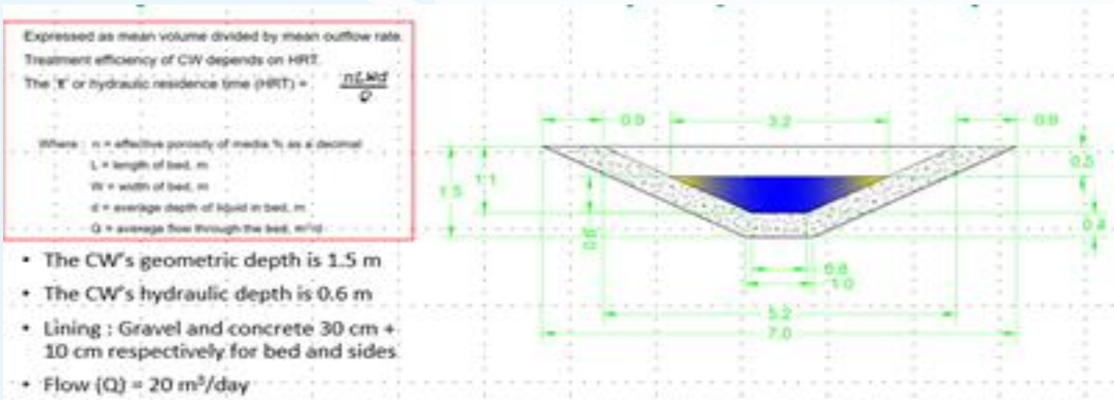

Figure 7. The cross sectional area of the trapezoidal treatment cells and the equation of the HRT

The following section (Figures 8 to 18) contains a chronical series of photos represents the actual CWT experimental installation stages (February to June 2023) in Sekem Farm El-Wahat El-Bahariya, Egypt. The chronological Photographic demonstration of the CWT shows also the sources of raw wastewater (Domestic sewage and agricultural drainage water). It represents the in-situe water quality laboratory which is used for the weekly basic water quality analysis. In addition, an extensive water quality analysis (physical, chemical, biological and heavy metals pollutants) is planned to be done on monthly at the Sekem/HU's central laboratories in Belbies, El-Sharkia Governorate.

Figure 8. Marking the site of the CWT pilot in Sekem El-Wahat farm, Egypt

Figure 9. Excavation work of the site of the CWT pilot in Sekem El-Wahat farm, Egypt

Figure 10. Configuring the trapezoidal cross section and longitudinal slope of the treatment cell. The construction of the water tanks

Figure 11. Constructing two overland (up-stream) tanks and two underground (down-stream) tanks. The CWT site is next to the main septic tanks of the Sekem farm El-Wahat


Figure 12. Finishing the construction of the two underground (down-stream) tanks and the poly ethylene lining materials of the two cells and four tanks

Figure 13. The project team reviewing the dimensions of the finished civil works)

Figure 14. Installing the flow meters and valve at each water tanks (four tanks)


Figure 15. The Azolla breeding tank and an agricultural drainage pond inside Sekem farm El-Wahat El-Bahariya

Figure 16. Equipping the in-situ water quality laboratory in Sekem farm El-Wahat

Figure 17. The main septic tank (source of sewage water) close to the main road inside Sekem farm El-Wahat

Figure 18. The trees belt surrounding Sekem farm El-Wahat (1st phase) and the Cactus field shall be irrigated by the treated wastewater (2nd phase)

5.3 CWT's Final Installed Design

Two types of design models of the CWT (Model I & Model II with two different configurations) were developed and finalized using engineering constructed instream wetland treatment technologies. One fits for large agricultural scheme, particularly for private sector investors in large agricultural schemes. The other one is designed to fit smallholder farmers in isolated rural communities. The first model (I) consists of: 1) two cells, 2) lined with synthetic sheets (heavy duty synthetic plastic sheets of 1 mm thickness) materials which can prevent precisely the wastewater from penetrating into the soil layers and reaching the groundwater aquifers; and 3) automated operation system. However, the model (II) is used for the case of smallholder farmers consists of: 1) one cell, 2) lining with compacted clay layer over gravel materials; and operated manually with no energy at all.

