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SETUP OF A SMALL-SCALE AQUAPONIC SYSTEM WITH POST-TREATED WASTEWATER

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ABSTRACT

Tunisia is regarded as a pioneer country in agricultural wastewater reuse through irrigation. However, wastewater-fish farming or hydroponics is an uncommon or even totally controversial practice in the local context.

Through this engineering graduation project, we contribute to ameliorate treated wastewater reuse by setting up a small-scale aquaponic system in GDA Sidi Amor. A post-treatment unit is implemented to meet the aquaponics water quality requirements, which has the following components: Vertical Flow Constructed Wetland, duckweed grow bed and HydroFLOW© technique.

The aquaponic small-scale system is designed with a fish tank; two media grow bed filters (MFG) and a deep water culture bed (DWC). The system setup was basically low-cost and based on local materials. Plants' choice is cut roses, and fish choice is common carp; which represent the best option according to the local context. The global perspective for the system is the monitoring plan and optimization.

Key words: Wastewater reuse, aquaponics, vertical flow constructed wetland, duckweed grow bed, HydroFLOW©, MFG, DWC.

RÉSUMÉ

La Tunisie est considérée comme un pays pionnier dans la réutilisation des eaux usées pour l'irrigation agricole. Cependant, l'élevage de poissons en eaux usées ou la culture hydroponique est une pratique peu commune, voire totalement controversée dans le contexte local.

Grâce à ce projet de fin d'étude, nous contribuons à améliorer la réutilisation des eaux usées traitées en mettant en place un système aquaponique à petite échelle à la GDA Sidi Amor. Une unité de post-traitement est mise en place pour répondre aux exigences de qualité de l'eau aquaponique, qui comporte les éléments suivants : Zone humide construite à flux vertical, lit de culture de lentille d'eau et technique HydroFLOW©.

Le système aquaponique à petite échelle est conçu avec un bassin à poissons, deux filtres à lit de culture en milieu (MFG) et un lit de culture en eau profonde (DWC). La mise en place du système a été essentiellement peu coûteuse et basée sur des matériaux locaux. Le choix des plantes été des roses coupées et le choix des poissons été des carpes communes, ce qui représente la meilleure option en fonction du contexte local. La perspective globale du système est le plan de surveillance et d'optimisation.

Mots clés : Réutilisation des eaux usées, aquaponie, zone humide construite à flux vertical, lit de culture de lentille d'eau, HydroFLOW©, MFG, DWC.

تلخيص

تعتبر تونس من الدول الرائدة في إعادة استخدام المياه المستعملة في الري الزراعي. استغلال هذه المياه في تربية الأسماك .أو الزراعة المائيّة هي ممارسة غير معتادة و وقد تثير الجدل في السياق المحلّي.
من خلال مشروع التخرج الهندسيهذا ، ساهمنا في تحسين استغلال مياه الصرف الصحي المعالجة عبر إنشاء نموذج لنظامفي مجمع التنمية الفلاحي بسيدي عمر. وقد تم إنشاء وحدة مابعد المعالجة لهذه المياه لتلبية متطلباتجودة المياه الأكوابونيكمصغّر، وتتكون هذه الوحدة من ارض رطبة مشيّدة ذات تدفّق عمودي و حوض يحتوي على طبقة من الطحلب البطّي و تقنية الهيدروفلو®.
تصميم نظام الأكوباونيك المصغّر هذا يحتوي على حوض اسماك و زوج من النظامين مع الركيزة وحوض المياه العميقة.

إنشاء هذا النظام كان منخفض التكلفة وتم استعمال المواد والأدوات المحلّية، النباتات التي تم اختيارها هي زهور للقطف، أما بالنسبة للسمك فقد تم اختيار سمك الشبّوط وهو الأفضلضمن هذا السياق. المنظور الشامل لهذا النظام تكوين خطة مراقبة .و تقوية مردوده.

كلمات المفاتيح: إعادة استخدام مياه الصرف الصحي ، تربية الأحياء المائية ، الأراضي الرطبة ذات التدفق العمودي ، أحواض نمو الطحلب البطي،الهيدروفلو®،نظام مع الركيزة ، حوض المياه العميقة.

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LIST OF ABREVIATIONS

BOD	Biochemical Oxygen Demand
CW	Constructed Wetland
DO	Oxygen Demand
DWC	Deep Water Culture
DWWT	Duckweed based Wastewater Treatment
FAO	Food and Agricultural Organization
FWS	Free Water Surface
HFCW	Horizontal Flow Constructed Wetland
HRT	Hydraulic Retention Time
KH	Hardness
MFG	Media Grow Bed Filter
NFT	Nutrient Film Technique
NGO	Non-governmental Organization
OLR	Organic Loading Rate
SSA	Specific Surface Area
TWW	Wastewater Treatment
VFCW	Vertical Flow Constructed Wetland
WSP	Wastewater Stabilization Pond
WWTP	Wastewater Treatment Plant

INTRODUCTION

Tunisia is a drought-stressed country with per capita renewable water availability of 429.20 cubic meters per year, well below the absolute water scarcity threshold of 500 cubic meters. As in most countries of the Middle East and North Africa region, agriculture accounts for the bulk of water consumption beyond 80%. Scarcity of fresh water in such areas has led to increased utilization of low quality, recycled wastewater and brackish groundwater (Besbes et al., 2014).The use of treated, diluted, and even raw domestic wastewater for agricultural irrigation is becoming an essential component of a more sustainable and integrated water resources management, especially in water-scarce regions. At the national scale, reuse of treated wastewater is an important strategy to cope with water scarcity in agriculture.

Although Tunisia was regarded as a pioneer country in agricultural water reuse by recording significant progress since the 1960s, this practice is currently experiencing a serious slowdown. The main common admitted concerns would be the issues of the reclaimed wastewater quality for irrigation and the public acceptance. Some wastewater use schemes have even been halted by the lack of social and cultural acceptance. One such example comes from the area of BorjTouil, where poor public acceptance (combined with other reasons) caused the wastewater irrigated area to shrink from 3145 to 340 ha. Moreover, wastewater is generally treated to only secondary level treatment that does not seem to be as sufficient as thought in providing an irrigation water quality consistently that meets reuse standards and farmers' expectations. Anyway, the complexity of the issues raised by the management of treated wastewater in agriculture goes beyond the constraints of water quality and should consider sustainable, inclusive and creative integrated approaches.

In this context, a local NGO (GDA Sidi Amor) has initiated five years ago a platform to promote wastewater reuse in BorjTouil area to help build socio-cultural acceptance through both demonstration of best practices and building community participation. This pilot-project proposes both the implementation of (tertiary) complementary treatments using constructed wetlands for water quality improvement *given the insufficiency of the secondary effluents quality to maintain right rates of reuse* and to raise awareness on water and Nature-based Solutions (NbS).Collaborative and participatory approach allowed the project to move from conception to successful implementation at pilot-scale.Among the challenges addressed are enhancing quality of reclaimed wastewater and supporting diversified crops and innovative patterns.

Furthermore, it would be worth to rethink the management of peri-urban farming with wastewater through innovative value-added activities adapted to local context.Aquaponics seems to be a promising approach to revive the local interest of reusing wastewater in agriculture and aquaculture.Aquaponics, also known as organic hydroponics, combines aquaculture with hydroponics in a self-sustaining symbiotic closed loop system that produces two crops in one facility: fish and plants. However, wastewater-fish farming or hydroponics is an uncommon or even totally controversial practice in the local context (very limited, not recommended).

In the present work, we established a small-scale aquaponic system based on post-treated wastewater implemented in GDA Sidi Amor. The post-treatment plant compromises a vertical flow constructed wetland, duckweed grow bed and two HydroFLOW© devices. The main objectives are:

- Assessment of the inlet water quality
- Design and establishment of the different components of the system

Chapter I: Bibliography

1. Constructed wetlands for wastewater treatment

Constructed wetlands (CWs) are engineered systems that have been designed and constructed to utilize the natural processes involving wetland vegetation, soils, and the associated microbial assemblages to assist in treating wastewaters. CWs for wastewater treatment may be classified according to the life form of the dominating macrophyte, into systems with free-floating, floating leaved, rooted emergent and submerged macrophytes. Further division could be made according to the wetland hydrology (free water surface and subsurface systems) and subsurface flow CWs could be classified according to the flow direction (horizontal and vertical) (Vymazal, 2010).

1.1 Main types of constructed wetlands

Various types of constructed wetlands differ in their main design characteristics as well as in the processes which are responsible for pollution removal. Anyway, for the purpose of our case study, only free water surface and subsurface CWs are considered.

1.1.1 Free water surface systems

Free water surface (FWS) wetlands are defined as wetland systems where the water surface is exposed to the atmosphere. In FWS treatment wetlands, water flows over a vegetated soil surface from an inlet point to an outlet point. In some cases, water is completely lost to evapotranspiration and seepage within the wetland (EPA, 2000).

1.1.2 Subsurface systems

Subsurface systems are designed to create subsurface flow through a permeable medium. Subsurface wetlands consist of gravel beds that may be planted with wetland vegetation. They are also frequently referred to as submerged flow, subsurface flow wetlands, and root-zone systems (Cooper & Green, 1995). According to the flow direction, there are two types of subsurface flow systems, Horizontal Flow Constructed Wetlands (HFCW) and Vertical Flow Constructed Wetlands (VFCW).

