International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 11 Issue 10 ǁ October 2023 ǁ PP. 231-241

Design and installation of a system for the sanitation of domestic wastewater with a capacity of 1.5 liters per second through a constructed wetland in the town of San Diego of Alejandria Jalisco, Mexico.

Aldo A. Castañeda Villanueva PhD.
Department of Engineering, CUAltos. University of Guadalajara, Mexico
Corresponding Author: acastaneda@cualtos.udg.mx

Abstract
Constructed Wetlands (CW) are natural systems used for the sanitation of domestic wastewater, which have advantages such as acceptable quality of the treated water, low installation, operation and maintenance costs. The main objective of this work is the design, installation, operation and stabilization of a system for the sanitation of domestic wastewater using a CW in a rural population in the Altos de Jalisco, Mexico. The system has a capacity for 130 m³/day; it consists of a pretreatment where both light substances (plastics, fats and oils) and heavy substances (minerals and metals) are retained. The CW has 1800 m² and a depth of 0.60 m operational substrate with macrophyte plant species such as typha latifolia, endemic to the region, as well as the post-treatment consisting of a chlorination stage and the contact and retention pond. The system was started at the end of August (2023), requiring 4 to 6 months for the plant specimens to condition and reproduce so that the appropriate habitat is formed for the microorganisms responsible for treatment, once the operation was stabilized of complete system (pre and post treatment), the treated water can be reused for irrigation of crops and/or artificial recharge of the aquifer.
Keywords: *Artificial wetland, Domestic wastewater, Highlands of Jalisco Mexico, Treatment system design.*

Date of Submission: 09-10-2023 Date of acceptance: 23-10-2023

I. INTRODUCTION

Since 2006, the Convention on Wetlands of International Importance, especially as Waterfowl Habitat (Ramsar) [1], defined natural wetlands as: extensions of marshes, swamps and peat bogs, or surfaces covered with water, whether natural or artificial, permanent or temporary, stagnant or flowing, fresh, brackish or salty, including areas of marine water whose depth at low tide does not exceed six meters.

Likewise, wetlands are considered one of the most productive ecosystems, they provide various benefits to humans and the environment, known as ecosystem services or ecosystem services, some of these appear in the following table (Table 1) [2].

Table 1: Main ecosystem services provided by wetlands.

Ecosystem service	Ecosystem structure and function
Coastal protection	Attenuates and/or dissipates waves, dampens winds
Erosion control	Promotes the stabilization of sediments and soil retention
Flood protection	Regulation and control of water flow
Cultural, spiritual and religious benefits, legacy values	It offers a unique and aesthetic landscape, with cultural, historical or spiritual significance.
Water supply	Groundwater recharge/discharge
Water treatment	Promotes the uptake of nutrients and contaminants, as well as particle retention and deposition
Carbon sequestration	Generates productivity and biological diversity
Maintenance of fishing, hunting and foraging activities	Create suitable reproductive habitat and breeding areas with protected spaces
Tourism, recreation, education and research	It offers a unique and aesthetic landscape, as a suitable habitat for different species of fauna and flora.

In the table above it is possible to see that there are many vital functions of wetlands due to the physical, chemical and biological interactions of their components, which is why wetlands are commonly called “the kidneys of the world", due to their water purification capacity, retention of contaminants and sediments, among others [3]. Currently the amount of natural wetlands has decreased, up to more than 64% compared to 1900.

To promote the conservation and wise use of wetlands, a global treaty was signed in 1971, and the Convention on Wetlands of International Importance, known as the "Ramsar Convention", is the only treaty that focuses on a single ecosystem [4].

Constructed Wetlands (CW)

CW are systems that simulate phenomena that occur spontaneously in nature, generate effluents of acceptable quality, while presenting low operation and maintenance costs and do not require trained personnel [5].

These systems are based on phytopurification (Phyto=plant, purification=clean, purify) of wastewater through complex physical, chemical and biological processes. In artificial wetlands, phytopurification is based on macrophyte plants, which refer to those plants that live and develop in an environment with water [6].

CW are alternative systems for the sanitation of wastewater mainly from domestic origin, and are used as secondary treatments for other types of wastewater (commercial and industrial). They must be built on land that should have been waterproofed; otherwise, there is a risk of contaminating the soil used or groundwater tables.

In general, CWs can be classified into surface (SCW) and sub-surface (SSCW), likewise CWS are subdivided according to the type of plants they have: floating, submerged and/or emerging. The SSCW, depending on their flow, can be horizontal, vertical and/or mixed.

CWs are characterized by the fact that the water is in direct contact with the atmosphere, like most natural wetlands. These are basically a variation of conventional lagoon systems [7]. They must be installed on land surfaces with a high degree of impermeability to prevent infiltration of contaminants into the groundwater. Generally consisting of shallow channels, with a substrate for the roots of emerging macrophytes (Figure 1), such plants provide shade that prevents algae growth [8].