5.3.1 CWT's final installed design (CWT-Model I)

The manual operation of the CWT's tanks (filling and emptying) – Model (II) experienced delays and irregularity in the continuous operation due to the occasional workers' unavailability or trucks break down. The continuity of feeding treated wastewater to the Bamboo trees was not guaranteed. The HU team received additional fund from HU/Sekem management as additional in-kind contribution to the MED-WET project in order to install an automatic control system to allow continuous filling and emptying of the CWT's four tanks automatically without human intervention. The following electrical parts were installed, tested and currently operational with high precision (Inverter 5.0 K. Volt, 10 Photo-Voltaic (PV) solar panels, Steel frame for the PVs, four dry ultra-lithium rechargeable batteries (high voltage) and four pumps 2.0 HP each). Figure (19) shows the components of the fully automated CWT (Model II) experimental pilot in Sekem Farm El-Wahat El-Bahariya.

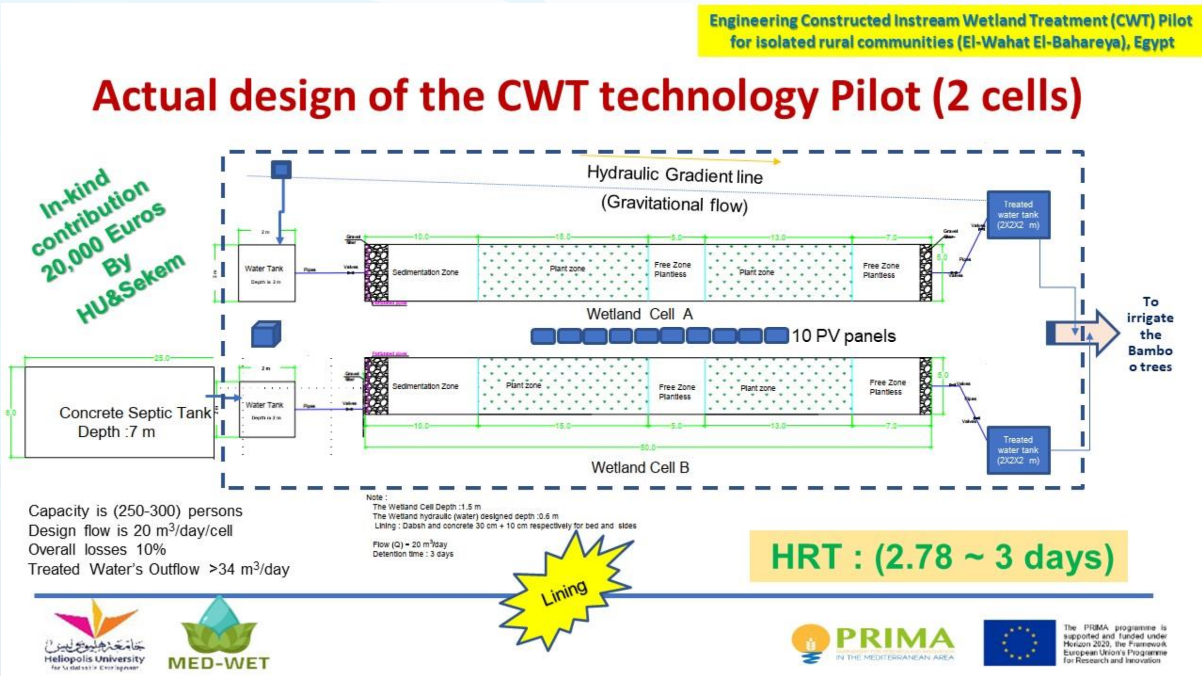

Figure 19. Components of (CWT-Model II), the fully automated CWT experimental pilot in Sekem Farm El-Wahat El-Bahariya

5.3.2 CWT's final installed design (CWT-Model II)

Hu team finalized the design of the CWT-Model II, to be disseminated to the smallholder farmers in the desert areas such as El-Wahat El-Bahariya and the other Egyptian oases as well as in isolated rural agricultural areas such as Eastern and Western Delta firings. The CWT-Model II consists of: 1) one native soil cell with trapezoidal cross section, 2) lining is formed by compacted impervious clay and native silt layer (5 cm depth) over a gravel layer (15-20 cm depth); the longitudinal slope is very mild. The dimensions of CWT-Model II are shown below.

