Analysis of Rehabilitation of the Sludge Treatment System at Guaynabo Water Treatment Plant, "Los Filtros"

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Abstract *— Los Filtros Water Treatment Plant serves approximately 58,800 families in the municipalities of San Juan, Caguas, and Aguas Buenas. The plant began operations in 1924 and have been producing water 24hrs/7days since then. Has a design capacity of 25 million gallons per day (MGD) but data provided shows that the plant have been producing an average of 23.27 MDG in 2019, 23.22 MDG in 2020, and 17.50 MGD in 2021. After Hurricane Maria, the treatment plant has been in detriment because of failures, lack of maintenance and repairs to equipment and tanks. The sludge treatment system has processed an average of 0.90 MGD in 2019, 0.81 MGD in 2020, and 0.91 MGD in 2021. Operational data was provided by plant management and statistically analyzed to compare production rates and water quality changes.*

Key Terms *— Drinking Water, Puerto Rico Aqueducts and Sewer Authority, Rehabilitation, Sludge Treatment System.*

INTRODUCTION

The Puerto Rico Aqueducts and Sewer Authority administers 124 filtration treatment plants producing an average of 600 million gallons per day (MGD). Guaynabo Water Treatment Plant (GWTP) is a conventional filtration system designed to produce 25 MGD. Figure 1 provides an identification of GWTP unit processes.

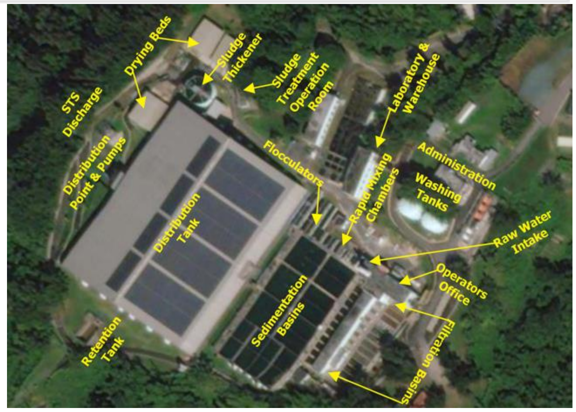

Figure 1

Guaynabo Water Treatment Plant Unit Processes

Under this project, there is an interest to analyze the generation and treatment of sludge. Goals includes but doesn't limit to find the ratio of sludge generation vs drinking water production, capacity of Sludge Treatment System to manage and treat effluent discharged to the system, and treatment alternatives for the Sludge Treatment System. GWTP was designed to produce 25 MGD and the Sludge Treatment System (STS) to treat all discharges from filters backwash, distribution tank overflow, tanks cleanings, and special events discharges. Originally, the STS was supposed to recirculate part of the effluent of the sludge gravity thickener but since the recirculating line is broken, approximately since 2016-2017 all effluent from the sludge gravity thickener is being redirected to the drying beds compromising the system ability to manage the influents volume.