- **HFCW**

HFCWs consist of gravel or rock beds sealed by an impermeable layer and planted with wetland vegetation. The wastewater is fed at the inlet and flows through the porous medium under the surface of the bed in a horizontal path until it reaches the outlet zone, where it is collected and discharged. In the filtration beds, pollution is removed by microbial degradation and chemical and physical processes in a network of aerobic, anoxic, anaerobic zones with aerobic zones being restricted to the areas adjacent to roots where oxygen leaks to the substrate. In HFCWs organic compounds are effectively degraded, suspended solids are retained predominantly and the removal efficiency is very high. For the other main removal mechanisms, we consider denitrification and dephosphatation (Vymazal, 2010).

- **VFCW**

In the VFCW, the water is fed in large batches and then the water percolates down through the medium. The new batch is fed only after all the water percolates and the bed is free of water. This enables diffusion of oxygen from the air into the bed. As a result, VFCWs are far more aerobic than HFCWs and provide suitable conditions for nitrification. On the other hand, VFCWs do not provide any denitrification. VFCWs are also very effective in removing organics and suspended solids. However, Removal of phosphorus is low (Vymazal, 2010).

1.2 Wetland macrophytes‘ role

Constructed wetlands can be classified through the types of macrophytes. The larger aquatic plants growing in wetlands are usually called macrophytes. The term includes aquatic vascular plants (angiosperms and ferns), aquatic mosses, and some larger algae that have tissues that are easily visible (Brix & Schierup, 1989).

1.2.1 Life forms of wetland plants

The macrophytes growing in wetlands may be classified in the following major groups (fig. 1) according to their life form (Brix & Schierup, 1989).

Emergent aquatic macrophytes: The plants are morphologically adapted to growing in a water-logged or submersed substrate. This life form comprises species like Phragmites australis (Common Reed) and Typha spp. (Cattails).

Floating-leaved aquatic macrophytes: These includes both species which are rooted in the substrate and species which are freely floating on the water surface like Pistia stratiotes (Water Lettuce), Lemna spp. and Spirodella spp. (Duckweed).

Submerged aquatic macrophytes: These have their photosynthetic tissue entirely submerged but usually the flowers exposed to the atmosphere. Two types of submerged aquatics are usually recognised: the elodeid type and the isoetid (rosette) type.

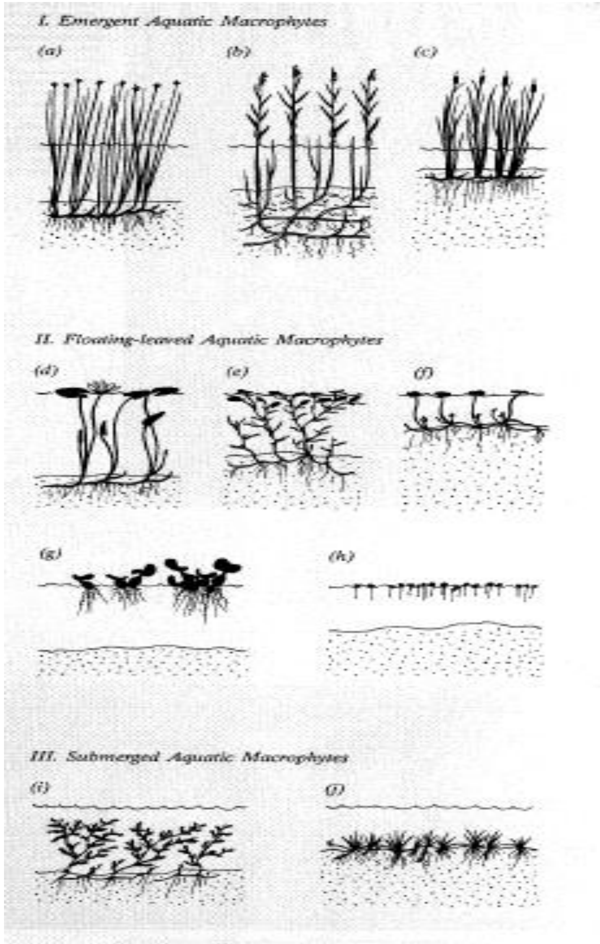


Figure 1: Sketch showing the dominant life forms of aquatic macrophytes. The species illustrated are (a) Scirpus lacustris, (b) Phragmites australis, (c) Typha latifolia, (d) Nymphaea alba, (e) Potamogeton gramineus, (f) Hydrocotyle vulgaris, (g) Eich. Source: Brix & Schierup, (1989).

1.2.2 Polluant removal mechanism

The macrophytes growing in constructed wetlands have several properties in relation to the treatment process that make them an essential component of the design (Brix & Schierup, 1989). The removal mechanism of macrophytes is divided into three major mechanisms, physical chemical and biological.

Physical processes are often used in primary treatment of traditional wastewater treatment systems. The processes are no different than in wetlands. Water that flows through wetlands moves rather slowly due to resistance from plant matter and a uniform sheet flow of water. The plants in the wetland help trap sediment but not as much as sediment that settles from lower velocity (DeBusk, 1999).

One of the most important mechanisms for pollutant removal in wetlands is done by biological means. The main and most well-known way this is done is by plant uptake (DeBusk, 1999). When plants directly uptake contaminants into their root structure, this process is called phytodegredation. For example, they can uptake and store inorganic nitrogen and heavy metals. Some plants accumulate metals significantly e.g. duckweed which canstore a huge amount of metals such as Cu, Cd and Se (Sharma et al., 2019). When plants secrete substances that add to biological degradation, this process is called rhizodegradation. The process from where contaminants entered the plants biomass and transpired through the plant leaves is called phytovolatilization (Interstate, 2003).

The last process involved in contaminant removal in wastewater wetlands is by chemical means. Sorption is the most important chemical processthat includes the processes adsorption and precipitation.Adsorption could occur through plant roots like phosphorous removal (Vymazal, 2006).

1.3 Constructed wetlands for tertiary treatment

In general, conventional secondary and tertiary wastewater treatment used for polishing effluent includes slow sand filtration, oxidation, activated sludge, trickling filter and finally disinfection methods, such as chlorination, ozonation, and UV radiation .Among those, ozonation, chlorination, and UV disinfection are the mostsuccessful technologies used for pathogen inactivation in tertiary treatment (Shingare et al., 2019). Constructed Wetlands is a sustainable and cost-effective technology that is applicable for the elimination of both pollutants and pathogens from domestic and industrial wastewater.

1.3.1 HFCW and VFCW

Contructed wetlands can be considered as a sustainable alternative to the tertiary conventional treatment of domestic and industrial wastewater, thus making it possible for reuse. Provided the minimal maintenance necessities, the easiness of operation and the decent removal performance of contaminants, the cost-effective constructed wetland technology can help to relieve the current wastewater management problem in developing countries (Thalla et al., 2019).

1.3.2 Duckweedbased wastewater treatment

Wastewater treatment using duckweed is known to be significant as an option capable of achieving effluent standards. Furthermore, existing duckweed based wastewater treatment (DWWT) systems are able to reduce concentrations of organic compounds and pathogens to acceptable levels (Smith & Moelyowati, 2001). DWWT systems have several advantages such as high nutrient removal, inhibition of algal growth, prevention of odour and insect breeding, reduction of the effect of chlorine by-products, relatively low cost and high possibility for income generation.

1.3.3 Stabilization pond

Aerobic Ponds, also called Wastewater Stabilization Ponds (WSPs) are commonly referred to as a maturation, polishing, or finishing pond because it is usually the last step in a series of ponds and provides the final level of treatment. It is the shallowest of the ponds, ensuring that sunlight penetrates the full depth for photosynthesis to occur.

A settling pond is usually placed at the beginning of the treatment series, but may also be a pond at the end of the system. The amount of time that effluent is retained in a settling pond can vary from 24 hours to some proportion of the time it takes the water to move through entire system. This can result in a hydraulic residence time (HRT) greater than 10 - 15 days. Most state standards distinguish between the two, but may not provide an explanation of the need for a correctly designed settling pond to help control algae in the effluent before it is discharged (Mara, 1997).

2. HydroFLOW© technique

2.1 The Hydropath signal

The signal that is used in all the Hydropath units has a very distinctive and easily recognized form, although the details of its size and shape will vary depending on the particular application. The signal consists of high frequency oscillations that gradually die away (decay) and then repeat at varying intervals (fig. 2). Technically, this is referred to as an exponentially decaying sine wave." This form of the signal allows us to give the ions and particles in the water a relatively large “kick" (because of the initial peaks) without using too much power (because the peaks die away). The timing of the pulses changes allowing the signal to treat all different plumbing systems (Rodrigues, 2012).

Figure 2: An example of a short section of the Hydropath Signal. The red arrow indicates the “peak-to-peak voltage". (Rodrigues, 2012).

2.2 Hydropath technology and bacteria

Hydropath technology applies a charge to any particles or bacteria, passing through the ferrite ring of a unit. Therefore, the unit applies a charge (either positive or negative) to any bacteria passing through the unit. According to Rodrigues (2012), this in turn will attract a layer of highly pure water that forms a wetting layer" or hydration layer" around the bacteria. Once this layer of water has formed, osmosis begins to act and again forces the water into the bacterial cell, bursting it.

3. Potential of aquaponics with wastewater

Aquaponics is the integration of recirculating aquaculture and hydroponics in one production system. In an aquaponic unit, water from the fish tank cycles through filters, plant grow beds and then back to the fish (McMurtry et al., 1990).