- The CWT's cell length is 50 m
- The CWT's longitudinal slope is 1:1000 or slightly less
- The CWT's geometric depth is 1.5 m
- The CWT's side slope is 1:3
- The CWT's bottom width is 0.8 m
- The CWT's top width is 5.0 m
- The CWT's hydraulic depth is 0.6 m
- Flow (Q) = 20 m^3/day
- The Hydraulic Retention Time (HRT) is about 3 days for easy operation.
- One upstream tanks are 2X2X2 m (above ground surface)
- One downstream tanks are 2X2X2 m (underground surface)

The treatment cell of CWT-Model II is provided with gravel and sand filters, sharp crested weirs (build with bricks and covered with cement, and substrate medium to support rooted aquatic plants. The cell consists of weeds plants, native soil, and floating green algae (Azolla) to naturally treat and remove the majority of the physical, chemical and biological water pollutants. The CWT-Model II is operated manually with no energy consumption at all. Therefore, the installation and operation cost of this model is almost zero. Figure (20) shows the final design of the engineering constructed instream wetland (CWT-Model II) designated for installation at the smallholder farmers in isolated areas.

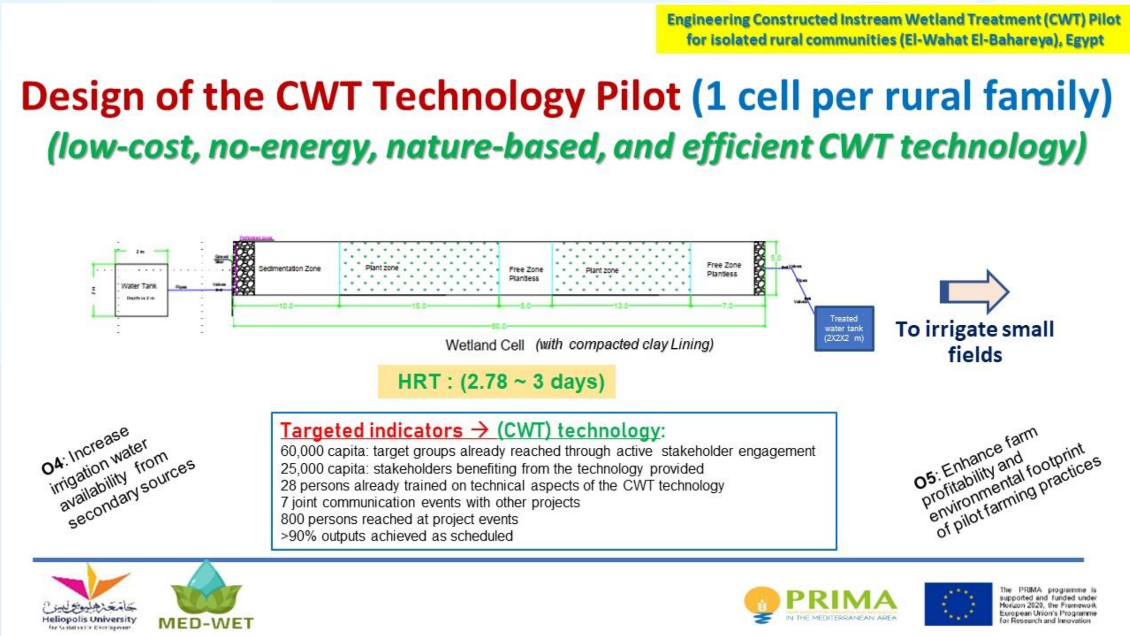

Figure (20) shows the final design of the engineering constructed instream wetland (CWT-Model II) designated for installation at the smallholder farmers in isolated areas

5.4 Bill of Quantities and Costing (CWT-Model I) & (CWT-Model II)

The (CWT-Model I) was designed for large agricultural schemes such as Sekem Farm for Land Reclamation in El-Wahat El-Bahariya. It fits with farms of agricultural investors and private agricultural companies. The reason is the considerably high construction cost of the CWT-Model I due to the poly ethylene lining materials as well as the renewable energy generation system and the automated operation system. Table (3) shows the bill of quantities needed to construct CWT-Model I.

