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Research Article

Municipal Wastewater from Tertiary Treatment to Restore a Wetland Ecosystem in a Semiarid Environment

Perfecto Barragan-Pena*, Gabriel Bonillas-García, Rommel F. Benitez-Paz, Irma V. Gil Delgado and Rafael Segovia Torres

Tecnológico Nacional de México/Instituto Tecnológico de Nogales. Ave. Instituto Tecnológico No.911, México

E-mail: eudiar7@gmail.com

Abstract

It has been well-reported the importance of wetland ecosystems due to the multiple services they provide to all organisms: besides they comprise habitats to a number of species, they contribute to recharge aquifers, and to carbon sequestration eventually. Municipal wastewater from a tertiary treatment was used to restore a wetland ecosystem. The site is located 23.5 Km south to Nogales, Mexico at Alisos watershed. The water was characterized for total coliforms and aerobic mesophiles, as well as Biochemical Oxygen Demand, to state its microbiologic quality. Soil characterization and hydrologic pattern study were carried out in order to know infiltration rate, type of soil, and watershed capacity. The design of the system consisted of three winding channels with gradual depth in the range 0.3-1.5 m that extended for 68 m downstream, at the end of which the channels enter a 0.8 m pond of 22 m of diameter. The forestation included native flora such as Juglans major, Asclepias angustifolia, and Platanus wrightii, among others. Due to its high microorganism content the water was conducted to a filtration process in conic tanks of 110 gal of capacity in which natural zeolite and limestone were packed. After 10 months of initiated both stabilization of system and earthworks to better maintain the green infrastructure on site, the area presents significant flora growth and a variety of pollinators can tell of the potential the restoration work has at Alisos watershed.

Keywords: Wetland, Hydrologic Pattern, Pollinators, Forestation, Restore

INTRODUCTION

Nowadays, water sources are scarce in semiarid regions, especially when intended to supply growing populations. Municipal wastewater can represent, though, if properly treated, a valuable resource to destine to a variety of purposes. Actually, water reclamation is a flawless strategy to derive an extra source to gain on the water resources diverted from the biological cycle of water to anthropogenic uses (Rao D G et al., 2013). The restoration of an ecosystem can play a dual role in the ultimate use of recycled water, it contributes not only to the aquifer recharging, but to the forestation process the landscape can experience to shelter a variety of wildlife, flora and fauna. Wetlands are perhaps some of the most outstanding ecosystems for the several services they provide.

Mangrove forests are a particular type of wetland that has been accurately characterized close to tropics in America. These ecosystems are very dependable on climate conditions, among other factors (Rivera-Monroy V H, 2017). As for Mexican Caribbean and Gulf of Mexico seashore in Veracruz, Mexico, mangrove forests associated to either coastal and inland regions, have been of interest to researchers in evaluating at least these services: run-off management, aquifer recharging, and carbon sequestration which eventually adds in to climate change issues (Agraz H CM, et al., 2015: Rodríguez-Zuniga MT et al., 2013).

When temperatures drop -6°C or underneath, mangroves cannot survive, though (Solarik K M et al., 2018). Likewise, semiarid landscapes, might not be a promising target for wetland restoration unless two factors coincide: a watershed and a regular supply of water (Comin F, 2014). Alisos watershed, located in the northwest of Sonora, Mexico, was the final destination of treated wastewater from the municipal wastewater treatment plant. The plant scope includes flocculation-sedimentation, and biological oxidation, before the water is discharged at a rate of approximately 220 L/s in a river. The present study

aimed to restore a wetland ecosystem to sustain wildlife, from pollinators, birds, reptiles to aquatic organisms, with treated wastewater, and at the same time, to recharge the aquifer and better manage runoff in monsoons. The site of study is 31º07'53" N, 110º56'12.23" W in the northwest of Sonora, Mexico, and it extends for 1.5 ha.

MATERIALS AND METHODS

To characterize the treated wastewater respect to microbiologic quality, analysis of E. coli and mesophiles as well as Biochemical Oxygen Demand (BOD) were carried out.

Total coliforms are widely used as an indicator of potable water in Mexico. Composed samples of water were obtained to perform the analysis, for a period of 4 h each. The aerobic mesophiles were determined with the standard plate count technique while total coliforms with the estimated aerobic plate counts from serial dilutions. Each analysis was performed in duplicate from samples taken in spring, summer and autumn to state possible trends.