3.1 Aquaculture

3.1.1 Wastewater-fed aquaculture

In 1988 FAO, introduced a definition of aquaculture saying that aquaculture is the aquatic equivalent of agriculture or farming on land. Three categories are taken into consideration based on productive technology which is extensive, semi-intensive and intensive (Jadhav, 2009) .A package of practices for sewage-fed aquaculture has been developed to benefit fish farmers through scientific interventions, including pond environment and biotic components.

3.1.2 Water quality requirements

Aquaculture generally uses sewage water only when it is found suitable for its reuse. Systematic treatments reduce the organic load and BOD (biochemical oxygen demand); the determining factor of the degree of sewage quality. The reduction of these two factors results in an increase of DO (dissolved oxygen) and pH; the standard limit of these parameters is essential for survival and growth of fish (Lucas at al., 2019). Table 1 represents a summary of the water quality required by aquaculture.

Table 1: Summary of the water quality for aquaculture

Parameter	Unit	Requirements
pH	mg/L	6.5 - 9
DO	mg/L	>5 - 6
TAN	mg/L	<0.01
NO_3^-	mg/L	<0.5
Pb	µg/L	<3.2
Cd	µg/L	<1.1
Aldrin	µg/L	0.003
Chlordane	µg/L	0.0043
DDT	µg/L	0.001
Dieldrin	µg/L	0.0019
Endrin	µg/L	0.004 - 0.0023
Heptachlor	µg/L	0.0038
Toxaphene	µg/L	0.005 - 0.0002

Source: Lucas at al., (2019)

3.2 Hydroponics

3.2.1 Wastewater-fed hydroponics

According to the FAO, hydroponics and soil-less system consist of not using soil as substrate for crop production (FAO, 2006).Integration of hydroponic cultivation into a wastewater treatment system has been proposed as an ecological alternative, where nutrients can be removed from wastewater (Bawiec et al., 2016). Hydroponic production systems have potential for the treatment of domestic wastewater and reuse of wastewater in intensive systems (Keeratiurai, 2013).

3.2.2 Water characteristics

Wastewater-fed hydroponics depends mainly on the water quality. Before use and before leaving the installation pathogens must be eliminated. Moreover, water quality should be uniform over the year”. In general, hydroponics requires a much higher quality water to feed the plants compared to traditional soil grown crops. In table 2, quality parameters are settled for Hydroponics.

Table 2: Water components and their limits in use for hydroponics

Parameter	Units	Degree of restriction on use		
		None	Slight to Moderate	Severe
EC	dS/ m	0 - 0.75	0.75 - 2.25	>2.25
Bicarbonates	mol /m^3	0 - 2 (0 - 120)	2 - 6 (120 - 360)	>6 (>360)
Nitrates	mol /m^3	<0.5	0.5 - 2	>2
Ammonium	mol /m^3	0	0.1 - 1	>1
Phosphorus	mol /m^3	<0.3	0.3 - 1	>1
Potassium	mol /m^3	<0.5	0.5 - 2.5	>2.5
Calcium	mol /m^3	<1.5	1.5 - 5	>5
Magnesium	mol /m^3	<0.7	0.75 - 2.25	>2
Sodium	mol /m^3	<3	3 - 10	>10
Chloride	mol /m^3	<3	3 - 10	>10
Sulfates	mol /m^3	<2	2 - 4	>4
Iron	mmol /m^3	-	-	>90
Boron	mmol /m^3	30	30 - 100	>100
Cupper	mmol /m^3	-	-	>15
Zinc	mmol /m^3	-	-	>30
Manganese	mmol /m^3	-	-	>10

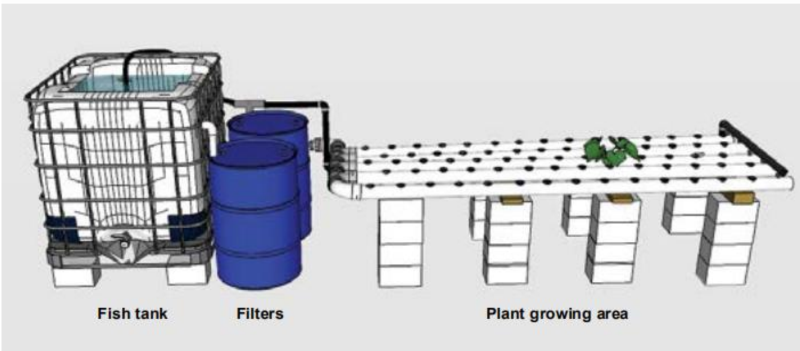
Source: De Kreij *et al.* (1999)

4. Aquaponics

4.1 Reclamation of wastewater

In a study conducted by Rana et al., (2011), wastewater reclamation by aquaponics proved to be effective. Anyway, there are three main types of aquaponics: the nutrient film technique (NFT) method (fig. 3.a); the deep water culture (DWC) (fig. 3.b) method; and, also known as the raft method or floating system and the media bedmethod, also known as particulate bed (fig. 3.c).The essential components for all aquaponic units are: the fish tank, the mechanical and biological filtration, the plant growing units (media beds, NFT pipes or DWC canals), and the water/air pumps. Differences between the three techniques and their requirements are well represented by Somerville et al., (2014).

- **Nutrient film technique (NFT) Units:** mechanical and biofiltration components are necessary along with high DO concentration.
- **Deep Water Culture (DWC) Units:** mechanical and biofiltration components are also necessary. Each canal should have a minimum retention time of 2–4 hours High DO concentration is also essential.
- **Media bed units:** made of strong inert material have a depth of about 30 cm provide separate zones for different organisms to grow. It depends on both high DO concentration and sufficient water quantity.



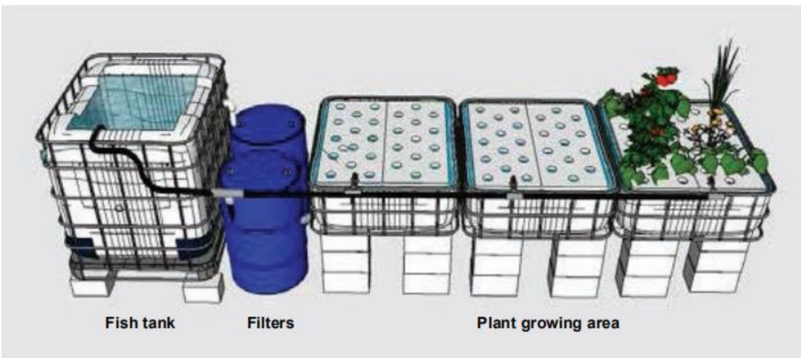


Figure 3: Illustration of different aquaponic designs. Source :Somerville et al., (2014).

4.2 Water quality

There are five key water quality parameters for aquaponics: dissolved oxygen (DO), pH, water temperature, total nitrogen concentrations and hardness (KH). Knowing the effects of each parameter on fish, plants and bacteria is crucial. Therefore, water testing is essential to maintain the good health and well being of fish and plants growth in aquaponic systems (FAO, 1985). In table 3, we represent a summary for water quality requirements in aquaponics.

Table 3: Summary of water quality requirements for different components of Aquaponics

Organism Type	Temp (°C)	pH	KH (mg/litre)	Ammonia (mg/litre)	Nitrite (mg/litre)	Nitrate (mg/litre)	DO (mg/litre)
Warm water fish	22 - 32	6 - 8.5	60 - 140	<3	<1	<400	4 - 6
Cold water fish	10 - 18	6 - 8.5	60 - 140	<1	<0.1	<400	6 - 8
Plants	16 - 30	5.5 - 7.5	60 - 140	<30	<1	-	>3
Bacteria	14 - 34	6 - 8.5	60 - 140	<3	<1	-	4 - 8
Aquaponics	18 - 30	6 - 7	60 - 140	<1	<1	5 - 150	>5

Source: FAO, (1985)

Chapter II: Materials and Methods

1. General framework: GDA Sidi Amor

Originally established around fifteen years ago, the Agricultural Development Group of Sidi Amor (GDA Sidi Amor) is a local NGO which is collectively owned by a group of skilled and competent activists, which has given itself the mission of the promoting and the development of the local natural resources of its territory, as well as landscape rehabilitation.

1.1 Location

It is located in a peri-urban forest area namely Djebel Sidi Amor Boukhtioua (fig. 4) which is part of the commune of Raoued (Governorate of Ariana), at about 15 km from the north of Tunis City. It covers a total area of 4 hectares.

Figure 4: Presentation of study area in GDA Sidi Amor, (Google Earth Pro, 2020)

1.2 Climate characteristics

GDA Sidi Amor area is located in the superior semi-arid region climate. The main reference station for climatological conditions follow-up is made by the INRGREF's Cherfech station.

Rainfall data gathered over the course of 40 years (1965-2005) states that the annual average of precipitation is 480 mm. Humidity is high from September to May and he average values recorded between 8 am and 4 pm oscillates between 66% and 80%. The study area is characterized by hot summers and mild winter, with an average annual temperature of 18°C. The lowest temperatures are recorded from December to March while the highest temperatures from June to September. Annual evaporation average measured by a Piche Evaporimeter is about 1306 mm.

1.3 Water resources

The activities at GDA Sidi Amor are diversified and are based among other on irrigated agriculture. Furthermore, these activities are highly dependent on water resources. The GDA has two resources, one conventional and the other unconventional recently developed.

- **Conventional water resources:** A solar-powered pump allows feeding a water tank located at the top of the hill of Sidi Amor (about 70 cubic meters at an altitude of 100 m) and allows water supply by gravity for different local uses agricultural and domestic. Water salinity is approximately of 1.2 g / l.