Guaynabo Water Treatment Plant

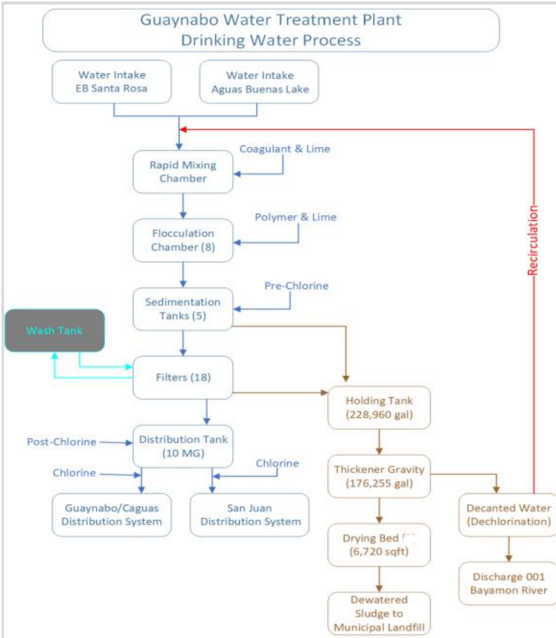

Figure 2

Guaynabo Water Treatment Plant Drinking Water Process

Figure 2 shows the diagram process of the GWTP drinking water production system. The drinking water treatment plant is composed of two raw water entrance; one is EB Santa Rosa that mix intakes from Bayamon and Guaynabo Rivers and the other is from Aguas Buenas Lake. From the intake the water goes to a rapid mixing chamber where the polymer is applied, then water goes to the flocculation tanks where slow mixing is applied to prevent early sedimentation and help the formation of floccules. After the flocculation process, the effluent goes to the sedimentation basins where floccules sediments and an initial dosification of chlorine is applied, effluent of sedimentation basins goes to the one of the 18 filters composed of sand and anthracite with a base layer of gravel. Filtered water goes to the distribution tank where a post-chlorine is applied. The distribution tanks have a capacity of 10 MG and it have two compartments, one for the Guaynabo – Caguas distribution system and one for the San Juan distribution system. Before distribution, a final dosification of disinfectant is applied [1].

Sludge Treatment System is composed of a holding tank with capacity for 228,960 gallons which receives all discharges from filters backwash and sludge from sedimentation basins. Effluent is pumped to the Sludge Thickener where decanted water is dechlorinated and discharged to the Bayamon River. Effluent from the sludge thickener is discharged to one of the eight drying beds that works in parallel, water recollected after sludge is dried is recirculated to the sludge thickener.

Justification

After Hurricane Maria, the Puerto Rico Aqueducts and Sewer Authority have been developing facilities assessment to improve and repair utilities and equipment. Improvements and repairs will be funded with Insurance and Federal Emergency Management Agency (FEMA) compensation. This project is considered under the Capital Improvement Projects (PMC, by its acronym in Spanish). The plant has been confronting issues with capacity and infrastructure to manage and treat sludge. Restoration and improvements to the plant are essential since the plant have been operating for the past 98 years non-stop. It is important that water treatment systems operate properly to maximize resources preservation and facilities efficiency.

LITERATURE REVIEW

Data Analysis

Production and quality data provided was filtered statistically analyzed to identify maximum, minimum, average, and total production of drinking water and sludge.

Sludge Treatment System Plans

Design drawings from 1996 are used to identify and characterize the Sludge Treatment System components dimensions and specifications.

National Pollution Discharge Elimination System – NPDES Permit

The NPDES regulates the fluent discharged from the Sludge Treatment System to the Bayamon

River. This permit sets the parameters and flow limits to the Guaynabo Water Treatment Plant STS.

Production Data Analysis

Water Treatment Plant analysis is performed only tacking in consideration data provided by the GWTP administration since visits where very limited and access to participation in daily operations was not granted. Table 1 shows the monthly and annual average of combined raw water intake from 2019 to 2021. The highes annual daily average intake was in 2021 with 20.64 MGD with a total of 247.67 million gallons that represents an increase of three thousand (3,000) gallons from 2020.

Table 1

Combined Raw Water Intake

Month	Million Gallons per Day 2019	2020	2021
January	18.9	18.28	20.6
February	16.58	18.48	20.88
March	19.9	20.84	20.06
April	18.27	21.26	21.05
May	20.39	23.44	21.87
June	18.73	23.93	20.17
July	18.06	19.38	21.21
August	17.94	19.16	19.28
September	18.97	19.85	20.38
October	19.75	20.72	19.87
November	17.51	20.06	20.91
December	17.81	19.03	21.39
Total Annual (Million Gallons)	**222.81**	**244.43**	**247.67**
Annual Average (Million Gallons per Day)	**18.57**	**20.37**	**20.64**

The highest drinking water distribution was in 2019, with an annual daily average 23.27 MGD and total annual production of 279.50 million gallons. Data from Table 2 shows a decrease in production from 2019 to 2021 of 32.92%.