The Biochemical Oxygen Demanda is an analysis that estimates the amount of oxygen required by a heterogenoeus population of bacteria to oxidize organic matter content in a sample of wastewater; the technique requires a specific sampling method, and the tests is run for five days at 20º C (NMX-AA-028-SCFI-2001).

For soil analysis the method of granule dimension with 10, 20, 40, 60, 100 and 200 mesh, was used, and the results evaluated according to Unified System for Classification of Soils criterion. To determine the density of soil a Modified Proctor Test, which calculates dry weight and percentage of humidity, was used. Infiltration rate was determined when measured the flow rate as a function of time in excavated areas with a penetrometer. This equipment is used to evaluate mechanical properties in soils at 5 feet depth, unless a significant change in materials is observed, and the method complies with ASTM D1586.

To investigate topography, hydrologic and erosion patterns in the watershed, a Dron Dji Phantom 4, GPS Spectra ProMark 120 post-process was used, and data processed with Spectra Precision Survey Office, CivilCad software and Flujos de Agua de las Cuencas Hidrográficas (SIATL).

Endemic native flora characterization was accomplished with a data bank through two American Organizations: Arizona Native Plants Society and Borderland Restoration. The latter contributed further with workshops on germination techniques to train collaborators in the project. The selection of plants for forestation considered the following criteria: a) To use native grass in order to eradicate the possibility of invasive plant growth such as Bermuda grass (Cynodon dactylon) and buffel grass (Pennisetum ciliare) which have been reported inappropriate for restoration projects (Van Devender et al., 2009), b) To include species enlisted in Mexican Normative NOM-059-SEMARNAT-2010, as endangered or of special care, c) To belong to a wetland ecosystem in semiarid landscapes of northwest of Sonora, Mexico, d) To lure pollinators as food or shelter. Furthermore, (Raphael A et al., 2019) reported that interactions among individuals, say diverse trees and grasslands, play a role in the stabilizing effect of vegetation growth.

A system design consisting of three channels and a pond was built to sustain the wetland. The channels were excavated with a bulldozer and have 0.30-1.50 m depth, winding downstream to the pond. The pond was 0.80 m depth and with 42 m diameter, close to the river. The water from the wastewater treatment plant outlet was pumped through 4" pipelines to three polyethylene tanks before entering the channels. These tanks have 110 gallons of capacity and were packed with 50 Kg of natural clinoptilolite supplied from La Colorada mines in Sonora, Mexico, and 25 Kg of coarse-grade limestone ($CaCO_3$). This pretreatment of the water was included in order to diminish the possible phosphorus excess and therefore avoid eutrophication. Natural zeolites, particularly the clinoptilolite type, have been proved to take up pollutants from aqueous systems, (Barragan P M et al., 2016). These adsorbents can remove Escherichia coli as well, and this property is enhanced when modified with silver (De la Rosa-Gomez I O et al., 2010) The natural zeolite was selected and packed first in these tanks to reduce fine particles and bacterial population, due to its microporous which contribute to a lower density (1160 Kg/m³) and can become saturated easily. The Figure 1 shows the order minerals were packed in the tanks.

The use of green infrastructure consolidated the system and led to a constant inspection of the site beyond the end of the project term. It consisted of berms and rock beds, basically, to slow down runoff and promote infiltration. The rocks used to place on the bottom of the channels were the same found in the site when digging out. They were placed with their irregular surfaces up so as to increase resistance to the flow of water; flat surfaces up of rocks were always avoided. Likewise, a number of rock rows were placed

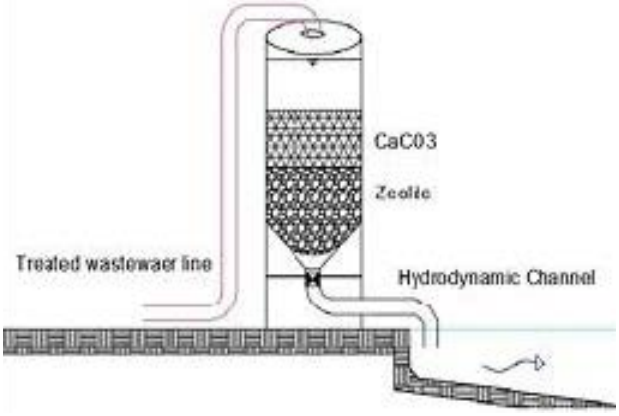

Figure 1: Tank packed with limestone ($CaCO_3$) and natural zeolite to pre-treat the water.

perpendicularly to channels in order to re-direct runoff that could erode the edges of channels. Erosion in the site was checked by evaluating the amount of sediment dragged to the channels; this was monitored with a monthly dron flight.