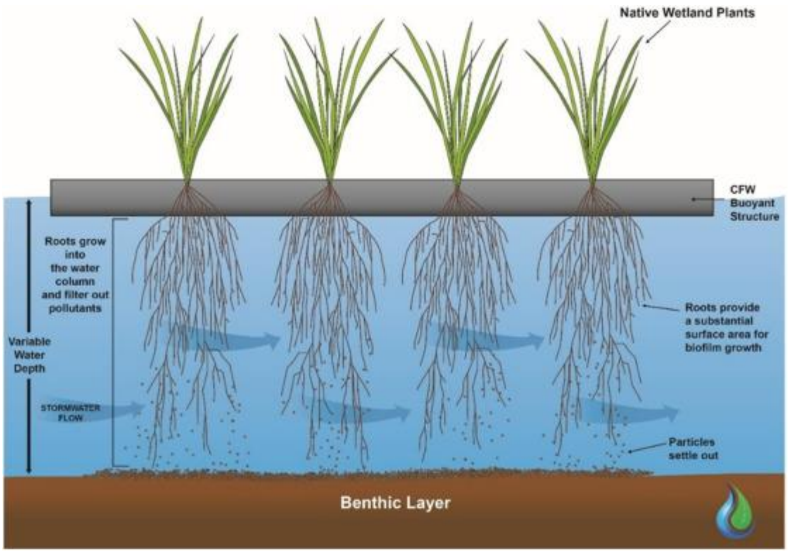

Figure 1: Floating CW [9].

In the SSCW, unlike the SCW, the water is not in contact with the atmosphere, instead, the substrate is found, where the biological reactions are considered to be carried out due to the activity of the attached microorganisms, see figure 2.

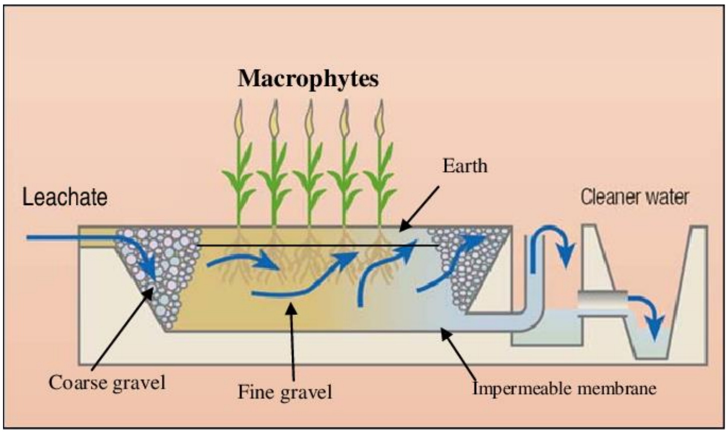

Figure 2: Illustration of SSCW [10].

For this reason, a SSCW may require less land than a free flow wetland for the same amount of wastewater to be treated. The main advantages and disadvantages of these are as follows: [11].

Advantages: Its requirements for electricity, mechanical equipment and highly trained personnel are minimal.

- Construction, operation and maintenance costs are lower than those of mechanical methods.
- They serve as secondary treatment except for low temperatures.
- They are pleasant to look at, they resemble a garden.
- They do not generate biosolids or residual sludge that would have required treatment.
- They are very effective in removing BOD, COD, total suspended solids, metals and refractory organic compounds from domestic wastewater as long as they are given a reasonable retention time. Significantly, longer time is required for nitrogen and phosphorus retention.
- Since the water is not in contact with the atmosphere, there are no problems with mosquitoes or other insects.

Disadvantages: Large land areas are required mainly if you want to remove nitrogen and phosphorus.

- Phosphorus, metals and some persistent organic compounds accumulate over time in sediments.
- Low temperatures cause a decrease in BOD removal.

The main factors that must be taken into account when designing a system for the sanitation of domestic wastewater using CW are:

1) Hydrology: as a branch of earth sciences, it studies water, its occurrence, distribution, circulation, and physical, chemical and mechanical properties in various bodies of water and the earth's atmosphere; its good operation and functionality will depend on this [12]. Likewise, a factor that affects the hydrology of the CW is the number of plants combined with their distribution, obstructing the movement of water when it tries to pass through the different parts of the plants. , and therefore does not allow its passage adequately. Wetlands, having low depths and large areas, carry out a mutual interaction with the atmosphere, through rainfall and evapotranspiration.

2) Plants: they function as a filter, promoting the separation of particles, they conduct oxygen through the roots, necessary for some microorganisms, they serve as a support, promoting the development of biofilms and they directly assimilate Nitrogen, Phosphorus and metals [13]. The type of plants used in artificial wetlands are hydrophytes, which are aquatic plants. One of its functions is to oxygenate water through the roots. They are classified according to:

Submerged: The plant is completely inside the water; therefore, all the oxygen passes directly to the water. Within this group of plants, the most used are Ranunculus aquatilis (water buttercup) and Potamogeton spp.

Amphibians: They are a type of macrophyte plants that have the characteristic of rooting in flooded areas, with one part submerged and another emerging. The most common for use in wetlands are cattails (Typha), reeds (Phrgmites), reeds (Juncus), Scirpus, Carex, among others [14].

Floating: They are found floating freely on the surface of the water.

They can be classified as free-floating plants (they have suspended roots) and rooted floating plants (their roots are anchored to the wetland mud). These plants generate shade, which makes it difficult for algae to proliferate. Care must be taken as they can become invasive, negatively altering the functioning of the wetland. The species most commonly used in aquatic water treatment systems are duckweed (Lemna minor) and water hyacinth (Eichornia crassipes).

To make a good decision about the plants to be used in the construction of the wetland, the following aspects must be considered [15]:

- Use native plants from the region, as well as avoid exotic species.
- Select species that have the ability to grow in saturated water, such as plants found in natural wetlands or on the banks of rivers, which are accustomed to these environments.
- Choose plants with extensive roots and underground rhizome system.
- Plants must have the ability to withstand short periods of drought, as well as tolerate periods of flooding.

