Optimizing the Cubuy Water Treatment Plant for Achieving the Long Term 2 Enhanced Surface Water Treatment Rule Requirements

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Abstract *— The Long Term 2 Enhanced Surface Water Treatment Rule is requiring additional removal or inactivation of Cryptosporidium Oocyst for public drinking water system. The Cubuy Water Treatment Plant needs to provide an additional one log removal/inactivation of Cryptosporidium. This project has the main objective of determining the most efficient alternative to achieve the Long Term 2 Enhanced Surface Water Treatment Rule requirements. Three alternatives were considered using different approaches for removal or inactivation of the microorganisms. Existing facilities were evaluated to determine performance limiting factors. Field test were performed to identify possible operational or infrastructure deficiency problems. The best alternative was selected based on: Net Present Value, Reliability, Complexity, and Environmental Impacts. The recommended alternative includes filter plant optimization and disinfection using ultraviolet reactors. This alternative is capable of comply with the new regulatory requirements and corrects other Plant compliance problems.*

Key Terms *— Cryptosporidium, Filter Assessment, Long Term 2 Enhanced Surface Water Treatment Rule, Water Treatment Plant.*

INTRODUCTION

The Safe Drinking Water Act (SDWA) is the main federal law that protects the public health by regulating the nation's public drinking water supply. Later, the SDWA authorized the Environmental Protection Agency (EPA) to set standards for potable water protection to work together to ensure that these standards are complying. The 1996 amendments to the SDWA require EPA to develop rules to balance the risks between microbial pathogens and disinfection byproducts (DBPs).

In order to improve the public health protection through the control of microbial contaminants, it was created the Long Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR). Later on January 5, 2006 the USEPA published the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), to address higher risk of public water contamination with Cryptosporidium microorganism, aiming for protection measures beyond those required for existing regulations [1].

The LT2ESWTR has the objective of reducing microbial contamination, especially the protozoan parasite Cryptosporidium. The LT2ESWTR requires source water monitoring at public water system (PWS) that use surface water or ground water under the direct influence of surface water (GWUDI). Based on system size, systems need to monitor for Cryptosporidium, *E. coli*, and turbidity [2]. Therefore, not all systems will need additional protection, and the decision as to which treatment technique(s) should be implemented should be based on site specific conditions.

Current regulations require filtered water systems to reduce source water Cryptosporidium levels by 2-log (99 percent). Recent data on Cryptosporidium infectivity and occurrence indicate that this treatment requirement is sufficient for most systems, but additional treatment is necessary for certain higher risk systems [3]. These higher risk systems include filtered water systems with high levels of Cryptosporidium in their raw water sources and all unfiltered water systems, which do not treat for Cryptosporidium.

In order to comply, the EPA and the Puerto Rico Department of Health (PRDOH) have adopted a multiple barrier approach for treating drinking water. All Water Treatment Plants (WTP's) in Puerto Rico monitored there source water. Based on the EPA's Source Water Monitoring Guidance Manual for PWSs for the Final LT2ESWTR [4], water systems were divided into four groups depending on system size. This project is focused on Cubuy WTP included in Group 4, which are those systems that serve less than 10,000 people. For these systems two options were available to monitor their raw water sources: conduct *E. coli* monitoring first and based on those results, the system may or may not need to conduct Cryptosporidium monitoring; or systems may go directly to Cryptosporidium monitoring. The Puerto Rico Aqueduct and Sewer Authority (PRASA) selected option 2.

DESCRIPTION OF EXISTING FACILITY

The CWTP is a conventional surface water treatment plant, which provides drinking water for approximately 3,095 people in the Cubuy WTP service area. This service area includes the Maizales and Río Blanco sectors of Naguabo. The CWP has a design capacity of 0.50 million of gallons per day (MGD), with an average flow of approximately 0.31 MGD.

The raw water intake, known as "La Mina", is located approximately 1 mile from the CWTP. The intake has a single bar screen with the objective of retaining the larger suspended material, then the water is conveyed by gravity through an 8-inch raw water pipe to the treatment facility.

The CWTP is composed of two steel tanks modules consisting of flocculation, sedimentation and filtration compartments, a holding tank and a clear well. In order to treat the sludge accumulated, the plant has a holding tank, a sludge thickener and two sludge drying beds. The plant also has a dry sludge storage area.

Chlorine and primary polymers are injected into the raw water line prior to entering the flocculation unit. A static mixer installed in the pipe accomplished the rapid mixing necessary to promote particle destabilization to promote an adequate flocculation process. Then the water passes to the flocculation chamber, in which the slow mixing occurs to allow the formation of bigger flocs that will be able to settle in the next process. Following flocculation the water flows to the sedimentation chambers, which are equipped with tube settlers. Then the water is conveyed through surface collector launders to the filters. The filters are dual media filters, consisting of anthracite and sand media. The filtered water flows by gravity to the clear well, in which the post disinfection is performed. The facility uses chlorine for disinfection.