Table 3. The quantities of all in-situ work task estimated before installation (CWT-Model I)

CWT Cells	**m^2**
Bottom wide	0.7
Top width	5.0
Depth	1.5
Length	56.0
side slope lenght	2.7
Top width	1.0
Area of bottom	39.2
Area of slope (double)	302.4
Area of Top width (double)	112
Total area (one cell)	**453.6**

Tanks	**m^2**
Upstream tank	
Length	3.1
Depth	2.55
Width	2.3
Areas side 1 (2)	15.81
Area Side 2 (2)	11.73
Area of bottom	7.13
Total Area (one tank)	**34.67**

Downstream tank	**m^2**
Length	2.5
Depth	2
Width	2.1
Areas side 1 (2)	10
Area Side 2 (2)	8.4
Area of bottom	5.25
Total Area (one tank)	**23.65**

However, the bill of quantity for CWT-Mode II is considerably cheaper as it fits smallholder farmers (either one family household or two neighbor families' households) living in isolated communities with limited financial resources. Table (4) shows the bill of quantities needed to construct CWT-Model II.

Table 4. The quantities of all in-situ work task estimated before installation (CWT-Model II)

CWT Cells	**m^2**
Bottom wide	0.7
Top width	5.0
Depth	1.5
Length	56.0
side slope lenght	2.7
Top width	1.0
Area of bottom	39.2
Area of slope (double)	302.4
Area of Top width (double)	112
Total area (one cell)	453.6
Total area (2 cells)	**907.2**

Tanks	
Upstream tank	**m^2**
Length	3.1
Depth	2.55
Width	2.3
Areas side 1 (2)	15.81
Area Side 2 (2)	11.73
Area of bottom	7.13
Total Area (one tank)	34.67
Total 2 Upstram tanks	**69.34**

Downstream tank	**m^2**
Length	2.5
Depth	2
Width	2.1
Areas side 1 (2)	10
Area Side 2 (2)	8.4
Area of bottom	5.25
Total Area (one tank)	23.65
Total 2 Upstram tanks	**47.3**

The following Table (5) explains the details of the construction cost of the (CWT-Model I) including the installation of control equipment as well as the in-kind contribution paid by HU in order to transform the system into automated CWT self-operational (CWT-Model I).

Table 5. The details of the construction cost of the (CWT-Model I) including the installation of control equipment as well as the in-kind contribution paid by HU

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Cost of materials for the engineering constructed instream wetland treatment pilot in Sekem farm El-Wahat (CWT-Model I)

	Lining materials and labor cost (1 cm thickness smooth)	85	EG Pd/m2
	Total area needs to be lined in the pilot	1500	m2
Subtotal (1)	Total lining cost	127500	EGP
	Installing connection system (PVC pipes) ~ 40 m		
Subtotal (2)	4 discharge meters (gages) - 2000 EGP/ unit	8000	EGP
Subtotal (3)	4 valves - 500 EG Pd/ unit	2000	EGP
	Tanks & weirs construction + Treatment intervention		
Subtotal (4)	bricks, gravel, uniform sand & cement	30000	EGP
	Aquatic vegetation & micro-organisms		
Subtotal (5)	special species of rooted and floating plantation & algae	2000	EGP
Total cost of materials (MED-WET Budget)		**169500**	EGP
Total cost of materials (MED-WET Budget)		**3940**	Euro
HU's in-kind contribution to transform the CWT into automated system			
	PhotoVoltic Solat Pannel sheets		
Subtotal (6)	10 original sheets (PV) - Mono Cristaleen - single crystal X7850 EGP	78500	EGP
	Steel frame holders (10) for the PV sheets X 5000 EGP	50000	EGP
Subtotal (7)	Inverter 5 HP - 1 unit	58350	EGP
Subtotal (8)	4 water level sensors X 450 EGP	1800	EGP
Subtotal (9)	4 dry rechargeable lithium batteries (high voltage) X 22000	88000	EGP
Subtotal (9)	Digging a shallow well to collect agricultural drainage water (depth 15 m)	150000	EGP
Subtotal (10)	Accessories, wires, security room with gate for the inverter	20000	EGP
Subtotal (11)	Fencing the CWT pilot site for security with mesh stainless steel wire and steel columns	50000	EGP
Total cost of materials (HU's in-kind contribution)		**496650**	EGP
Total cost of materials (HU's in-kind contribution)		**11000**	Euro

It is obvious that the cost of construction of the CWT-Model I from the MED-WET project's budget is about 169,500 EGP (which is equivalent to about 3,940 Euro). HU carried the expenses of automated operation of the CWT-Model I of the amount of 496,650 EGP (which is equivalent to about 11,000 Euro).