3) The substrate: this is an essential part of the CW; it can be sand, gravel or rocks. It is the place where multiple reactions and processes are carried out that will result in water purification.

Its importance lies in:

- It serves as support for many of the organisms that live in the wetland.
- A large number of reactions, especially microbial, take place within the substrate.
- Plant remains accumulate, causing the amount of organic matter to increase, leading to the exchange of matter and the fixation of microorganisms.
- It is a source of carbon necessary for various biological reactions to be generated in the wetland.

The size of the substrate influences the hydraulic flow of the wetland; as the size of the substrate increases, the flow increases, but the filtration and absorption capacity decreases. Otherwise, if we decrease the size of the substrate, the wetland flow decreases, increasing the filtration and absorption capacity [16].

4) Microorganisms: these require carbon, inorganic nutrients, energy and reducing power for their growth. Autotrophic microorganisms can synthesize organic matter from mineral substances; heterotrophs need organic matter for their development and maintenance [17, 18].

5) Characterization of the wastewater to be cleaned: there are different types of water contaminants, with wastewater from large cities being the ones that mostly contribute to exacerbating this problem [19]. Water pollution is understood as the incorporation of foreign matter into it, this matter can be microorganisms, chemicals, industrial waste and wastewater [20].

In general, pollution deteriorates the quality of water and makes it useless for the various uses it could have, this represents an environmental, economic and social imbalance [21].

The municipality of San Diego of Alejandria (SDA) is located northwest of the state of Jalisco, it is located between the coordinates that range from 20° 52' 30" to 21° 02' 45" north latitude and 101° 54' 45" at 102° 05' 45" west longitude (figure 3). It borders to the north with Unión de San Antonio, to the south with Arandas, to the east with the state of Guanajuato and to the west with the municipality of San Julián. SDA is located at a height of 1,795 meters above sea level, and has a territorial area of 432.32 square kilometers. According to the Population Census, in 2020 the population in the entire municipality was 7,609 inhabitants [22].

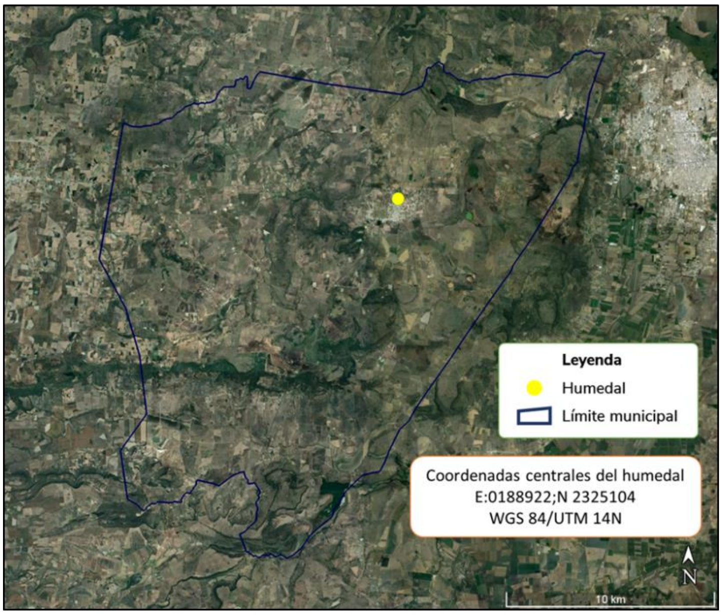

Figure 3: Location of the municipality of SDA Jalisco and the treatment system (CW).

Hydrologically, the municipality is located in the Administrative Hydrological Region VIII Lerma-Santiago-Pacific; Hydrological Region 12 Lerma – Santiago, in the Lerma – Chapala Hydrological Zone in the

Río Turbio-Verde Hydrological Basin, its main currents are: the Peña Blanca River and the Jalpa River; It also has the Arenillas, Casillas and San Agustín streams; There are also the dams: Vieja de Jalpa, Peña Blanca, La Amapola, San Fernando, Los Charcos and los Griegos. The climate is semi-dry, with dry autumn, winter and spring, and semi-warm, with mild winters. The average annual temperature is 17.6°C, with a maximum of 24.8°C and a minimum of 10.3°C. It has an average precipitation of 642.1 millimeters [23].

An important part of the wastewater generated in the town of SDA, approximately 1.5 liters per second (LPS), is discharged on the periphery of the urban area in the property called “Los Pérez”, where it is retained in a pseudo storage lagoon (figure 4) to later be used for irrigation of crops, mainly alfalfa, pastures and oats, the above due to the lack of other sources of supply, as well as the aquifer that supplies this resource to the population. It is overexploited (Aquifer 1444).

Figure 4: Wastewater collection lagoon in the “Los Pérez” property in the municipality of SDA.

It is worth mentioning that the production of forage with this type of water (without adequate treatment) can cause diseases to livestock, water users and the population in general due to pathogens that can be dispersed by water and wind, for example. On the other hand, wildlife is affected, such as resident and migratory ducks that use the wetland directly, as well as other groups of birds, mammals, reptiles and amphibians.

1.1.1 General objective

Installation and operation of a system for the sanitation of domestic wastewater of the population of SDA with a capacity of 1.5 LPS, using a CW.

Specific objectives

• Characterization and determination of the flow of domestic wastewater that reaches the property called “Los Pérez”, in the municipality of SDA.

• Topographic survey and study of soil mechanics in the “Los Pérez” property for the installation of the treatment system.