- **Non-conventional water resources:** GDA Sidi Amor initiated 5 years ago a pilot WWTP setup (as a tertiary treatment) to enhance the quality of a share of the treated wastewater (secondary effluents) stored in a reservoir (3,800 m^3) built in 1989 at the top hill overlooking Sidi Amor forest area. Post-treated wastewater meets national reuse standards and currently used for the development of irrigated agriculture and agroforestry.

2. WWTP of Sidi Amor

Sidi Amor’s pilot project consists of the implementation of complementary treatments constructed wetlands namely “Sidi Amor WWTP” for water quality improvement given the insufficiency of the current secondary effluents quality to support safe reuse in agriculture. Post-treated wastewater serves for irrigation of 7.5 ha distributed between the GDA Sidi Amor and 3 farmers' members of the project.

2.1 WWTP system

The main components of the WWTP Sidi Amor are (fig. 5):

- Horizontal flow constructed wetlands 1 (HFCW1)
- Horizontal flow constructed wetlands 2 (HFCW2)
- Stabilization Pond
- Buffer Tank (as storage facility of treated wastewater)

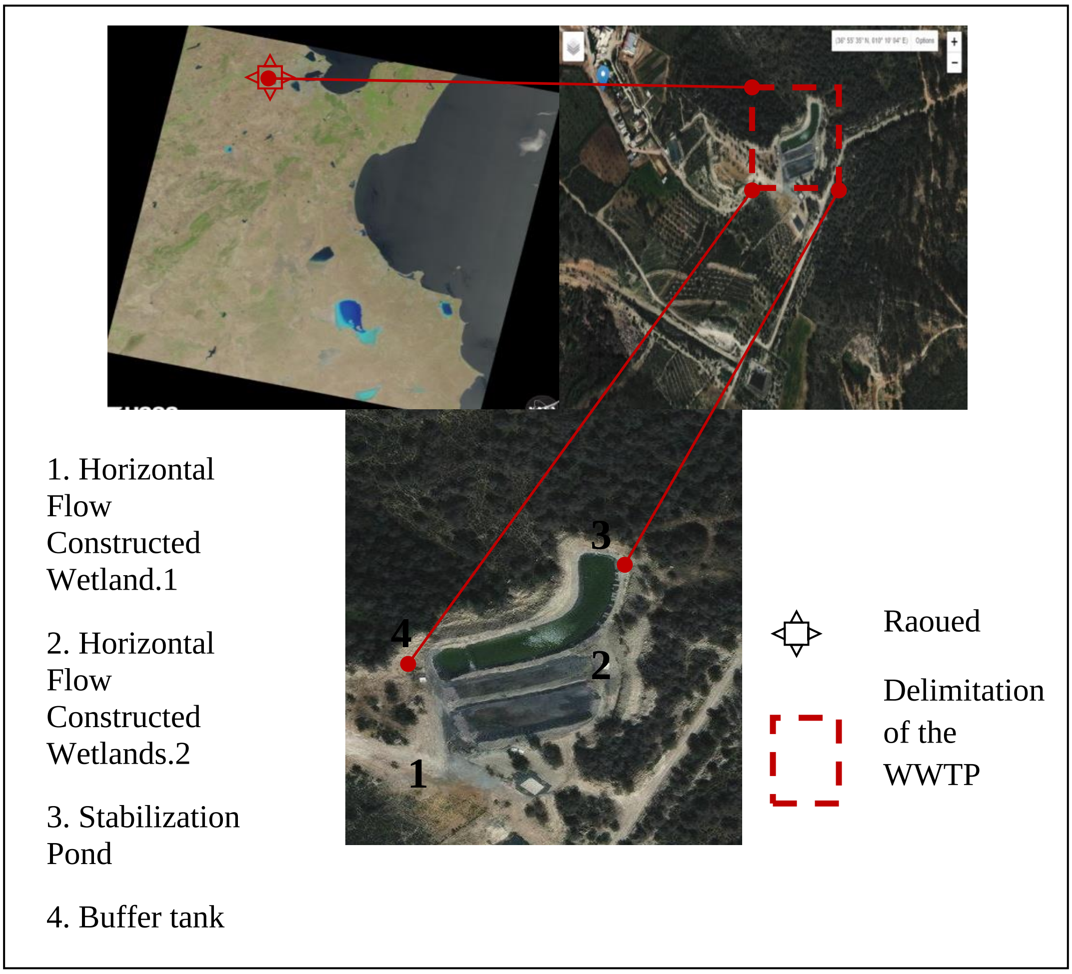


Figure 5 : Presentation of the WWTP in GDA Sidi Amor, retrieved from satellite imagery Landsat 8. Source: (USGS, 2020)

The system characteristics were retrieved from the ONAS reports (2015). Tables below represent the basic characteristics for the WWTP components. The daily capacity of the station is around 520 cubic meters per day and the sizing was carried out based on the following data:

COD = 160 mgO2/l

BOD5 = 100 mgO2/l

SS = 100 mg/l

Table 4: Characteristics of the WWTP

Dimension	HFCW1	HFCW2	SP
Length (m)	47,1	62.6	91,2
Width (m)	17,66	10.6	12,7
Height (m)	0.6	0.6	1,2
Effective Area (m^2)	751,03	663.56	1158,2
Base Area (m^2)	624	620	1035
Volume (m^3)	397.66	398.14	1389.88

2.2 Water quality data processing

The WWTP commissioning started in November 2017. For the purpose of this case of study, water quality data were collected from previous effluent quality analysis. The main efforts gave access to a database that provides an indication for posterior post-treatment essential techniques. Basically, the ONAS analysis monthly routine gave constructed a database, along with some added values.

In order to facilitate this task, a statistical software entitled InfoStat© was used to establish descriptive statistical results and to calculate the performance rates of the WWTP facility of GDA Sidi Amor.

InfoStat© is a general-purpose software for statistical analysis for Windows. It covers all the basic needs for descriptive statistical analysis and the production of graphs for the exploratory analysis. It is also connected to R, which facilitate its use.

Using the software InfoStat©, the statistical analysis of our database gathers the following information:

- A time series from 2017 until 2020
- 5 sample points, as shown in table 5

Table 5: Sample points of the database

Sample point	Indication
inlet	1
HFCW1	2
HFCW2	3
Stabilization pond	4
buffer tank	5

In this section, the results are discussed mainly for sample point 5. A comparison between the inlet and the outlet quality is crucial to analyze the performance of the WWTP.

3. Complementary Treatments' sets

In order to support both water quality requirements and safe wastewater-fed aquaponic system, a further post-treatment facility was established. The proposed approach consists of a vertical flow constructed wetland, a duckweed grow bed and two HydroFLOW© devices. The post-treated wastewater would thus serve to feed the projected aquaponics system.

3.1 Water supply line

The water source is derived from an irrigation existing system in GDA Sidi Amor, which was established recently in order to maintain the needs for TWW based activities. For flow rates assessments, we decided to simulate the TWW dynamics in the irrigation pipelines using EPANET 2.0 software. EPANET 2.0 is a software application used throughout the world to model water distribution systems. In this section, the main purpose for this simulation is to approach the inlet flow of our small-scale aquaponic system.

The inputs for the network are:

- Pipelines diameters and lengths
- Topographic technical sheet
- Base demand for each node in the system

3.2 VFCW setup

The VFCW is a low-cost treatment facility that could be the first post-treatment step in the system. The purpose of the VFCW is to get rid of suspended solids and other components such as phosphorus and organic matter. The design is inspired in part by the work of Stefanakis et al. (2014).

- **Type choice**

The design of the VFCW (as modified) is influenced by previous work on the so-called French system based on gravel media layers. The choice of gravel is explained by the water source quality which is relatively quite fluctuating especially organic matter and suspended solids. The feeding strategy for VFCW is intermittent loading which compromises both feeding and resting period with a downflow water supply that goes from the surface to the bottom. Initially, the VFCW is unplanted and works as a compost bioreactor, but it should be planted next (to be confirmed).

- **Sizing parameters**

For the VFCW, the main characteristics are possibly:

- **Organic Loading Rate (OLR):** It indicates the amount of volatile solids to be fed into the digester each day. Volatile solids represent that portion of the organic-material solids that can be digested, while the remainder of the solids is fixed. It is measured in g $BOD_5/m^2/d$ or g $COD/m^2/d$.

  $$\mathbf{OLR = Q \times COD}$$

  Where:

  OLR: g COD/m^2/d

  Q: m^3/d

  COD: mg/l

- **Hydraulic Loading Rate (HLR):**is defined in a wastewater treatment process unit as the volume of wastewater applied to the surface of the process unit per time period. It is often expressed in m3/m2/d or m/d. In temperate climate, 120 l/day is suitable (Stefanakis et al.,2014).
- **Unit Area Requirement:** Generally, it is measured by m^2/person. In our case study, we chose to work on 1.1 m^2.

- **Media Porous Layers:** Clogging is one of the main problems common in constructed wetland systems. The key factor for the proper operation and performance is the maintenance of an adequate hydraulic conductivity. We decided to construct a three layer Khadel gravel bed at various dimensions with a total media depth of 80 cm; from the top to the bottom:
    - **40 cm grain size 4 mm**
    - **20 cm grain size 8 mm**
    - **20 cm grain size d(4/30)**
- **Water inlet and outlet:** depending on the inlet water flow, a certain elevation is required to maintain the hydraulic dynamic inside the system, whereas the water flow is lead by gravitation. For the outlet, a drainage layer is built up through the coarse gravel layer (4/30) in which three drainage pipes are connected on one side to a 40mm collection pipe that discharges the effluent. The drainage system is passively aerated by vertical pipe (32mm) extending 0.3m over the filter bed surface (Brix & Arias, 2005).