The following Table (6) explains the details of the construction cost of the (CWT-Model II) which does not include any energy generation nor automated operation equipment. The (CWT-Model II) operates manually to save cost yet results in similar pollutants' removal efficiency to (CWT-Model I). The (CWT-Model I) fits well the smallholder farmers living in isolated communities with limited financial resources.

Table 6. The details of the construction cost of the (CWT-Model II)

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Cost of materials for the constructed wetland pilot for smallholder farmers communities (CWT-Model II)

Subtotal (1)	Total lining cost (pervious compacted clay (native material) - only labor	2000	EGP
	Installing connection system (PVC pipes) ~ 40 m		
Subtotal (2)	2 discharge meters (gages) - 2000 EGP/ unit	4000	EGP
Subtotal (3)	2 valves - 500 EG Pd/ unit	1000	EGP
	Tanks & weirs construction + Treatment intervention		
Subtotal (4)	bricks, gravel, uniform sand & cement	15000	EGP
	Aquatic vegetation & micro-organisms		
Subtotal (5)	special species of rooted and floating plantation & algae	1000	EGP
Total cost of materials (MED-WET Budget)		**23000**	EGP
Total cost of materials (MED-WET Budget)		**510**	Euro

It is obvious that the cost of construction of the CWT-Model II from the MED-WET project's budget is about 23,000 EGP (which is equivalent to about 510 Euro). Compared to (CWT-Model I); (CWT-Model II) is very cheap (it is equivalent to about 5% of the cost), with pollutants' removal efficiency the same like (CWT-Model I).

6. CHALLENGES FACED DURING THE CWT INSTALLATION

During the CWT-Model I installation, a number of technical problems arose and actions were taken to overcome those technical problems as shown in Table (8).

Table (8): Installation challenges and actions taken to overcome them (CWT-Model I)

Technical challenges	Actions to overcome
Assure uniform flow along the cross-sectional area of each cell	Wide perforated pipes were installed to distribute the treated water along the cross-sectional area of each cell
Silts leaks into the flow meters	Fine screen mesh pieces were wrapped at the pipes inlets to prevent the silt particles
Leakages from underneath the freeboard crested weirs	Insolation and water-stopping materials were installed then, the freeboard crested weirs were re-constructed above
Water falling from above the freeboard crested weirs touching the walls without enough mixing and aeration process	A stainless-steel sheets were installed above the freeboard crested weirs in order to allow for more mixing and aeration
Small shrubs and dry wooden stems move and fall inside the treatment cells due to the high wind	A metal mesh fence was installed surrounding the experimental site provided by a secured entrance gate.
The calibration of flow inside each cell to fulfil the estimated Hydraulic Retention Time (HRT = 3.0 days) so that 15 m^3/day can be properly treated	Sensitive-type valves were installed that allow specific slow discharge accumulate the target outflow of treated water of 15 m^3/day/cell.
Windblown fine sand precipitate inside the four tanks	All four tanks to be covered.
The gravel, basalt and course sand filters were not properly catching the whole flow of wastewater.	Adjustment were made in the setup of the gravel, basalt and course sand filters to ensure high screening efficiency.
Aquatic weeds die off quickly	Increase the substrate layers of native soils.
Leakage was noticed a few fittings connections	Fixed properly
Site landscape needed enhancements	Done properly
The operation rules are missing	A clear stand with the operation rules was put inside the CWT site.
The site protections, guidance and cleaning is poor	Guiding signs and warning/instruction signs were put.

6.1 CWT pre-installation - challenges faced

The excavation and digging of the trapezoidal cross section channel for two cells of length 50 meters each was very tough process due to very fine and deep sandy layer. Each time the excavator works, the same amount of sand goes back filling the pits. In addition the prevailing wind speed all the time added more difficulty to the excavation process. The HU and Sekem technical team had to hire a larger excavator with bigger capacity to be able to continue the excavation successfully.