To follow up these strategies specific actions can mitigate adverse effects caused by runoff from rain which may turn out a plight into a success. Green infrastructure can contribute to the stability of the ecosystem not only for the organisms on the shore, inhabitants of Alisos watershed, but also the aquatic one (fish, crustaceans, aquatic plants, and algae). By avoiding sediments are dragged all the way to the river bed, appropriate green infrastructure can reduce the likelihood of disappearance of surface effluents (Rivera-Monroy V H, 2017). On the other hand, the risk of flooding for nearby communities decreases too, what accounts for a favorable social impact.

For any restoration process is compulsory to eliminate the carbon contribution by plant debris, and therefore, to avoid a setback due to the cells decay which could eventually break the system stabilization. Consequently, a regular program to take plant debris out was set.

Once the whole system was set, physical inspection and monitoring became a well-established program on regular basis which students from local university supported.

RESULTS AND DISCUSSION

The results for the microbiologic and physical-chemical analysis of the treated wastewater are described in Table 1.

The results in Table 1 show a serious bacterial input in the effluent regardless what pH and BOD can suggest. Mexican Normative NOM-014-CONAGUA-2003 establishes BOD as 30 mg/L for treated wastewater discharged into lagoons or rivers, and 5.5.-10.0 for pH values. The pretreatment of the water, though, as Biochemical Oxygen Demand analysis was determined at the inlet and outlet of tanks, worked out. The results are shown in Table 2.

BOD in discharged water is very important to monitor since it can trigger off critical issues. The permisible limits in international normative set it at 20-50 mgL^{-1} (Rao D G et al., 2013). The Mexican normative establishes as upper limit, for agricultural purpose and sea water, in 200 mg/L, as daily average (NMX-AA-002-SEMARNAT 1996).

Soil analysis

According to the graph in Figure 2, the coefficient of Uniformity, 3.75, determined that the sample is poor graduated sand. This means there is a diversity of particles in the sample. For effects of mechanics, the behavior we can expect from a soil like this compromises solid foundation and brittle compaction.

The average density of the soil was 86.83% respect to maximum dry volumetric weight, which comprises a moderate compact soil. Figure 3 describes dry weight as a function of humidity.

The permeability test outcome was 1.82 L/h for infiltration rate, and showed 1:2 ratio of horizontal infiltration to vertical. Therefore, the soil can be classified as semi-permeable with slight retention properties.

Some measurements were necessary to take so as to achieve stabilization of the system: the use of rocks in the channels to slow down the flow of water, what could increase vertical infiltration, and to place a polyethylene cover on the bottom of the pond to have water retention and succeed in the aquatic species shelter.

Hydrologic pattern and topography

The drainage area of the basin was10.18 km^2, with a maximum flow rate 116.49 m^3/s on a critical event, however, since the neighborhood is not an urbanized area, the natural terrain and vegetation contribute to discard floods in the site of study.

Another important factor that reduced the possibility of ponding was the slope of the basin, which is up to 4%, and the slope of the project area, around 2%, so the water

Table 1. Results of water sampled at Alisos Wastewater Treatment Plant for different seasons.

Test	Spring	Summer	Autumn
Total E. coli (EAPC/100 mL)*	2400±20	>1100	>1100
Mesophiles (CFU/mL)**	110±15	3900±11	1910±25
Biochemical Oxygen Demand (mg/L)	112	202	72
pH	6.00	6.50	6.85
Phosphorus (mg/Kg)	-	-	<Q.L.[1]
%Nitrogen	0.30%	0.65%	0.34%

*Estimated Aerobic Plate Count

**Colony-forming units/mL

[1] Quantification limit, set at 31 mg/Kg

Table 2. BOD in treated wastewater before it entered the channel system.

Check point	BPD mg/L	BOD mg/L	BOD mg/L
Inlet of tank	112	202	72
Outlet of tank	35	38	18