3.3 Duckweed pond

- **Specie choice**

Duckweed (Lemnaceae) is a family of floating monocotyledons consisting of 4 genera (Lemna , Spirodela, Wolffia and Wolffiella) and 28 species. They are green and have a small size (1-3 mm). They also have short but dense roots (1-3 cm). Duckweed grows on a wide range of quiescent or slow-current waters, and also relatively polluted waters, saline waters and eutrophic water bodies. Typical pH range is 4.5-7.5 is very sufficient. Duckweeds are able to grow at water temperatures as low as 5-7°C.

Water lances of *Lemna gibba* have been proved to be extremely effective in terms of heavy metals, organic matter and bacterial removal (Al- Hashimi & Joda, 2010).The implementation of a duckweed grow bed should support the hypothesis of its capacity to filtrate heavy metals, and other (micro)-polluants, especially when the VFCW is unplanted, which expresses the need for a phytoepuration complementary treatment.

- **Sizing parameters**
    - **Hydraulic Loading Rate (HLR):**is defined in a wastewater treatment process unit as the volume of wastewater applied to the surface of the process unit per time period. It

is often expressed in m3/m2/d or m/d. For our case study, the duckweed pond operates with 120 l/m2/d.

- **Unit Area Requirement:** Generally, it is measured by m²/person. In our case study, we chose to work on 1.1 m² (Stefanakis et al.,2014).
- **Hydraulic retention time (HRT)** for reducing organic materials depends on the influent BOD. HRT influences the performance of treatment, the yield and the protein content of duckweed produced. The longer the retention time, the higher the efficiencies of treatment in reducing pathogens, but this causes more anaerobic conditions and lower protein content of duckweed produced.

Hydraulic Retention Time (d) = Volume/HLR

Where: Volume: (m^3)
HLR: ($m^3/m^2/d$)

- **Water depth:** There are no exact values for water depths to produce high treatment performance but shallow ponds are likely to be better than deep ponds, low water depths between 0.2 and 0.6m are likely to be most suitable to minimize temperature gradients over the depth of the pond. In this case, a 0.25m depth is suitable (Mandi, 1994).
- **BOD/COD loading**: DWWT is designed on the basis of volumetric BOD or COD loading due to the possible anaerobic process underneath the duckweed mat. Mandy's experiment proved that DWWT ponds tolerate maximum influent COD concentrations from 300 to 500 mg/l (Mandi, 1994). The formulae for organic loading are mostly dependent on temperature as written below:

BOD loading rate (λv, $g/m^3/d$) are as follows: (where T is temperature, ºC)

90% of BOD removal $\lambda = 0.2995\ T + 3.3308\ R^2 = 0.8465$

95% of BOD removal $\lambda = 0.2302\ T + 2.5601\ R^2 = 0.8465$

3.4 HydroFLOW©

HydroFLOW© is a commercially available Electromagnetic field (EMF) device typically includes a signal generator and a treatment module. It basically operates in a way or another to maintain a certain quality of the water depending on the device characteristics (Piyadasa *et al.,* 2017). HydroFLOW© has been proved to be effective when it comes to the disinfection of wastewater. It is important to note that an electric field is applied to the pipe (as opposed to magnetic field). This is what makes the technology so much more effective than magnet based conditions (Rodriquez, 2012). HydroFLOW© devices have the following impacts:

- Prevention of limestone structuring
- Algae and bacteria elimination
- Flocculating effect
- Decrease of corrosion

We chose to work with HydroFLOW S38© and HydroFLOW K40© devices. Each device has a specific role depending on its position in the system (Table 6).

Table 6: HydroFLOW® devices impacts on the unit

	HydroFLOW K40	**HydroFLOW S38**
Impact on the unit	prevents floculation and eliminates bacteria, enhances the water agregation	maintain the electrical chain in the system, enhances bacterial removal in a recycling aquaponic system

Source: Balazoo, (2013)

4. Aquaponics setup

The calculations are based on the FAO technical sheet for small-scale aquaponic systems (Somerville et al., 2014).

4.1 Design and sizing

Before designing an aquaponic system, general requirements are needed to obtain the optimal conditions for fish and plants, which are:

- Stability
- Less exposure to wind, rain and snow
- Exposure to sunlight and shade
- Utilities, fences and ease to access

4.1.1 Design

For a post-treated wastewater based aquaponic system, it can create controversial subjects around restricted crops in terms of local reuse standards.

- **Fish**

The chosen specie is Common carp *(Cyprinus carpio)*. Carp are tough and able to survive even in low water quality compared to other fish, making them a great option for aquaponic environments.

- **Plants**

With the same perspective, the plants choice must be quite related to the main activities of the whole site. GDA Sidi Amor is well known for its rose's protection and multiplication. Therefore, the cut roses are a good choice for such educational purposes.

4.1.2 Sizing

- **Calculating the amount of ammonia and biofilter media for an aquaponic unit**
    - **Calculating assumptions**

All calculations are based on a small-scale media bed unit, with 3 m² of growing space and 1000 litres of fish tank space (Somerville et al., 2014).

- Fish = Common carp
- Plants = Cut roses.

Representing the following parameters:

- Total Ammonia Nitrogen (TAN) produced by fish feed
- Conversion Rate of Ammonia to Nitrate by bacteria

    - **Determining the amount of ammonia produced by feed**

- 20 kg of fish in a 1000 liters IBC, eating 1% f their body weight/ day (200 g of fish feed).
- 200 g feed (32% protein, 4.5% of Ammonia produced)

$$200\ g\ feed\ \times \frac{32\ g\ protein}{100\ g\ feed} \times \frac{16\ g\ nitrogen}{100\ g\ protein} \times \frac{61\ g\ wasted\ nitrogen}{100\ g\ total\ nitrogen} \times \frac{1.2\ g\ NH3}{1\ g\ nitrogen} = 7.5\ g\ ammonia$$

- **Determining the amount of biofilter media needed by nitrifying bacteria**

Providing a 200 g daily feed rate, it is necessary to provide bacteria with an operating surface area of 13.3 m² (1 m^2 can eliminate 0.57 g of ammonia so the following equation give as the total SSA needed).

$$7.5\ g\ ammonia\ \times \frac{1\ m^2}{0.57\ g\ ammonia} = 13.3\ m^2$$

The Surface for bacteria can be obtained from a wide range of choices, each with a specific surface area (SSA), measured in (m²/m^3).

Pumice and volcanic gravel are light and they can provide good root support. They are riddled with holes and air-passages, like a sponge, so have a better SSA than actual rock, making them more conductive to bacterial growth.The Volcanic gravelhas an SSA of 300 m²/$\boldsymbol{m^3}$. In our case study, pumice will cover two media grow bed (MFG) filter, with 21.5cm depth each.

The following equation calculates the volume of tuff needed:

$$13.3\ m^2\ \times \frac{1\ m^3}{300\ m^2} = 0.0443\ m^3$$

$$\frac{44.3\ litres\ tuff}{200\ g\ feed} : \frac{1\ litre\ tuff}{4.5\ g\ feed}$$

The system design described in this study has a tuff volume of 400 liters, almost 10 times higher than the volume needed to process the ammonia produced from 200 g of feed.
The main variables to consider when balancing a unit are:

- At what capacity will the system function.
- Method of aquaponic production.
- Type of fish (carnivorous vs. omnivorous, activity level).
- Type of fish feed (protein level).

- Type of plants.
- Type of plant production (single or multiple species).
- Environmental and water quality conditions.
- Method of filtration
- The following table represents the needed values needed for balancing calculations.

Table 7: Balancing the components: fish and plants

Plants	fruiting vegetables
40 - 50 g of fish feed per square meter	50 - 80 g of fish feed per square meter
20 - 25 plants per square meter	4 plants per square meter
fish feeding rate	
1 - 2 % of total body weight per day	

Source: Somerville *et al.,* (2014)

Roses require 6 weeks to grow once the seedlings are transplanted into the system, and 25 cuttings per week are harvested (Somerville *et al.,* 2014), therefore:

$$25\ cuttings/week \times 6\ weeks = 150\ heads\ in\ system$$

Each 25 cuttings of roses require 1 m² of growing area space, therefore:

$$150\ heads\ \times \frac{1\ m^2}{25\ cuttings} = 6\ m^2$$

Each square meter of growing space requires 50 g of fish feed per day, therefore:

$$6\ m^2\ \times \frac{50\ grams\ feed/day}{1\ m^2} = 300\ grams\ feed/day$$

The fish (biomass) in a system eats 1 – 2 percent of their body weight per day, therefore:

$$200\ grams \frac{feed}{day} \times \frac{100\ grams\ fish}{1 - 2\ grams\ feed/day} = 10 - 20\ kg\ of\ fish\ biomass$$

After identifying the sizing parameters, a simulation through EPANET 2.0 took place to verify the water dynamics through the system.

4.2 Material supply

According to the FAO technical guide for aquaponic low-cost constructions (Somerville *et al.*, 2014), the supply is based on local materials. Therefore, established at the previous sizing steps, we define the needed materials for each component in the small-scale unit, as represented in annex 1.

4.3 Implementation steps

The small-scale aquaponic system has several steps during the setting up phase. We can organize them into two categories:

- Environment organization
- Handiwork assistance. The main steps are mentioned in annex 2 with their corresponding pictures.