6.2 CWT lining process

Another challenge was the selection of the lining materials which can prevent precisely the wastewater from penetrating into the soil layers and reaching the groundwater aquifers, in the meantime it should be capable of removing and adding treatment interventions from the cells without being cracked or damaged (the lining materials). This is essential in the CWT experiment to assess and evaluate more treatment scenarios applied and tested. Finally, HU and Sekem technical team decided to install a poly ethaline synthetics plastic of 1.0 mm thickness, which is durable and sustainable in desert conditions (tested successful before in Sekem farm El-Wahat and in the neighboring farms).

6.3 CWT's Pipes and fittings installation

The hydraulic retention time designed for the CWT operation is 3 days, the flow should not exceed (5-6) liters per minute, therefore, it was difficult to identify the precise and accurate valves that allow such small discharge flow. HU team were able to allocate the needed four valves and were installed. There were also four discharge flow gages installed to estimate the amount flow per day or week or month as needed.

6.4 CWT's filling and empting system

The manual operation of the CWT's tanks (filling and emptying) experienced delays and irregularity in the continuous operation due to the occasional workers' unavailability or trucks break down. The continuity of feeding treated wastewater to the Bamboo trees was not guaranteed.

6.5 CWT's Post-installation and initial testing operation checks

The acquisition of a reliable hand-held water quality kit for in-situ analysis at (CWT-Model I) in Sekem El-Wahat El-Bahariya took time and caused some delays in starting the regular water quality analysis. Because of the high prices of new hand-held water quality kit, HU decided to repair one original and good set of water quality kit in the amount of 35,683 EGP (equivalent to about 800 Euro). HU team trained a number of technicians on how to estimate the basic water quality parameters in-situ using the hand-held water quality kit. After resolving all previous challenges, the CWT-Model I proved reliability and efficiency during the post-installation and initial testing stage.

7. CWT'S INITIAL OPERATION AND TESTING

After overcome all previous challenges, the CWT-Model I proved reliability and efficiency during the initial operation stage at Sekem Farm in El-Wahat El-Bahariya.

8. CWT'S AUTOMATION SYSTEM AND GREEN OPERATION

Due to the proven delay in manual operation during the testing period due to the technician's unavailability in some days, the HU team worked out a permission to increase HU's in-kind contribution in order to install an automatic control system to allow continuous filling and emptying of the CWT's four tanks without human intervention. The following electrical parts were installed, tested and currently operational with high precision (Inverter 5.0 K. Volt, 10 Photo-Voltaic (PV) solar panels, Steel frame for the PVs, four dry ultra-lithium rechargeable batteries (high voltage) and four pumps 2.0 HP each). The automated operation system depends on renewable energy from the sun, so that it is considered green operation. Figure (17) above illustrates the CWT-Model I's final layout and configuration.

9. CWT'S POLLUTANTS' REMOVAL EFFICIENCY AND REUSING THE TREATED WATER

There are more than 40 parameters need to be monitored. Frequency of monitoring shall be two categories; monthly extensive (physical, chemical, micro-biological, and heavy metals) analysis planned to be done in the certified Atos/Sekem laboratories, and weekly basic (physical and salts: cations and anions) analysis planned to be done in the in-situ water quality laboratory at Sekem Farm El-Wahat El-Bahariya. The research experiment duration to determine the optimum treatment scenario that leads to the highest treatment efficiency is excepted to be one year. The main parameters to be monitored are as follows:

- Physical, chemical and micro-biological parameters: pH, EC, DO, salts (anions and cations), heavy metals (e.g., Fe, Cu, Mn), TDS, BoD, COD, Fecal coliform, E. Coli bacteria, pathogens, viruses, and water-borne diseases.
- Monitoring frequency is one week for the basic water quality analysis and one month for the extensive water quality analysis.
- Samples of the irrigated trees tissue and top soil layers shall be analyzed to determine the water quality of residual pollutants, if any.

The pollutants' overall removal efficiency is estimated as the summation of percentages of residual pollutants after the treatment divided on the summation of same pollutants before treatment. The grade of treatment using the CWT-Model I can be derived by comparing the percentages of residual pollutants after the treatment to the threshold values (maximum allowable concentrations) of the same pollutants in the Egyptian Code of Practice for Wastewater Treatment in Agriculture (ECP 501 for 2015).