Table 2

Drinking Water Distribution

Month	Million Gallons per Day 2019	2020	2021
January	20.92	24.43	17.89
February	20.63	24.84	18.80
March	22.24	25.27	17.71
April	22.17	25.79	18.55
May	24.41	26.50	18.83
June	23.41	27.58	17.40
July	23.76	26.18	17.92
August	23.86	25.02	15.34
September	23.94	18.53	16.97
October	25.30	18.50	`16.37
November	24.78	17.59	16.84
December	23.78	18.37	17.43
Total Annual (Million Gallons)	**279.20**	**278.60**	**210.05**
Annual Average (Million Gallons per Day)	**23.27**	**23.22**	**17.50**

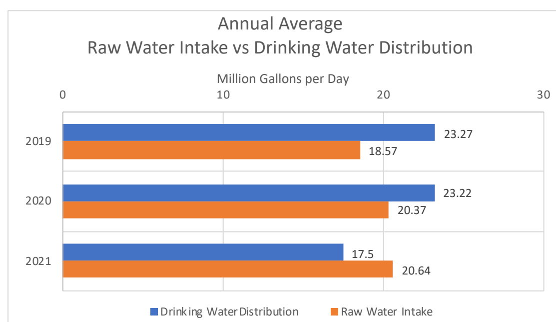

Figure 3

Average Raw Water Intake vs Drinking Water Distribution

Figure 3 shows that the average intake of raw water has been increasing since 2019 and drinking water distribution have been decreasing. This could represent a lost of water during treatment or tanks cleanings. Lost during treatment could be due to broken pipes and/or valves, failures in the control systems, errors in operation, among others.

The Sludge Treatment Systems manages an annual daily average of 0.91 MGD and a total discharge of 10.86 million gallons in 2021. There is an increase of approximately 100,000 gallons of sludge production daily from 2020 and 10,000 gallons of sludge from 2019 as shown in

Table 3. The highest sludge discharge recorded was during the months of October, November, and December; that is consecuent with the wettest months. Heavy rain fall events could impact the production of sludge since the turbidity in the raw water intake increases, afecting the generation of floccules and the system operation in general. Also, the increase could be related to the lack of automatic sludge recolection system in the sedimentation basins.

Table 3

Sludge Treatment System Discharge

Million Gallons per Day			
Month	2019	2020	2021
January	0.94	0.63	1.02
February	1.11	0.66	0.63
March	0.88	0.66	0.99
April	1.02	0.59	0.80
May	1.31	0.72	0.62
June	1.02	1.11	0.70
July	0.76	0.70	0.64
August	1.06	0.61	0.63
September	0.65	0.66	0.80
October	0.77	1.15	1.23
November	0.64	1.11	1.34
December	0.69	1.07	1.47
Total Annual (Million Gallons)	**10.84**	**9.66**	**10.86**
Annual Average (Million Gallons per Day)	**0.90**	**0.81**	**0.91**

Sludge Treatment System – STS

The STS is composed of the following:

- (1) Holding Tank
- (1) Gravity Thickener
- (8) Drying Beds
- (1) Recirculation Pump Station to Plant Headworks
- (1) Recirculation Pump Station to Thickener Gravity

Figure 4 shows the components and characteristics of the Sludge Treatment System in GWTP. Recirculation lines and pumps are out of service. Design drawings estimates the STS can manage and treat 2,096,736 gallons of sludge daily. In 2021 the average discharge was 0.91 MGD which indicates the systems has the capacity to handle sludge generated. The sludge generated in the GWTP is from the backwash of the filters and cleaning of the sedimentation basins.

The sedimentation basins are supposed to have an automatic system to collect the sludge, but since the mechanical system hasn't been operating regularly since 2016 to clean the basins, the operator lowers the volume but at least 30% – 50% of the tank is discharged to the STS to clean each basin.