Chapter III: Results and discussion

1. Performance of Sidi Amor' WWTP

1.1 Descriptive statistics

InfoStat© software performs a descriptive statistical analysis for our case study (Table 8). The following table indicates mean, standard deviation, minimum and maximum values of some water quality parameters (pH, conductivity, salinity, turbidity, COD, BOD_5, suspended solids, kjeldahel nitrogen, total phosphorus and fecal colifroms) as well as the performance rates of the WWTP.

Table 8: Summary statistics of the effluent quality

	Summary statistics WWTP inlet				Summary statistics WWTP outlet			
Variable	**Mean**	**S.D.**	**Minimum**	**Maximum**	**Mean**	**S.D.**	**Minimum**	**Maximum**
pH	7,45	0,31	6,58	8,37	7,76	0,6	7,19	9,2
Conductivity (µS/cm)	3470	372,55	2850	4120	3558,43	1155,48	1410	7615
Salinity (mg/L)	2,23	0,23	1,88	2,68	2,15	0,49	1,46	4,03
Turbidity (NTU)	20,94	7,07	11,8	38	9,68	2,95	6	17,6
COD (mg O2 /L)	153,93	177,7	29,5	800	76,31	93,77	29,5	600
BOD5 (mg O2 /L)	49,88	65,31	3	380	30,47	81,87	6	470
SS (mg/L)	78,69	139,02	26	790	21,02	10,14	6,1	46
NTK (mgN/L)	26,71	17,13	12,3	85,1	8,91	4,53	3,7	18,7
Total Phosphorus (mg/L)	2,25	1,05	1,12	4,9	0,61	0,55	0,07	2,07
Fecal Coliforms (logCFL/100 mL)	5,14	0,89	3,97	7,06	3,96	1,51	1,56	6,06

Source: InfoStat© (2020)

The WWTP demonstrated the ability to reduce turbidity by 58.7%, COD by 47.2%, suspended solids by 92.7%, kjeldahel nitrogen (NTK) by 73.5%, total phosphorous by 47.6% and a low fecal coliforms removal rate. Compared to a case study conducted by Steyo, (2013), the removal efficiency of a HFCW planted with Phragmatis Australis, reaches the following values: 71% BOD5, 58% COD, 95% total phosphorous and 92% fecal colifroms. Besides, performance rates of Sidi Amor WWTP were lead by the influent quality fluctuation over the years. The effluent quality (sample point 5), overcomes the water quality limit concentrations in mg/l indicated in the national Tunisian standards for wastewater reuse (NT 106.03): 90 COD, 30 BOD_5 and 30 SS. Overall, the effluent water quality doesn't meet the aquaponics requirements (table 8), which leads to the setup of post-treatment advanced techniques.

Table 9: Target ranges for each parameter for fish requirements

Parameter	Range
pH	6_7
Water temperature	18 - 30 °C
DO	5_8 mg/l
Ammonia	<1 mg/l
Nitrite	<1 mg/l
Nitrate	5 - 150 mg/l
KH	60 - 140 mg/l

Source :Somerville *et al.,* (2014)

1.2 Partial conclusion

The Sidi Amor WWTP represents the perfect geographical framework for a small-scale aquaponic system based on wastewater reuse and low-cost configurations. Therefore, it would be worth to rethink the management of peri-urban farming with wastewater through innovative value-added activities adapted to local context. Aquaponics seems to be a promising approach to revive the local interest of reusing wastewater in agriculture and aquaculture. However, advanced treatment steps are required to meet the aquaponics target ranges for water quality parameters.

2. Constructed wetlands' techniques technical sheets

2.1 Water line supply

The results are represented in figure 6 and in annex 1. The final available flow for the aquaponic system is estimated by 0.52 l/s.

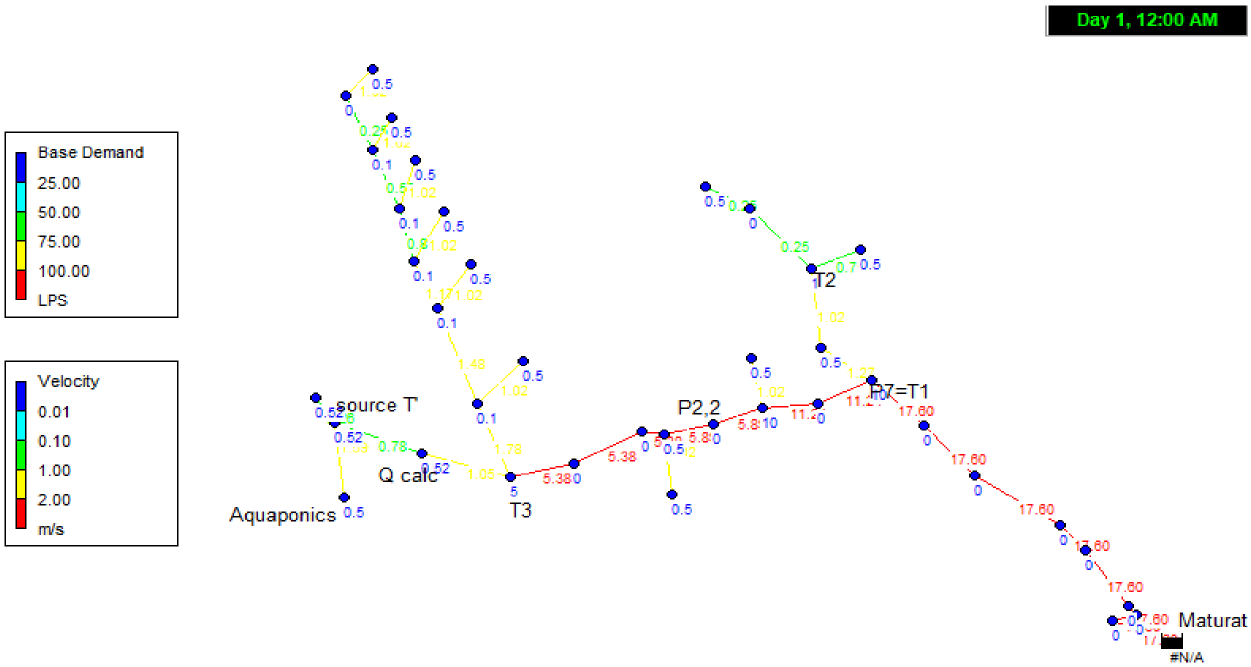


Figure 6: simulation of the irrigation pipelines established in GDA Sidi Amor. Source: EPANET 2.0

In some nodes in the irrigation system, the velocity is higher than 2 m/s, which can cause some damage on the network pipelines. This simulation was conducted to estimate the flow available value for our aquaponic system.

2.2 VFCW technical sheet

Figure 7 represents the proposed VFCW design. Organic Loading Rate is (OLR) is an important parameter. For our case, it reaches 9.16 gCOD/day. According to Stefanakis et al., (2014), the French system with a 1.1 m² area and a 120 l/day hydraulic loading rate can remove 20g COD/day. However, our system receives an influent with 76.31 mg/l COD value. In this case, our system is oversized. With the corresponding values and fluctuation of the effluent quality, it is assuring the maximum performance rate of the VFCW.

Hydraulic Loading Rate (HLR). In warmer climates, HLR increased up to 120l/day, which is the case for our system.

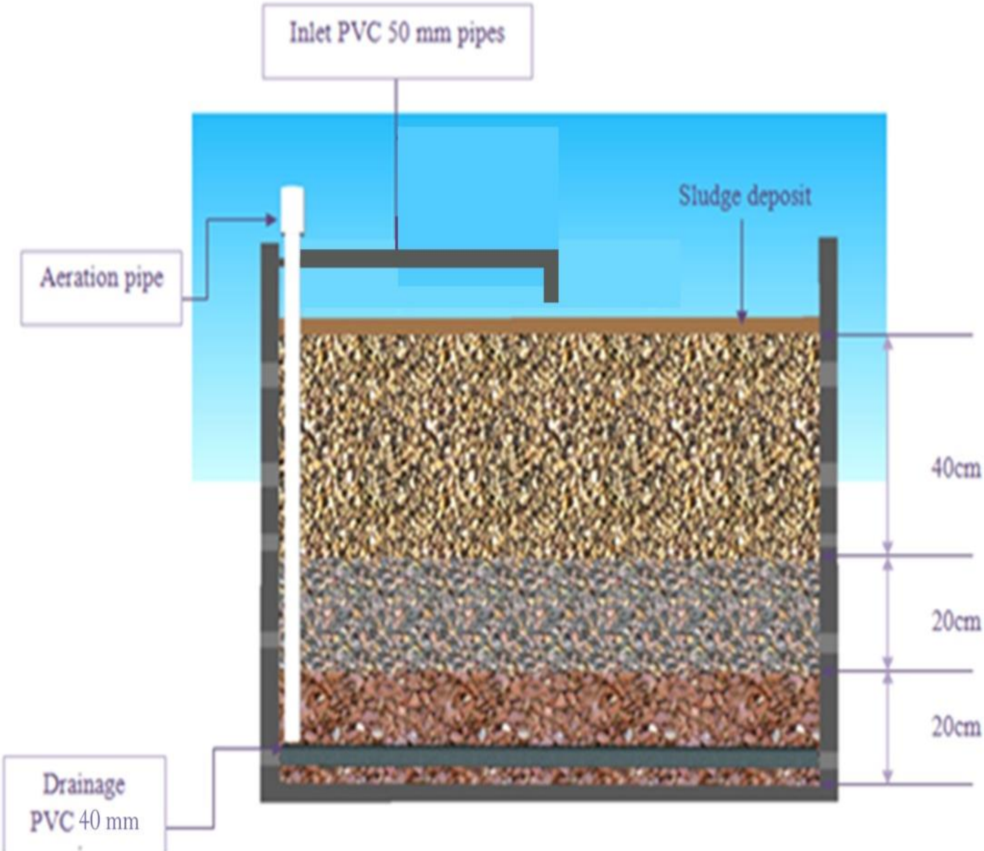


Figure 7: Transversal section of the Vertical Flow Constructed Wetland. Source: Sketchup 2020

By intermittently dosing the wetland (twice per week for our case), the filter goes through stages of being saturated and unsaturated, and, accordingly, different phases of aerobic and anaerobic conditions. During a flush phase, the wastewater percolates down through the unsaturated bed. As the bed drains, air is drawn into it and the oxygen has time to diffuse through the porous media. The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation.