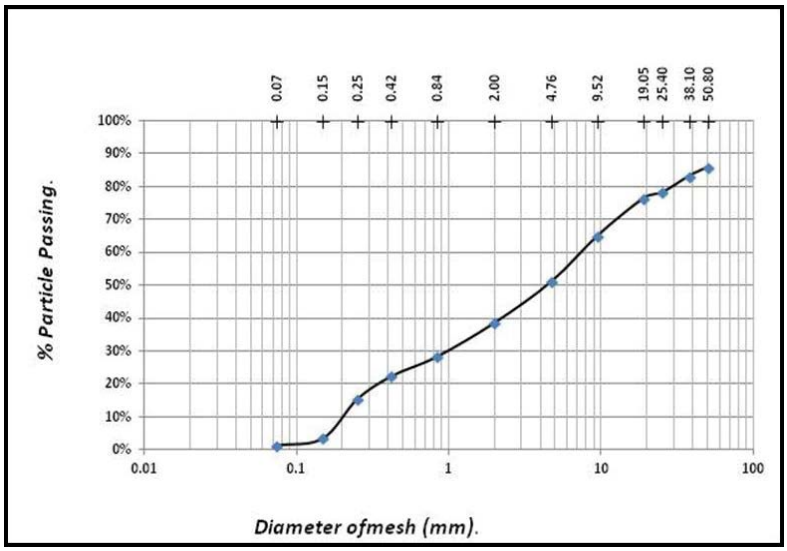

Figure 2. Granular composition of soil sampled at Alisos Watershed

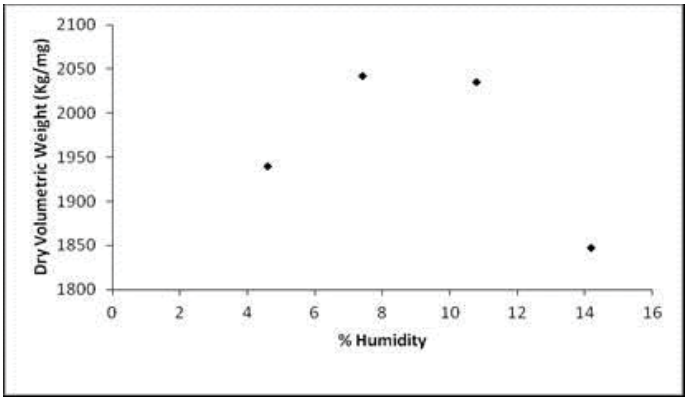

Figure 3. Curve of Compaction to determine Maximum Dry Density in soil.

runs off quite fast. It has been well-reported that increased runoff results in increased sedimentation downstream, what eventually results in loss of depth in rivers (Lepeska T, 2016).

The treated wastewater pipeline used to connect to tanks was 200 m long and 4 inches of inner diameter (made of polyvinyl chloride, PVC).

As it can be observed from Figure 4, the site of study is located on a watershed, close to a wastewater treatment plant. The plant receives municipal wastewater from a city 15 Km north, and discharges treated water at a rate of 220 L/s.

The design system implemented at Alisos watershed can be easily appreciated form the upper view in Figure 5.

The water, once the pond fills up at its maximum capacity (17.6 m^3), flows to the riparian on the right, which eventually ends up in the Alisos river.

The hydrologic patterns are closely related to the green infrastructure maintenance, a lot of stewardship added to environmental education at different levels works, since one of the principles of green infrastructure points out that it requires long term commitment (Benedict M A, 2006). Therefore a regular assignment to get involved in hands-on training was included in the program of the Sustainable Development subject at Instituto Tecnológico de Nogales.

Flora selected to forest the site

The plants selected to forest the site were Juglans major, enlisted as a species of special care in NOM-059-SEMARNAT-2010; (Naturales S d, 2010) Platanus wrightii, associated to Eleocharis montevidensis which is an aquatic plant typical of Sonoran wetlands; Asclepias angustifolia and Conoclinium greggii, both very valuable to Monarch butterflies, where they have found shelter and food, respectively; Lilaeopsis schaffneriana, an aquatic plant that has been reported as an indicator of the health of wetlands in the northwest of Sonora and southeast of Arizona (Titus J, 2008). Except for Lilaeopsis schaffneriana and Platanus wrightii, the plants were donated by Borderlands Restoration, an organization located in Patagonia, Arizona,