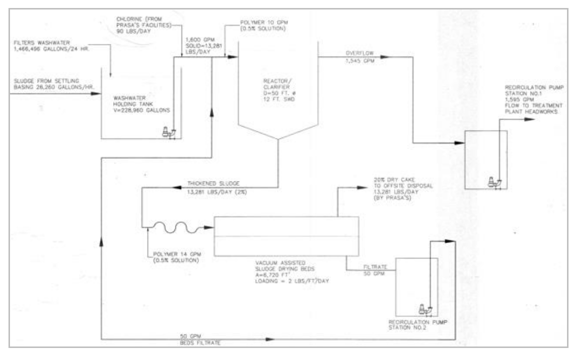

Figure 4

Guaynabo Water Treatment Sludge Treatment System

Holding Tank

The holding tank has a volume capacity of 228,960 gallons. Tank dimensions are 12m x 8.07m x 7.62m with two submersible pumps of 1,600 gallons per minute.

Gravity Thickener

The Gravity Thickener dimensions are:

- Diameter – 15.24 m
- Depth – 3.66 m

Designed to process 13,281 lbs/day thickened sludge at 2% of solids. The overflow or decantant is designed to be 1,545 gallons per minute and to be recirculated to the plant headworks. Thickened sludge is deposited to the drying beds.

Drying Beds

The STS have six (6) vaccum assisted drying beds with an area of 6,720 ft^2 and loading of 2 $lbs/ft^2/day$. Each drying bed have four plug valve, floors are ceramic tiles and ceilings are light colored chevrone. Figure 5 and Figure 9 shows an example of a drying bed, one bed was freshly filled and one already dry and ready to be recollected and discarded. Drying beds are desinged to produce sludge with atleast 20% solids at a rate of 13,281 lbs/day. Effluent is being discharged to the Bayamon River.

Figure 5

Sludge Drying Beds

Figure 6

Sludge Drying Beds

Recirculation Pumps

STS is designed to operate with two recirculation pumps, both stations have been out of service for several years.

- Station No. 1 – Manages the overflow from the gravity thickener and redirects it to the plant headworks with a capacity of 1,595 gpm.
- Station No. 2 – Recirculates the effluent from the drying beds to the gravity thickener with a rate of 50 gpm.

Figure 7

Recirculation Pump Station No. 1 [2]

National Pollution Discharge Elimination System – NPDES

The NPDES regulates the Sludge Treatment System characteristics and volume discharged to the Bayamon River. NPDES No. PR0022438 is in the renewal process until September 1, 2022. Table 4 shows the parameters and limits for the STS effluent identified as Discharge 001 [3].

Table 4

NPDES Parameter Limits

Parameter	Units	Maximum Daily	Sampling Frequency
BOD	mg/L	5.0	Monthly
Color	Pt-Co	15	Monthly
Cooper (Cu)	µg/L	10.84	Monthly
Dissolved Oxygen	mg/L	<5	Daily
Effluent Flow	MGD	2.37	Continuous
Lead (Pb)	µg/L	3.98	Quarterly
Mercury (Mg)	µg/L	0.050	Quarterly
pH	SU	Min: 6.0 Max: 9.0	Daily

Residual Chlorine	µg/L	11	Daily
Temperature	°C	30	Daily
Total Ammonia Nitrogen	µg/L	Monitor	Monthly
Total Phosphorous	µg/L	160	Monthly
Turbidity	NTU	50	Monthly

METHODOLOGY

The following information explains the methodology used in this research.

Through the data and information collection process, were made three (3) visits to the Los Filtros Treatment Plant. During the visits the operators reported that the holding tank would overflow when eight (8) or more filters are washed daily, or a combination of filters and sedimentation basins. Also, overflow have been reported on heavy rainfall events. With the information and data initially obtained in the site visits it was possible to propose three (3) different alternatives to that could qualify to solve sludge treatment management problem and improve the operation and process of the treatment plant. In addition, the data provided by the Aqueduct and Sewer Authority (AAA for the Spanish acronyms) was filtered statistically analyzed to identify maximum, minimum, average, and total production of drinking water and sludge for understand the sludge treatment management process and operation and reach to the finals results.