With a planted VFCW, the top layer is planted and the vegetation is allowed to develop deep, wide roots, which permeate the filter media. The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics. From our perspective, the VFCW will be planted in order to ensure its performance capacity (to be confirmed).

Regards the other parameters, they were established according to our local available materials (1.1 × 1). Following the setup concept for the VFCW, a technical sheet (Table 10) was established gathering the geometric and hydraulic characteristics of the system.

Table 10: Technical sheet of the VFCW

Dimension	**Value**
Area (m^2)	1,1
Length (m)	1,1
Width (m)	1
Height (m)	0.8
Water inlet level (m)	0,9
Water outlet level (m)	0,70
OLR (gCOD/day)	9,16
HLR (l/day)	12

2.3 Duckweed grow bed conception

Al- Hashimi & Joda, (2010) developed a 1.89 m² duckweed grow bed, using *Lemna gibba***,** with a hydraulic retention time of 3 days. Water lances of *Lemna gibba* have been proved to be extremely effective in terms of some heavy metals, organic matter and bacterial removal. Here are some performances rates: (87% Cu, 85% Zn, 27% Cd, 59% BOD, 54% COD, 63% TSS, 63% NH_3 – N, 93% Fecal coliforms).

For our unit, we establish a 1.1 m² surface, according to the available local materials, with a 2.29-day hydraulic retention time, a 9.258 BOD removal (90%), a HLR estimated by 120 l/day and a water height estimated by 0.25 m.

According to the previous researches with *Lemna gibba*, our grow bed provides a sufficient treatment efficiency. Table 4 represents the duckweed grow bed technical sheet (Table 11).

Table 11: Technical sheet of the Duckweed grow bed

Dimension	**Value**
Area (m^2)	1,2
Length (m)	1,2
Width (m)	1
Water depth (m)	0.25
OLR (g/d)	9.258
HLR (l/d)	120
HRT (d)	2.29

Duckweed unit was chosen to eliminate heavy metals. Analysis survey is crucial to obtain the performance of the unit.

2.4 Partial conclusion

Constructed wetlands are meant to be applicable for low-cost techniques and systems, Within the last decades, it was made gradually clear that using near-nature technically modified ecosystems, like ponds and wetlands, is an appropriate and attractive option for an economic and environmentally friendly treatment of wastewater. The justification for each unit choice is related its impact on the effluent quality. From our perspective, VFCW gets rid of suspended solids and minimizes the organic load and duckweed grow bed purifies the heavy metals and pushes the process for HydroFLOW© devices inlet quality. The main objective is to prevent flocculation and to eliminate the bacteria. The configuration of the unit can be optimized depending on the performance rates.

3. Innovation by combination

3.1 Post-treatment techniques combination

In our case of study, physical operations are maintained within the primary and secondary treatment in the STEPs. These treatments have shown to be very economic and reliable systems for most cases like municipal wastewater. There are, however, cases in which effectiveness of these treatments drops (soluble substances for physical separation, non biodegradable and/or toxic substances for biological ones).

For this last case, advanced treatments are needed in order to meet local and international standards in terms of wastewater reuse and effluent discharge. With the hybrid combination between the HFCW and the VFCW, we managed to get rid of suspended solids and most commonly effective rates of organic and mineral matter. At this point, the post-treated wastewater doesn’t meet the aquaponic system standards, which drove us to innovate and add a phytoepuration grow bed where the majority of heavy metals are eliminates through the duckweed capacity of absorption. In the present study the efficiency of duckweed (Lemna gibba L.) as an alternative cost effective natural biological tool in wastewater treatment in general and eliminating concentrations of both nutrients and soluble salts was examined in an outdoor aquatic systems.

The present configuration gave us a second throught about the system: Is the actual quality sufficient to meet the standards for an aquaponic system? In order to make sure that the fish/plant combination won't have any risk assessed, an extra treatment unit is needed to provide a 100% assurance in terms of water quality.

HydroFLOW© technique drives a signal in the water. It is important to remember that the signal actually travels through the water itself: water conducts electricity as long as it has ions dissolved in it (Rodrigues, 2012). The signal travels in both directions, i.e. upstream and downstream, at close to the speed of light. The signal travels so fast that as far as the signal can tell, the water is still. This is why the signal travels as well upstream as downstream and also why the signal can travel through static water just as well as through moving water. (Rodrigues, 2012).

Hydropath® technology applies a charge to any particles or bacteria, passing through the ferrite ring of a unit. Therefore, the unit applies a charge (either positive or negative) to any bacteria passing through the unit. According to Rodrigues (2012), this in turn will attract a layer of highly pure water that forms a wetting layer" or hydration layer" around the bacteria. Once this layer of water has formed, osmosis begins to act and again forces the water into the bacterial cell, bursting it.

The purpose of this study was to test the efficiency of a HydroFLOW S38© and HydroFLOW K40© units for wastewater disinfection for the aquaponic system. The following are the major findings of the study of Blazo (2013). First, the HydroFLOW© unit was unable to remove E. coli in a continuous flow reactor without recirculation for detention time lower than or equal to 10 minutes and the removal efficiency of the unit increases with time. This study shows that the HydroFLOW© unit is effective to kill bacteria. However, an adequate reactor design must be made in order to achieve a higher killing efficiency at a reasonable detention time in order for this system to be competitive with conventional chlorination.

3.2 Partial conclusion

Optimal wastewater treatment is today's challenge. On one hand there are very different kinds of wastewater compositions, in the other hand there are many different kinds of possible treatments. Depending on water quality, final requirements and economical aspects some processes are better suited than others for each case.

4. Wastewater-fedaquaponics design and optimization

4.1 Design and optimization

Following the FAO technical sheet, the following results for the configuration are:

- 20 kg of fish in a 1000 liters IBC, eating 1% f their body weight/ day (200 g of fish feed). For our case, 800 liters is the maximum capacity for our fish tank
- 200 g feed (32% protein, 4.5% of Ammonia produced)
- Total Ammonia Nitrogen (TAN) produced by fish feed, estimated by 7.5g
- Conversion Rate of Ammonia to Nitrate by bacteria expresses the need for 13.3 m² of SSA
- 400 liters of pumice, that is 10 times higher than the needed SSA. The configuration has two MFG, each with 200 liters of pumice as a media. It gathers three roles: mechanical, biological filtration along with a plantation base.
- 40 – 50 g of fish feed per square meter, which can develop 20 – 25 cut roses per square meter

Figure 8 represents an illustration for the whole system.

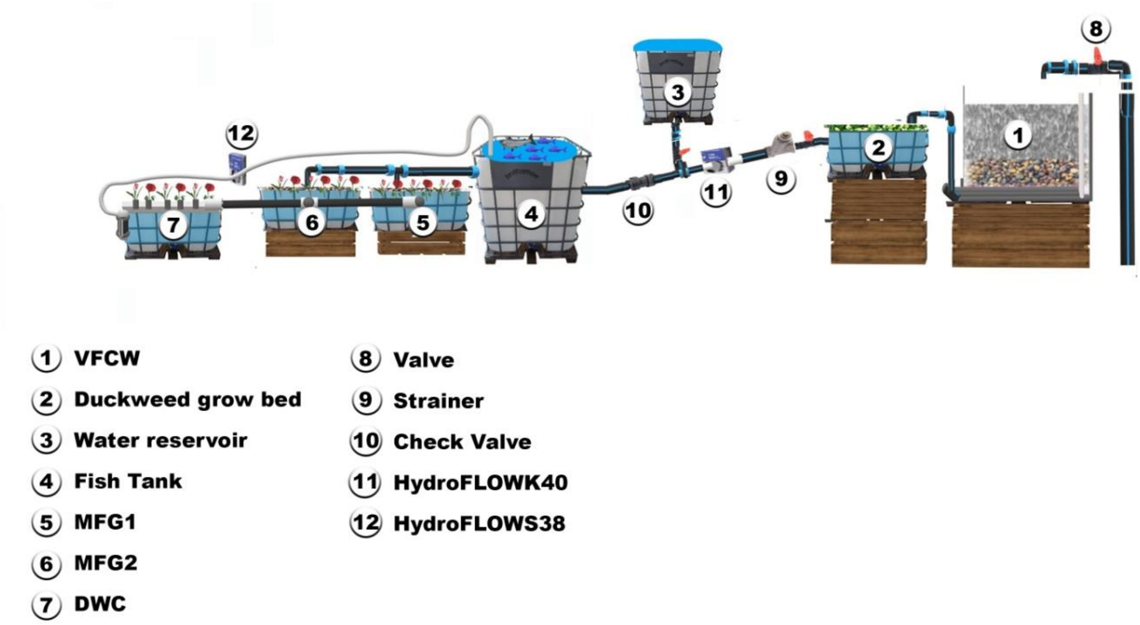


Figure 8: Illustration of a small-scale aquaponic system based on post-treated wastewater. Source: Paint 3D

Finally, EPANET 2.0 was also used to verify the water dynamics in the whole system, which gives a validation access as mentioned in the following figure (fig .9).