10. EMERGENCY PROTOCOLS AND CONTACTS OF RESPONSIBLE PERSONS

While the CWT is designed with safety and efficiency in mind, unforeseen circumstances or malfunctions can arise. In such situations, it's crucial to have a well-defined set of emergency protocols and a list of contacts to address the situation promptly and minimize potential damage.

10.1 In Case of Equipment Malfunction

1. Immediate Shut Down: If any component or equipment shows signs of malfunction within the site of the CWT at Sekem El-Wahat, such as unusual noises, excessive heat, or smoke, immediately shut down the CWT electrical equipment and close all valves.

2. Avoid Direct Contact: Do not touch any equipment that appears to be malfunctioning or overheating. Wait for it to cool down or for a professional to assess the situation.

3. Isolate the Area: Cordon off the affected area to prevent any unauthorized or uninformed individuals from coming into contact with malfunctioning equipment. This has been implemented already for the CWT site in Sekem El-Wahat. Information signs installation is needed at the Bamboo fields irrigated with the treated wastewater. So that not to have direct contact with the irrigation water thus to avoid the possible transmission of any remaining harmful effects in such treated wastewater.

10.2 In Case of Structural Damage

1. Evacuate: if there's any sign of structural damage to the CWT at Sekem El-Wahat, such as cracks or collapses, ensure everyone inside the CWT site is safely evacuated.
2. Inspect and Repair: once the area is secured, conduct a thorough inspection to assess the damage. Seek professional assistance for any necessary repairs.

10.3 In Case of Electrical Issues

1. If you suspect any electrical malfunctions, immediately turn off the main power supply to the CWT at Sekem El-Wahat.

2. Seek Professional Help: Do not attempt to fix electrical issues without the guidance of a certified electrician.

10.4 Emergency Contacts

For immediate assistance at the CWT site, the following individuals can be contacted:
- Eng. Mohamed Owis, Manager of Sekem Farm El-Wahat, Mobile: (+20) 100 172 3984
- Mr. Sobhi El-Saadani, Administration Manager, Sekem Farm El-Wahat, Mobile: (+20) 105 004 5719

In case of any technical issue, please contact the following:
- Prof. Wael Khairy, PI of the MED-WET Project, HU, E-mail: wael.khairy@hu.edu.eg, Mobile: (+20) 122 479 8846
- Eng. AyaAllah Yasser, Research Assistant, MED-WET Project, HU, E-mail: aya.yasser@hu.edu.eg, Mobile: (+20) 115 983 3222

10.5 Feedback and Updates

- Continuous Improvement: constructive feedback helps identify areas of improvement, ensuring that the CWT at Sekem El-Wahat remains at the forefront of sustainable agriculture and irrigation water production's cheap and simple technologies.
- User Experience: feedback provides insights into the practical experiences of those operating and maintaining the CWT at Sekem El-Wahat, ensuring that its design and functionality align with the needs of all users including the smallholder farmers as well as the large agricultural scheme investors.
- Safety: feedback can help identify potential safety concerns or areas where clearer instructions may be required, ensuring the safety and well-being of all personnel.
- The CWT's technical guidelines & installation manual is a dynamic document. Periodic updates will be made to incorporate new technological advancements, address feedback, and ensure that the manual remains relevant and up-to-date.
- Users are encouraged to regularly check for updates and ensure they are working with the latest version of the manual.

11. ACKNOWLEDGEMENTS

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The President, senior management officials of HU and the Dean of the Faculty of Engineering for their insightful remarks and advices during the planning and installation phases of the CWT in Sekem El-Wahat.

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The local community and all stakeholders in El-Wahat El-Bahariya who have been involved in the project for their valuable feedback, reflections and cooperation.

11.1 Disclaimers

Equipment Variability: while this manual provides guidelines for the installation of the CWT, users should be aware that treatment segments, equipment and components might vary in brands and sizes. Always consult specific instructions provided by equipment manufacturers or suppliers.

Liability: the CWT installation must be carried out under the supervision of qualified personnel. The responsibility for ensuring that all installations adhere to local and international safety standards lies with the installing party, HU and Sekem. No third party will be held liable for any damages or injuries resulting from incorrect installation or operation of the CWT.