Design of a treatment system using a CW with capacity for 1.5 LPS

Installation, operation and optimization of the treatment system.

Controlled reuse of treated water (agriculture, artificial recharge of the aquifer)

II. RESULT AND DISCUSSION

For the characterization of the wastewater discharged on the "Los Pérez" property, in the municipality of SDA, where the installation of the treatment system was planned, samples and measurements were taken during the period of November 2022 and April 2023, the results appear in table 2.

Table 2: Composition of wastewater at SDA, Jalisco.

PARAMETER (mg/L)	AVERAGE
BOD	655
COD	1130
Phosphorus	32
Fats and oils	74
Total nitrogen	82
Settleable solids	1.3
Total suspended solids (TSS)	530

Likewise, the selected substrate consisted of coarse red tezontle-type gravel, which had a porosity of 42.7% (n=0.427), with a standard suggested depth of 60 cm (h=0.60).

Uniform piston-type laminar flow conditions are assumed and that there are no restrictions for contact between the constituents of the wastewater and the organisms responsible for the treatment.

For the output, values of the CW treated water, the parameters of the current official standards are considered:

1) NOM-001-SEMARTAN-1996, which establishes the maximum permissible limits on discharges to bodies of water and soil and,

2) NOM-003-SEMARNAT-1997, which establishes the maximum permissible limits for treated water that is reused for the irrigation of green areas.

Thus, the basic data for the CW designs according to the selected models appear in table 3:

Table 3: Data for the design of the CW treatment system

PARAMETER (UNIT)	ID	AVERAGE
Average flow (m^3/day)	Q	129.6
Raw water BOD concentration (mg/L)	Co	655
BOD concentration treated water (mg/L)	Ce	20
Substrate porosity (%)	n	42.7
Substrate depth (m)	h	0.60
Average field temperature (°C)	T	18

Calculation memory

1) Constructed wetland: Taking into consideration both the climatological conditions and the topographic characteristics of the region where the treatment system is installed, the use of the Reed model [23] is proposed for the calculation and design of the CW, as follows: determined the value of the reaction rate constant (Kt), according to the average temperature of 18°C and the BOD variable, we have according to Reed:

$$Kt = K20(1.06)\exp(T - 20)$$

Where Reed suggests;

$$K20 = 1.104/\text{day}$$

So;

$$Kt = 1.104(1.06)\exp(18 - 20)$$

$$Kt = 0.982556/\text{day}$$

With this value (Kt) it is possible to determine the surface area using the following equation:

$$Sa = \frac{Q(lnCo - lnCe)}{Kt\ n\ h}$$

Where:

Sa: Surface area of CW (m^2)

Q: Average flow (m^3/day)

Co: BOD in raw water (at wetland entrance) (mg/L)

Ce: BOD in the treated water (at the outlet of the wetland) (mg/L)

Kt: Reaction rate constant, dependent on temperature (1/day)

n: Porosity of the material that forms the substrate (decimal fraction).

h: Substrate depth (m).

Substituting the corresponding values:

$$Sa = \frac{129.6(ln655 - ln20)}{(0.982556)(0.427)(0.60)}$$

Sa = 1796.21 m^2 (figure 5)

To determine the hydraulic retention time (HRT), we use the equation;

$$HRT = \frac{(Sa)(h)(n)}{Q}$$

Substituting values:

HRT = (1796.21) (0.60) (0.427) / (129.6)

Therefore, HRT = 3.55 days

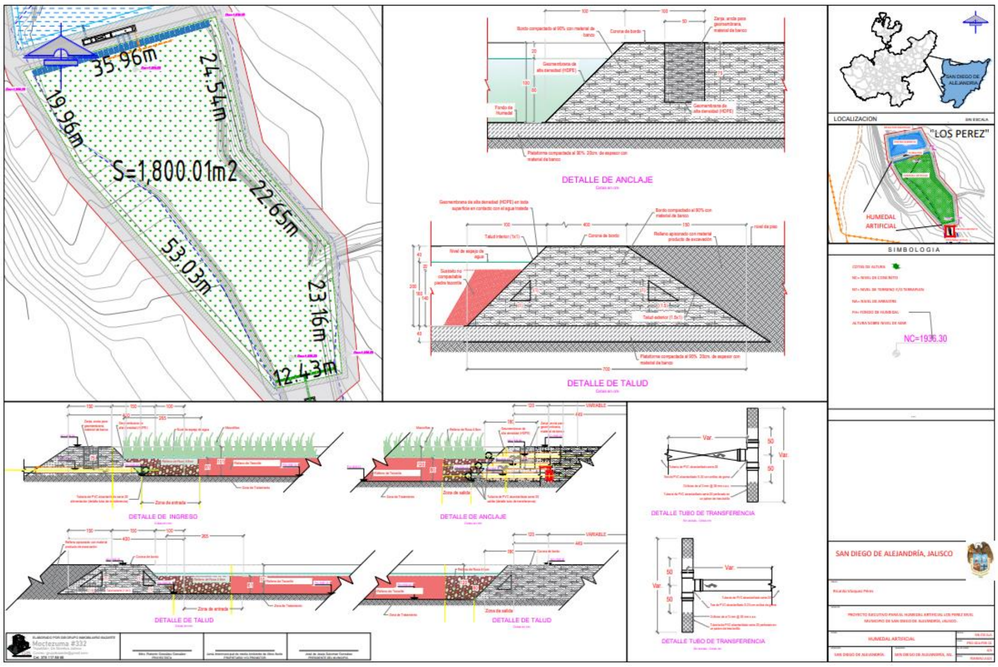

Figure 5: Specifications of the CW cell, of the Treatment System at SDA.