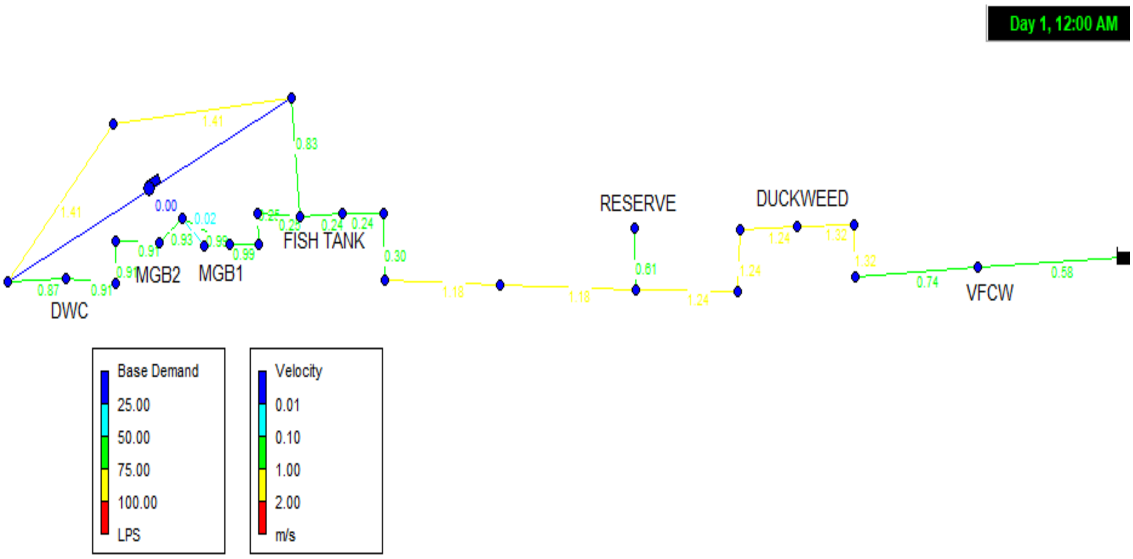


Figure 9: EPANET simulation of the small-scale aquaponic system

4.2 Partial conclusion

The aquaponic unit configuration is a low-cost and environmentally friendly approach than can be developed and optimized through time. The design and sizing part are crucial to reach the symbiosis equilibrium between fish and plants of the system. The costs are related to the productivity of the system, whereas it can be higher if we take into consideration the time spent by human resources. On the other side, such configuration needs monitoring. It is a crucial component that maintains the equilibrium. Therefore, it compromises both water quality and daily monitoring of fish feeding along with valve control calendar during each week.

CONCLUSION

The reuse of treated wastewater has been applied in the last few decades in Tunisia. The interest is now focused on the reuse of treated wastewater to solve several agricultural and economic issues. However, wastewater reuse is restricted to a limited set of applications like irrigation and agroforestry.

In order to enlarge the variety of applications, we contribute to improve wastewater reuse and valorization in the local context of GDA Sidi Amor through the setup a small-scale pilot aquaponic system based on post-treated wastewater. The system aims to produce cut roses and common carpe.

Mean inlet water quality is pretty compliant with national standards for wastewater reuse, water quality levels are fluctuating over time. With this in mind, we decided to integrate advanced post-treatment techniques in order to reach water quality aquaponic requirements. The post-treatment unit involves a vertical flow constructed wetland (1.1×1), duckweed grow bed (0.5×1.2) with a hydraulic loading rate of 120 l/day per each and two HydroFLOW© devices (HydroFLOW© S38 and HydroFLOW© K40).

The aquaponic system was designed as follows: a fish tank with 800 liters maximum capacity, two media grow bed filters with 200 liters volume of pumice each and a deep water culture unit with a 25cm water height. The system is capable to produce 20Kg of fish, with 200g daily feeding rate. The conception was basically low-cost (nearly 3000Dt) and adapted to the local context. However, an aquaponic system needs daily monitoring routine to ensure the best environment for fish and plants.

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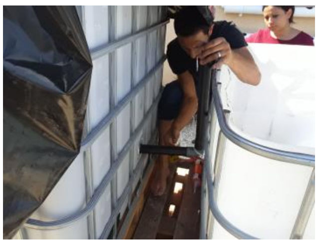
APPENDICES

Appendice 1

Number	Designation	Qt	PPU	Net price (Dt)
1	T connector 40 / glue	12	5,227	62,724
2	PVC elbow 90° 40mm	22	3,57	78,54
3	connector PVC male 40/50/1"1/2	3	3,887	11,661
4	Endcap PVC 40 / glue	6	3	18
5	connector 3P PVC 1"1/4	1	7,65	7,65
6	reduction PE 33/26	1	40,189	40,189
7	connector PVC male 40/32/1"	1	3,084	3,084
8	elbow PVC 90° D32	2	1,278	2,556
9	PEHD pipe 25 PN 10	27	2,219	59,913
10	PVC glue 1 Kg	2	45,295	90,59
11	Teflon	2	3,123	6,246
12	string DN28	50	1,995	99,75
13	string DN50	15	3,458	51,87
14	vices	65	0,365	23,725
15	pegs DE 8MM	100	0,1	10
16	PVC pipe D40 PN16 EP3	4	19,152	76,608
17	PE 50 elbows	5	13,377	66,885
18	TE PE 40/40/40	1	10,155	10,155
19	one-way valve 33/42	2	54,251	108,502
20	one-way valve 40/49	1	67,63	67,63
21	PVC valve OR 40	2	19,777	39,554
22	PVC reduction 110/40	1	3,552	3,552
23	elbow PVC 90° 110	2	3,994	7,988
24	adapter sleeve 26/34	1	2,716	2,716
25	connector male PE 25/3/4	1	2,54	2,54
26	reduction 40/20	1	4,612	4,612
27	valve PE 1AR 50/1"1/2	2	24,989	49,978
28	connector male PE 50/1"1/2	1	6,282	6,282
29	Plast cable strangler	30	0,071	2,13
30	hardware glue	2	25	50
31	silicone	3	9	27
32	gravel (4/8/(4/30))	60	5	300
33	IBC tanks	5	97	485
34	Trapaulin layers	3	139/95	373
35	Handiwork assistance	2 days	100	200
36	Geotextile	5m²	6	30
37	wood blocks	22	20	440
38	gravel (40)	1	112	112
39	transportation	1	240	240
			Total Price	3272,63

Appendice 2

Number	Description	Picture and illustration
1	cutting and cleaning the IBC tanks	 
2	setting up the IBC tanks in their position	
3	land leveling with wood blocks and cut/fill arrangement	 
4	covering the IBC tanks with different layers of tarpaulin	
5	setiing up the drainage pipes for the VFCW and the gravel filling	 
6	connecting the components with 40mm pipes, elbows and connectors to ensure their tightness	

7	setting up the water exits for the VFCW, duckweed grow bed, fish tank, MFG1 and MFG2	 
8	implementing the siphons for all the components	 
9	setting up the water inlet of the whole system with a 50mm pipe, and an exit with a 20mm pipe for he water excess	 
10	filling up the MFG with pumice Media	

Appendice 3: EPANET's simulation results for the irrigation network

	Length	Diameter	Flow	Velocity
Link ID	**m**	**mm**	**LPS**	**m/s**
Pipe 1	36.05	50	34.56	17.60
Pipe 2	8.98	50	34.56	17.60
Pipe 3	7.13	50	34.56	17.60
Pipe 4	25.09	50	34.56	17.60
Pipe 5	13.55	50	34.56	17.60
Pipe 6	36.41	50	34.56	17.60
Pipe 7	24.44	50	34.56	17.60
Pipe 8	24.64	50	34.56	17.60
Pipe 9	22.46	50	2.50	1.27
Pipe 10	24.58	50	2.00	1.02
Pipe 11	31.79	50	0.50	0.25
Pipe 12	14.07	50	0.50	0.25
Pipe 13	33.04	30	0.50	0.71
Pipe 14	18.11	50	22.06	11.24
Pipe 15	18.14	50	22.06	11.24
Pipe 16	24.13	25	0.50	1.02
Pipe 17	18.13	50	11.56	5.89
Pipe 18	17.55	50	11.56	5.89
Pipe 19	33.24	25	0.50	1.02
Pipe 20	7.82	50	10.56	5.38
Pipe 21	26.74	50	10.56	5.38
Pipe 22	25.29	50	10.56	5.38
Pipe 23	30.68	50	2.06	1.05
Pipe 24	32.98	50	1.54	0.78
Pipe 25	19.10	50	0.52	0.26
Pipe 26	40	20	0.50	1.59
Pipe 27	31.49	50	3.50	1.78
Pipe 28	38.69	50	2.90	1.48
Pipe 29	17.57	50	2.30	1.17
Pipe 30	18.16	50	1.70	0.87
Pipe 31	20.75	50	1.10	0.56
Pipe 32	20.54	50	0.50	0.25
Pipe 33	25.52	25	0.50	1.02
Pipe 34	20.3	25	0.50	1.02
Pipe 35	19.66	25	0.50	1.02
Pipe 36	17.67	25	0.50	1.02
Pipe 37	17.08	25	0.50	1.02
Pipe 38	19.21	25	0.50	1.02

Source: EPANET 2.0