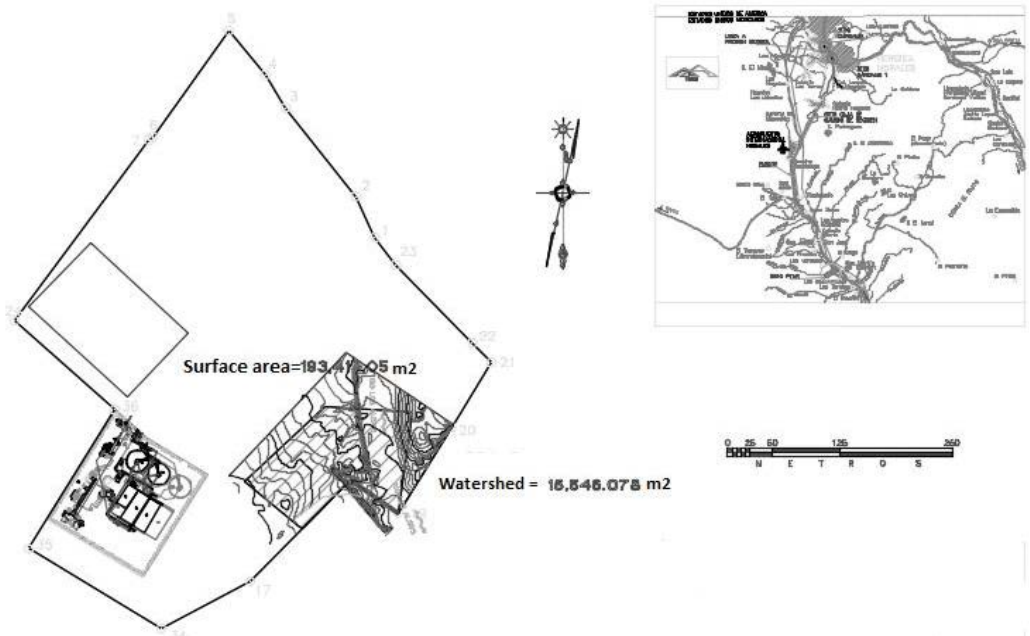

Figure 4. Alisos watershed site location. The wastewater treatment plant can be spotted down on the left

Figure 5. Upper view of the design system at Alisos watershed.

USA. They have a nursery where reproduce native plants of Sonoran desert.

To fight back invasive grass such as buffel grass (Pennisetum ciliare) and bermuda grass (Cynodon dactylon) three endemic types of grass were planted in the site: Aristida purpúrea, Muhlenbergia rigens and Arandu donax. These native grass types were replanted from the nearby sites along Alisos river. As for Arundo donax, it grew up to 8 cm within four months since replanted. Aristida purpurea only needed six weeks, though. Finally, two other species found south to the site, about 25 Km in Terrenate, were transplanted to Alisos watershed: Nastartium officinali, an aquatic, and Heliomeris longifolia; both species have proved to resist temperatures as low as -11ºC. There were a few incidents regarding fauna visiting the site from some ranches nearby, needless to say that the fence put up around the site dissuaded these domestic animals. So far, the wetland has made some progress and the potential to shelter wildlife can be appreciated in the Figures 6 and 7.

Both species depicted in Figure 6 have more than moderate water need, but only Arundo donax is perennial.

Asclepias angustifolia, an annual resistant to crude winter, grew strongly and appealed a lot of Monarch butterflies at the site in early fall. Muhlenbergia rigens and Aristida purpurea, helped to control invasive grass growth throughout the restoration process (Arizona Native Plant Society data bank, 2018) (Figure 7).

Figure 6. Arundo donax, native grass, and Heliomeris longifolia, from sunflower family

Figure 7. Native grass (Muhlenbergia rigens and Aristida purpurea) on the sides, and Asclepias angustifolia in the center

CONCLUSIONS

Wastewater from tertiary treatment was used successfully for restoration of a wetland ecosystem in a semiarid landscape. The water pretreated in tanks packed with limestone and natural zeolite, sustained endemic flora carefully selected respect to water needs, extreme weather conditions in the region, and typically related to Sonoran wetlands. The tanks packed with limestone and clinoptilolite-type natural zeolite worked out to diminish BOD in the water.

Pollinators were a priority to select the plants which were either reproduced in a nursery or in some cases replanted. A four month period was enough to spot Arundo donax growth, eight cm height, while Aristide purpurea needed only six weeks.

The aquifer was re-charged with the channel and pond design of the system, this achieved infiltration in both directions: horizontal and vertical. Despite the type of soil in the site, semi-permeable, water retention was accomplished with the use of rocks and a polyethylene cover. Invasive species were fought back with forestation of native grass. Environmental education anticipated the hard work involved in a long term commitment for restoration project, this implied students from local university to get involved which contributed to make them aware of the importance of recycling water in any community. The use of green infrastructure helped to manage rainwater runoff in the monsoon. The government support to this study was crucial and favored the use of 1.5 ha of land with no time restriction. Any ecosystem restoration project is very complex, therefore the authors understand the need to pursue the system health conditions along with newcomer students from the local university.

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