2) Pre-treatment

Considering the characteristics of the wastewater (table 2), as well as the climatic conditions of operation of the treatment system, a minimum hydraulic retention time of 30 minutes is established, with an effective depth of 1.0 m, the pre-treatment of the system is designed (figure 6).

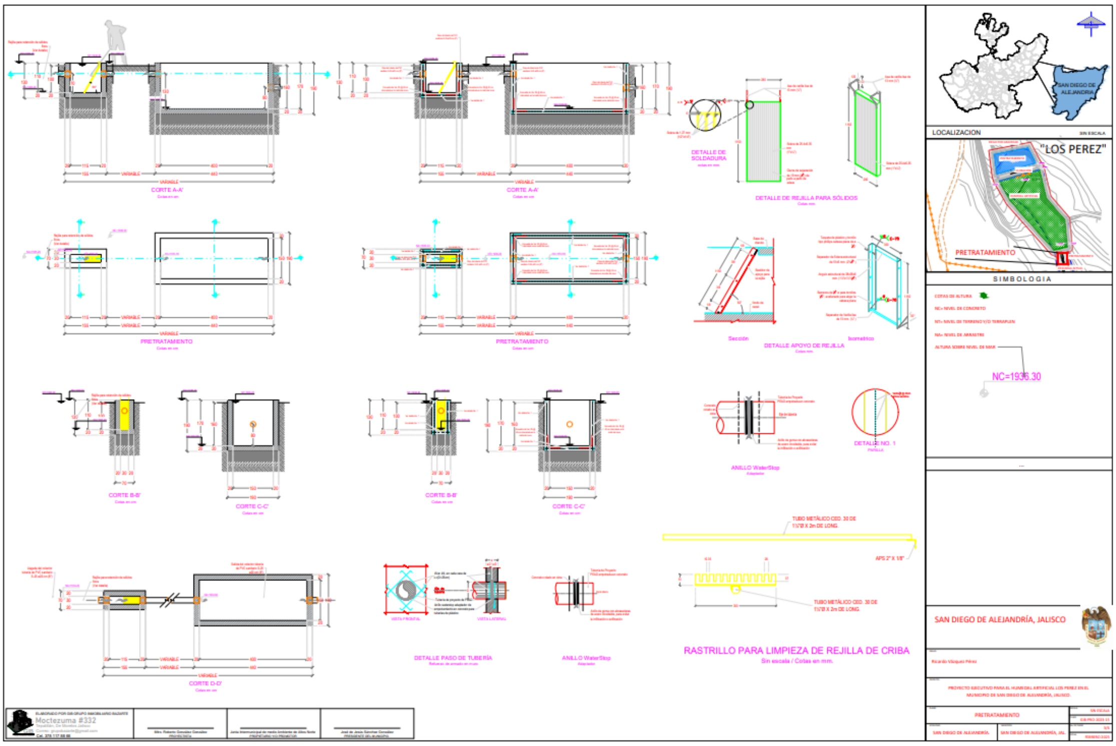

Figure 6: Pre-treatment diagram.

3) Post-treatment

Likewise, taking into consideration the specifications required for the treated water (NOM), and the minimum retention time under critical conditions (temperature, humidity, flow) in the post-treatment (figure 7) and including a chlorination stage using hypochlorite of calcium (solid) in contact labyrinth (figures 8):