For each alternative an investigation was carried out to analyze their advantages and disadvantages. After analyzing the alternatives and the data provides by (AAA), a conclusion of results was reached, and the most viable alternative was selected.

Sludge Treatment Alternatives

The *Biosolids Technology Fact Sheet* [4] by the Environmental Protection Agency, presents the operation and process for Centrifuge Thickening and Dewatering Centrifuges. The information provided in this fact sheet was essential to select one of the alternatives for the management sludge treatment system (STS) for the GWTP. The alternatives considered in this project are:

- Decanter Centrifuge
- Plate Filter Press
- Restoration of Drying Beds and Recirculation System

Decanter Centrifuge

Decanter centrifuges are designed for the sludge thickening and dewatering process in municipal and industrial wastewater treatment plants. Centrifugal thickening and dewatering is a high speed process that uses the force from rapid rotation of a cylindrical bowl to separate wastewater solids from liquid with a focus on profitability, reliability, ease of operation and sustainability. Centrifuges have been used in wastewater treatment since the 1930s.

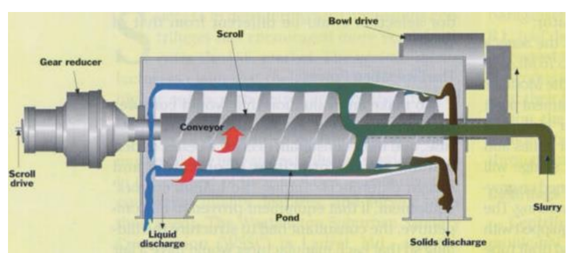

Figure 8

Decanter Centrifuge [4]

According to the *Biosolids Technology Fact Sheet* [4] centrifuges operate as continuous feed units which remove solids by a scroll conveyor and discharge liquid over the weir. Routine maintenance is relatively simple because it is usually performed by the manufacturer. Centrifuges are normally operated to obtain maximum solids concentrations, while maintaining a 95 percent solids capture.

Advantages

- Lower overall operation and maintenance costs.
- Require a small amount of floor space relative to their capacity.
- Minimal operator attention when operations are stable.
- Centrifuges can handle higher than design loadings and the percent solids recovery can usually be maintained with the addition of a higher polymer dosage.

Disadvantages

- High power consumption.
- Spare parts are expensive and internal parts are subject to abrasive wear.
- Start-up and shut down may take an hour to gradually bring the centrifuge up to speed and slow it down for clean out prior to shut down.
- Mechanical dewatering equipment may not be the most cost-effective alternative for treatment plants operating at less than four MGD.

Costs

According to the *Biosolids Technology Fact Sheet* [4], a centrifuge equipment sized to process 750 pounds of solids per day in an eight-hour shift will cost about $215,000. To install the equipment in an existing building with a polymer feed system and odor control will run about $650,000. Capital costs of a centrifuge can be less expensive depending on size of plant, cost of polymer, cost of labor, local electric rates, whether wash water is plant water or potable water, as well as other factors [4].

Filter Press

The filter press is a machine that has a series of filter elements that work in parallel. Each filter press is characterized by having a filtering surface and a retention volume for solid parts, which, depending on the number of plates and their size. Press filters and filtration installations carry out "mechanical" filtrations, removing the solid particles present inside liquids.

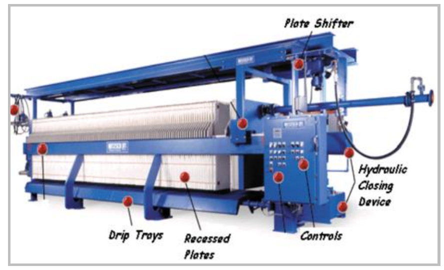

Figure 9

Recessed-Plate Filter Press [5]

According to the *Biosolids Technology Fact Sheet* [5], recessed-plate filter presses are used to remove water from liquid wastewater residuals and produce a non-liquid material referred to as "cake". Recessed-plate filter presses are among the oldest types of dewatering devices. Filter presses are used to reduce volume, saving money on storage and transportation, eliminate free liquids prior to landfill disposal, reduce fuel requirements if the residuals are to be incinerated or further dried, produce a material with sufficient void, space, and volatile solids for composting, when blended with a bulking agent, reduce pooling or runoff, which can be a problem when liquid biosolids are land applied among others uses.