Dynamic Document: this technical guidelines & installation manual is subject to periodic updates to incorporate technological advancements or feedback. Users are encouraged to ensure they are referencing the most recent version of the manual.

12. CONCLUSION AND RECOMMENDATIONS

The installation of the Engineering Constructed Instream Wetland Pilot (CWT) with its low-cost, low-energy, nature-based and efficient technologies is an excellent demonstration site for all smallholder farmers of El-Wahat El-Bahariya and the surrounding desert communities in El-Farafra, El-Kharga, El-Dakhla and Siwa Oases. In addition, it is considered an added value for the Sekem Farm El-Wahat because it contributes to increasing the water productivity for irrigation and reducing the pollution hazards of the domestic wastewater inside the farm.

Remember always to consult specific instructions provided by equipment manufacturers and suppliers, as these will cater to the unique specifications and requirements of each component.

Throughout the installation process of the Engineering Constructed Instream Wetland Pilot (CWT), various other documents have been referenced to provide comprehensive insights, specific instructions, and detailed guidelines. For ease of access and to ensure that all procedures are followed with utmost precision, a list of these referenced documents is provided below.

13. CITED REFERRENCES

Abdel-Ghaffar, A. S. El-Attar, H. A. and El-Sokkary I. H., 1988. Egyptian experience in the treatment and use of sewage and sludge in agriculture. Proceedings of the FAO regional seminar on the treatment and use of sewage effluent for irrigation, Nicosia, Cyprus, 7-9 October 1985, London, Butterworths.

Arthur F.M. Meuleman, Richard van Logtestijn, Gerard B.J. Rijs, and Jos T.A. Verhoeven, 2003. Water and mass budgets of a vertical-flow constructed wetland used for wastewater treatment, Ecological Engineering, doi:10.1016/S0925-8574(03)00002-8, Vol 20, pp 31-44, Elsevier, University of Utrecht, The Netherlands, URL: https://www.sciencedirect.com/science/article/abs/pii/S0925857403000028

Drainage Research Institute, Project team, 2003. Natural Wastewater Treatment Systems (Desk Study Report), Report No. Tech-1, Passive In-Stream Wetland Treatment of Drain Water Project, August 2003.

Eid, El-Mohamady, 1988, Impact of Treated Effluent Reuse on the Environment with Special Reference to Egypt. FAO Regional Seminar on Wastewater Reclamation and Reuse, Cairo, Egypt.

Figoli, A. and Criscuoli, A. eds., 2017. Sustainable Membrane Technology for Water and Wastewater Treatment. Springer.

Gearheart, R. A. and Hendrich, J. H., 2000. Passive Wetland Water Quality Management System Incorporating the Existing Drainage Canals in Fayoum, A conceptual Plan for treating village drainage and irrigation return flow for reuse. Harza Engineering, Cairo, Egypt.

Grady Jr, C.L., Daigger, G.T., Love, N.G. and Filipe, C.D., 2011. Biological wastewater treatment. CRC press.

Guangzhi Sun. 2018. Wetlands for the Treatment of Agricultural Drainage Water, journal Water, ISSN 2073-4441, ISBN 978-3-03897-209-9, MDPI • Basel • Beijing • Wuhan • Barcelona • Belgrade, Edith Cowan University, Australia, URL: http://www.mdpi.com/journal/water/special issues/

J.D. Rhoades, A. Kandiah & A.M. Mashali, 1992. The use of saline waters for crop production - FAO irrigation and drainage paper 48, Soil Resources, Management and Conservation Service Land and Water Development Division, FAO, M-56 ISBN 92-5-103237-8.

Lema, J.M. and Martinez, S.S. eds., 2017. Innovative wastewater treatment & resource recovery technologies: impacts on energy, economy and environment. IWA publishing.

Mosalam H, Shenouda A, Kamh Y, Samii E, El-Kholy RMS, 2017. Adequate design for aquaponics with case study. EACBEE, 6th International Conference on Chemical, Agricultural, Environmental & Biological Sciences, Paris, France Dec. 7-8 2017

USEPA, 1981. Process Design Manual for Land Treatment of Municipal Wastewater. EPA 625/1-81-013, Environmental Protection Agency, Washington D.C. 1981

William J. Mitsch and James G. Gosselink, 2000. Wetlands, 3rd Edition, John Wiley & Sons, Inc.