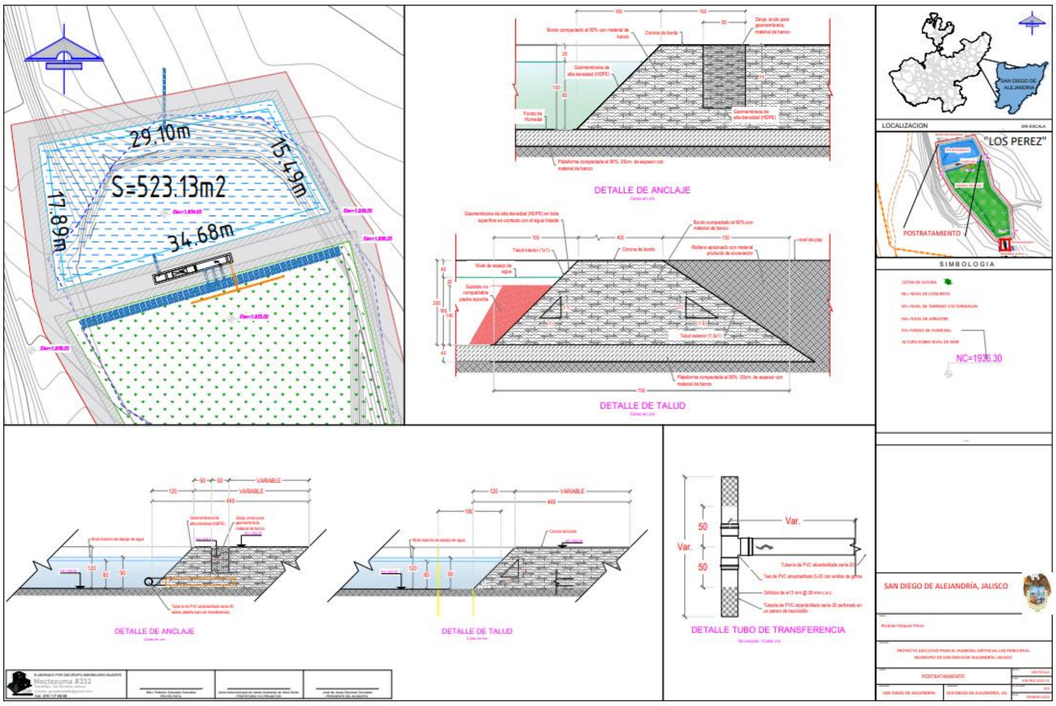

Figure 7: Post-treatment

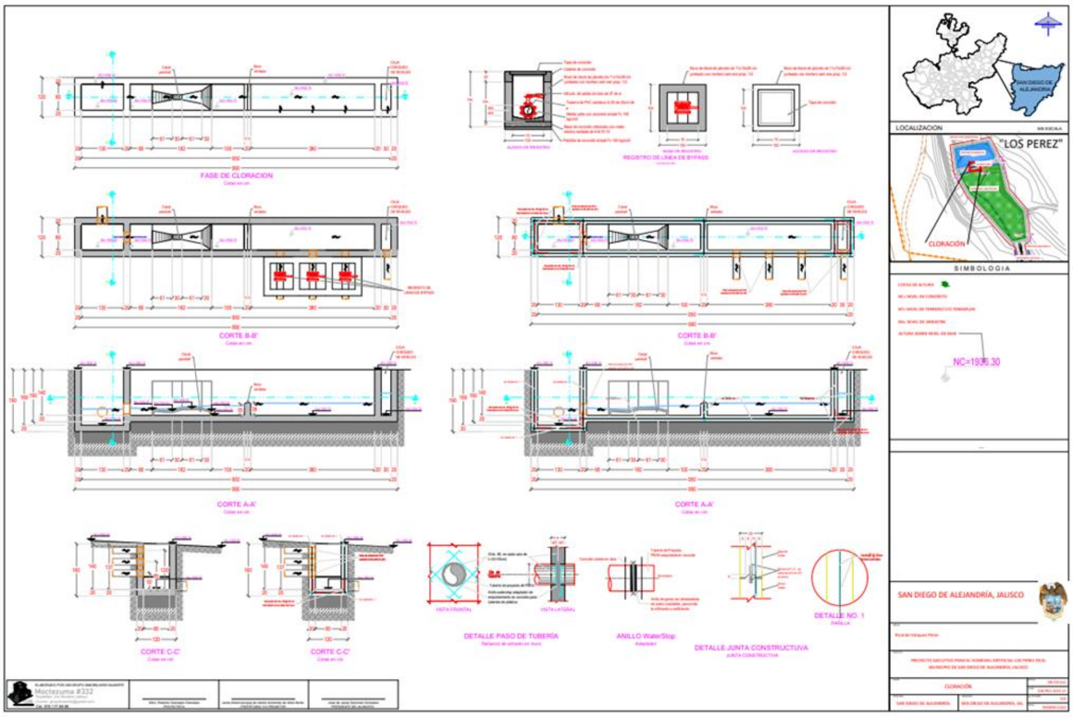

Figure 8: Chlorination system in Post-treatment

Likewise, the minimum dimensions for the post-treatment pond and its operating parameters appear in table 4:

Table 4: Dimensions and minimum operating parameters of the pond for post-treatment

Dimension/parameter	
Surface (m²)	500
Nominal depth (m)	0.6
Storage capacity (m³)	312
Retention time (hrs)	57.7

The activities for the design, installation and operation of the treatment system on the Pérez property in SDA began practically at the end of 2022; however, they were completed in mid-2023, according to the following schedule (table 5).

Table 5: Schedule of activities.

Activity	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec
Characterization of the effluent and estimation of flows	xxxxxxxxxx					
topographic survey	xxxxxx					
Treatment System Design	xx	xxxxxxxx				
Study of soil mechanics		xxxxxx				
Earthworks for CW adaptation		xx	xxxxxxxxxx			
Geomembrane installation			xxxx			
Pipe laying				xxx		
Substrate placement				xxxxxxxx		
Civil works for Pre-treatment/grit removal			xxxxxxxxxx			
Civil works Post-treatment: stabilization pond			xx	xxxxxx		
Transplantation of specimens (Macrophytes)				xxxxxxxxxx		
Starting the treatment system					xxxxxxxx	
Water quality monitoring		xxx		xxx	xxx	xxx
Operation and optimization					xxxxx	xxxxxxxxx