Advantages

- High cake solids concentration with associated low biosolids storage, hauling, and disposal costs.
- Little or no operator attention during dewatering phase of cycle.
- Produces a drier cake.
- Removes water uniformly.
- The cycle time for a selected cake solids concentration is usually lower.

Disadvantages

- Batch operation produces more heterogeneous influent
- Process is mechanically complex.
- Capital costs are relatively high
- Requires special support structure
- Requires relatively large area
- Filter cloth preparation, cleaning, and cake
- Removal may be operator intensive

- Mechanical dewatering equipment may not be the most cost-effective alternative for treatment plants operating at less than four million gallons per day (MGD).

Costs

The *Biosolids Technology Fact Sheet* [6] presents the operation costs for the filter press facilities at Williamsburg, Virginia. The total costs approximately $40/dry ton and maintenance costs amount to $12/dry ton. Therefore, it can be concluded that recessed-plate filter presses carry relatively high capital costs.

Rehabilitation of Drying Beds

According to the *Biosolids Treatment Processes, Handbook of Environmental Engineering* [6] sludge drying bed dewatering is perhaps the simplest dewatering process. Dewatering occurs by drainage through the sludge mass, and by evaporation from the surface exposed to air.

Drying beds are commonly used in small plants, since they require little operator attention and skill, and use little energy. The limitations of this process are that it requires a large land area, requires stabilized sludge to prevent nuisance odors, is sensitive to climate, and is labor-intensive.

Advantages

- Low capital cost
- Low energy consumption
- Low to no chemical consumption
- Low operator skill and attention required
- Less sensitivity to sludge variability
- Higher cake solids content than that of most mechanical methods

Disadvantages

- Large space requirements
- Need for prior sludge stabilization
- Consideration of climatic effects
- Odor potential
- Sludge removal labor intensiveness

Costs

US EPA Municipal Wastewater Treatment Plant Construction Cost Index for the 2nd quarter of 1977, the capital construction cost could be approximated by Eq (1). The associated costs include excavation, process piping, equipment, concrete, and steel. In addition, such costs, as those for administration and engineering could be calculated from Eq (2). The total capital cost could be estimated from Eq (3).

Eq (1): $C_c = 25.27 \times 10^4 Q^{1.35}$ (1)

Eq (2): $C_{ae} = 0.2264 \times C_c$ (2)

Eq (3): $C_t = C_c + C_{ae}$ (3)

Where:

C_c is capital construction cost
Q is plant design flow, in MGD
C_t is total capital cost
C_{ae} is administration and engineering costs

Since the STS is designed to treat and manage 2 million gallons of sludge the total capital cost estimated is $790,000.00 for new drying beds [7].

SUMMARY AND CONCLUSIONS

Guaynabo Water Treatment Plant parameters and sludge production were analyzed to identify possible alternatives to rehabilitate or modify the current Sludge Treatment System. Plant operators complained about multiple overflow events, but data proved that the sludge generated and treated was an average of 0.90 MGD in 2019, 0.81 MGD in 2020, and 0.91 MGD in 2020. The design capacity of the STS is for 2 MGD, which indicates that the STS has the capacity to manage the effluent generated by the drinking water treatment process. The recirculation system is not working because the principal line and pumps are broken which causes that the STS could not be working properly. For better operation and treatment practices it is recommended to repair and rehabilitate the existing Sludge Treatment System. Also, it is highly recommended to replace the sludge recollecting system in the sedimentation basins.

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