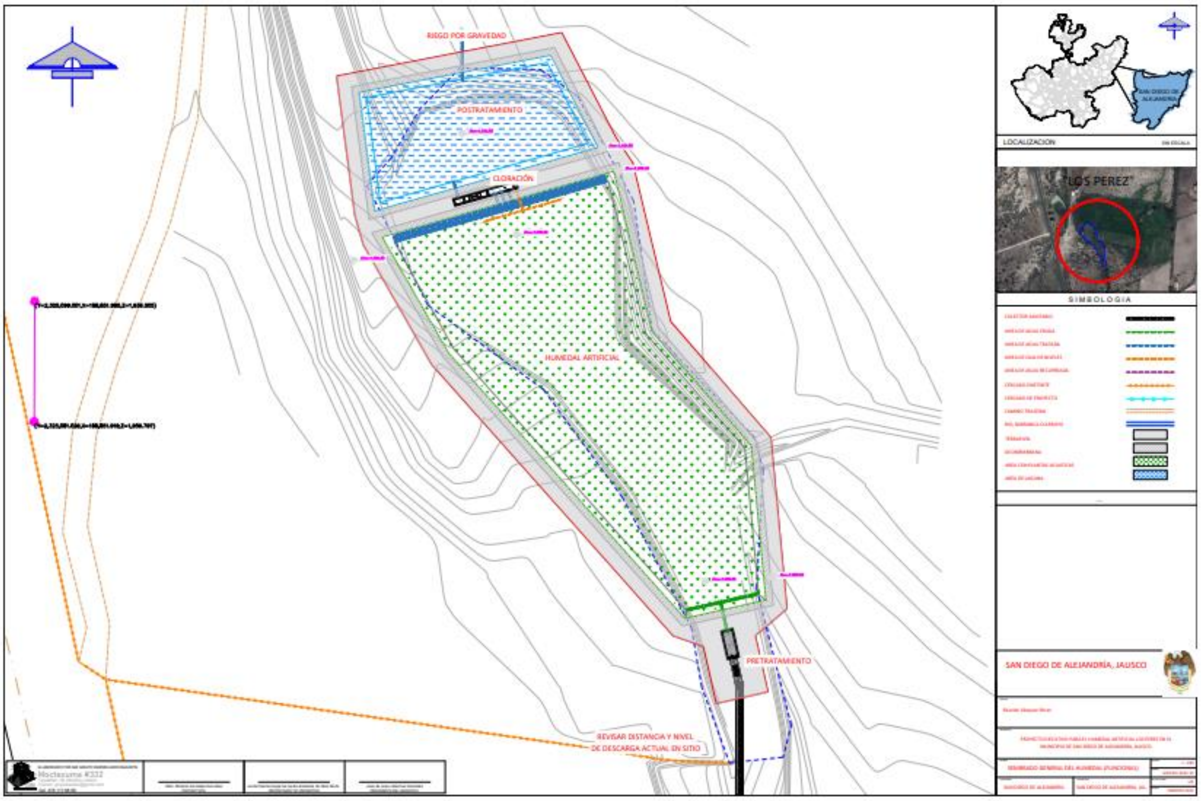

Figure 9: General diagram of the CW treatment system at SDA.

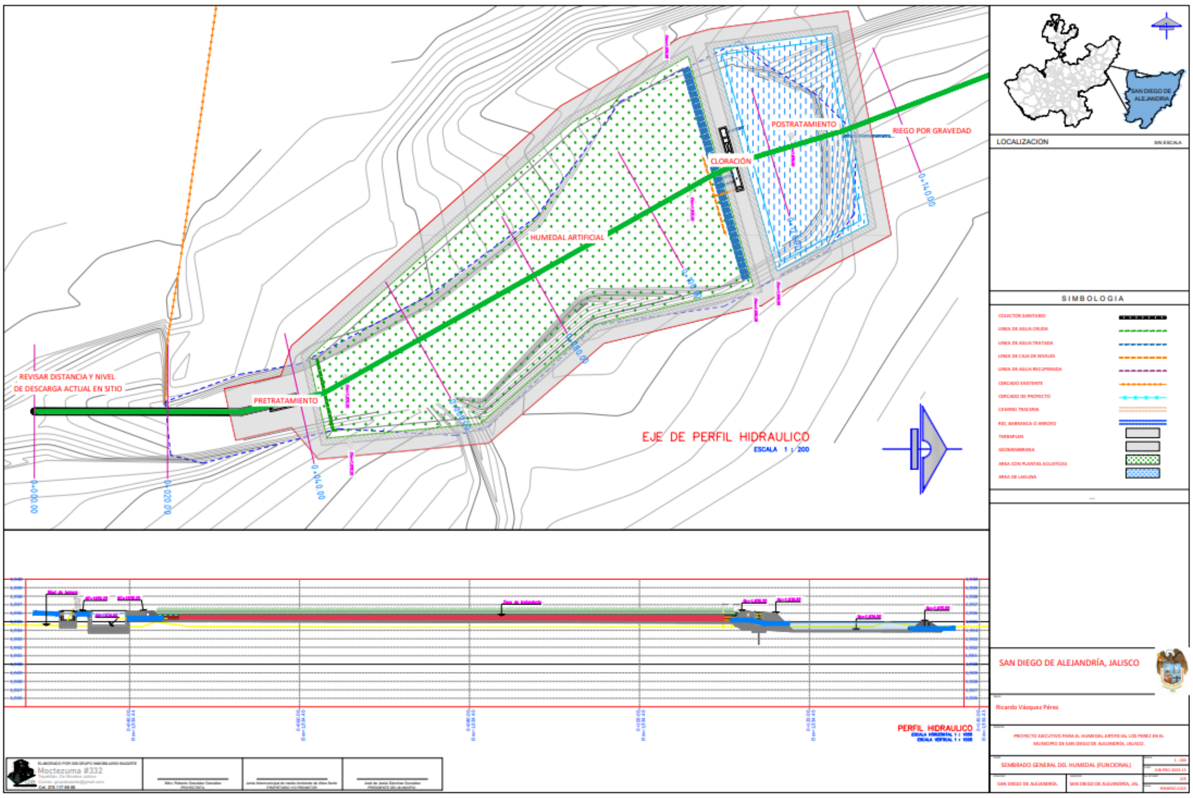

Figure 10: General hydraulic profile (functional) of the treatment system at SDA

III. CONCLUSION

The System for the sanitation of wastewater with a capacity of 129.9 m³/day (1.5 LPS), consists of a pretreatment where both light substances (plastics, fats and oils) and heavy substances (minerals and metals) are retained, the HC has of 1800 m² and an operational substrate depth of 0.60 m with macrophyte plant species such as tule (typha latifolia) endemic to the region, as well as the post-treatment consisting of a chlorination stage and the contact and retention pond. The system was started at the end of August (2023), 4 to 6 months are required for the plant specimens to acclimatize and develop, forming with their roots and the substrate the appropriate habitat for the microorganisms responsible for treatment, a Once the operation of the complete system is stabilized (pre and post treatment), the treated water can be reused for irrigation of crops and/or artificial recharge of the aquifer.

REFERENCES

[1]. Ramsar, (2006) Manual de la Convención de Ramsar, 4a. edición. Suiza.
[2]. Brink, P., et al. (2013) La Economía de los Ecosistemas y la Biodiversidad Relativa al Agua y los Humedales.
[3]. Astudillo, D., López, F. and Rodas, M. (2010) Valoración Socioeconómica de Humedales Altoandinos. Universidad Técnica Particular de Loja: Ecuador.
[4]. Romero, M., et al. (2009) Tratamiento de aguas residuales por un sistema piloto de humedales artificiales: evaluación de la remoción de la carga orgánica. Revista internacional de contaminación ambiental. 25(3): p. 157-167.
[5]. Fernández, M. (2018) Manual de fitodepuración. p. 61-77.
[6]. Delgadillo, O., et al. (2010) Depuración de Aguas Residuales por medio de Humedales Artificiales. Bolivia: Centro Andino para la Gestión y Uso del Agua (Centro AGUA).
[7]. EPA, (2000) Humedales de flujo libre superficial. Folleto informativo de tecnología de aguas residuales. 2000: Estados Unidos. p. 10.
[8]. Martínez, P. (2014) Evaluación y Diseño de un Humedal Construido para la Depuración de Aguas Residuales Domésticas, in Departamento de Química Agrícola, Geología y Edafología. Universidad de Murcia. p. 495.
[9]. Gujar, A. (2022) Constructed Wetlands for Wastewater Treatment. Floating Constructed Wetlands. In: https://blog.mywastesolution.com/constructed-wetlands-for-wastewater-treatment/
[10]. Madera, C. and Valencia, V. (2009) Landfill leachate treatment: one of the bigger and underestimated problems of the urban water management in developing countries. 9th World Wide Workshop for Young Environmental Scientists WWW-YES-Brazil-2009: Urban waters:resource or risks?. In: https://www.researchgate.net/publication/228494057_Landfill_leachate_treatment_one_of_the_bigger_and_underestimated_problems_of_the_urban_water_management_in_developing_countries
[11]. Kadlec, R. and Wallace, S. (2009) Treatment Wetlands. 2da ed. USA: CRC Press.
[12]. Fernández, G.J., et al. (2016) Manual de Fitodepuración, Filtros de Macrófitas en Flotación. España: Ayuntamiento de Lorca, Universidad Politécnica Madrid, Fundación Global Nature, Obra Social
[13]. Hoffmann, H., et al. (2011) Revisión Técnica de Humedales Artificiales de flujo subsuperficial para el tratamiento de aguas grises y aguas domésticas. Agencia de Cooperación Internacional de Alemania, GIZ Programa de Saneamiento Sostenible ECOSAN: Eschborn. p. 39.
[14]. Andreo, M. (2014) Evaluación y Diseño de un Humedal Construido para la Depuración de Aguas Residuales Domésticas, in Facultad de Química. Universidad de Murcia: España. p. 495
[15]. LaHora, C. (2003) Depuración de aguas residuales mediante humedales artificiales: La edar de los gallardos (Almería), in Ecología, manejo y conservación de los humedales. Almerienses Editor. p. 99-112.
[16]. Ferrer, J. and Seco, A. (2008) Tratamientos biológicos de aguas residuales. España: Alfaomega, p. 188.
[17]. Waldo, V. (2010) Contaminación del Agua. Revista Virtual Redesma. 4(2): p. 76.
[18]. Gil, H., et al. (2013) Tecnologías verdes para el aprovechamiento de aguas residuales urbanas: análisis económico: p. 119-128.
[19]. Castañeda, A. y Flores, H. (2013) Tratamiento de aguas residuales domésticas mediante plantas macrófitas típicas en Los Altos de Jalisco, México. Revista de Tecnología y Sociedad, "innovación y difusión de la tecnología". Año 3, número 5, abril-septiembre 2013.
[20]. EPA, (2000) Humedales de flujo subsuperficial. Folleto informativo de tecnología de aguas residuales. USA, p. 13
[21]. Lara, B. (1999). Depuración de Aguas Residuales Municipales con Humedales Artificiales. Universidad Politécnica de Cataluña: España. p. 122
[22]. INEGI, (2023) In: https://cuentame.inegi.org.mx/monografias/informacion/jal/territorio/div_municipal.aspx?tema=me&e=14
[23]. Municipio de San Diego de Alejandría en Jalisco (2023). In: http://www.municipios.mx/jalisco/san-diego-de-alejandria/
[24]. Castañeda, A. et al. (2018) "Comparación de tres modelos para el diseño de un humedal artificial para el tratamiento de las aguas residuales de poblaciones rurales en Los Altos de Jalisco" In: http://www.cutonala.udg.mx/sites/default/files/aldo_antonio_castaneda_villanueva_comparacion_de_tres_modelos_para_el_diseno_de_un_humedal_artificial_.pdf