METHODOLOGY

In order to achieve the objectives of this Project, the following methodology will be followed.

Assessment of Plant Performance

The performance assessment uses historical data from plant records supplemented by data collected during a filter assessment. This data was used to determine the status of the Cubuy WTP relative to achieving certain performance criteria to comply with the LT2ESWTR, and allows identifying possible causes of non-compliance. To achieve compliance, the Cubuy WTP must demonstrate that it can produce consistent high quality finished water, regardless of constant changes in raw water characteristics. The performance assessment determines if major unit treatment processes consistently perform at optimum levels to provide maximum multiple barrier protection. To achieve great result of the assessment of the plant, various analyses of the plant operation and unit processes must be performed.

Evaluation of Major Unit Processes

The major unit process evaluation is an assessment of the treatment potential, from the perspective of the capability of existing treatment processes to achieve enhanced performance levels. The major units were evaluated for capacity of each individual unit, and also for the capability to handle peak instantaneous flows [5]. The peak instantaneous flow is generally determined from historical data. The major unit processes evaluated was: flocculation, sedimentation, filtration and disinfection. The evaluation was based on an assessment of the existing unit process to meet enhanced performance goals, not the goals that the existing facility was designed to achieve. The objective is to classify the treatment units in one of three types of units. Type I: can manage the peak instantaneous flow; Type II: can manage the peak instantaneous flow with operational changes; and Type III: the units that will require infrastructure improvements.

Review and Trend Charting of Plant Operating Records

Trend graphs were prepared based on the maximum daily turbidities, from one year of data of Cubuy WTP operating records. Turbidity data were collected for the raw water, settled water, finished water, and individual filter effluents. A performance potential graph is used to evaluate major unit processes. The potential graph will show the flow capacity of each major unit; this would be compared to the instantaneous peak flow of the plant. Maximum data from the most recent one year were used, to prepare trend charts since the goal is to assess the integrity of each barrier at the peak time.

The CT, concentration of chlorine per contact time, was calculated to evaluate efficiency of disinfestation and inactivation for Giardia lamblia and virus.

In addition, a filter assessment was performed to evaluate each filter to identify anything that is hindering the performance of a non-optimized filter. Different tests can be performed to evaluate the performance of each filter: Visual inspection of the media condition, Evaluating backwash protocol, Visual backwash observation, Bed expansion test, Rise rate test, and Backwash water turbidity profile are some.

EVALUATION OF EXISTING FACILITY

As part of this design project, an evaluation of the plant's current compliance status was performed. The compliance status evaluated several parameters including haloacetic acids (HAA_5), turbidity, total organic carbon (TOC), and total trihalomethanes (TTHM). The results were compared with the EPA regulatory compliance data in order to identify the improvements that are needed to achieve full compliance.

Total Carbon and Disinfection by Products

Under Stage 1 of the Environmental Protection Agency, Disinfectants and Disinfection By-product Rule, a treatment technique is established for the removal of TOC. By reducing the level of TOC, the formation of the Disinfection by Products (DBP's) will also be reduced. The treatment technique is enhanced coagulation and it applies, depending on the TOC and alkalinity levels in the raw water source, to public water systems using conventional filtration.

Figure 1 shows the average removal ratio of TOC per trimester. The federal regulations requires to the public drinking water system to inform the running annual average ratio. The regulation requires that systems maintain through the year a removal ratio equal or greater than 1. Based on these values, the annual running average from January 2010 to December 2011 is 1.10. There was no data available for the second trimester of 2011.

Figure 1
Removal Ratio for TOC in Cubuy WTP

Other parameters evaluated were HAA5 and THHM. The regulatory maximum contaminant levels (MCL) of these compounds are 0.08 parts per million (ppm) and 0.06 ppm for TTHM and HAA5, respectively.

Figure 2 shows the HAA5 data obtained during period 2010 to 2011. It can be observed, that compared to the MCL the parameter was achieved consistently over these periods. However, it is important to point out that the second trimester of the two periods evaluated overpassed the 75 percent of the MCL. This requirement goal is established in order to notice that the results are close to reach the MCL and in case that in a near future the regulation change, it could be possible that the Plant would not achieve compliance. The reason that the results of this parameter are higher than the requirement goal could be because the season of the year; the second trimester comprise the months from April to June which are considered months of high precipitation.

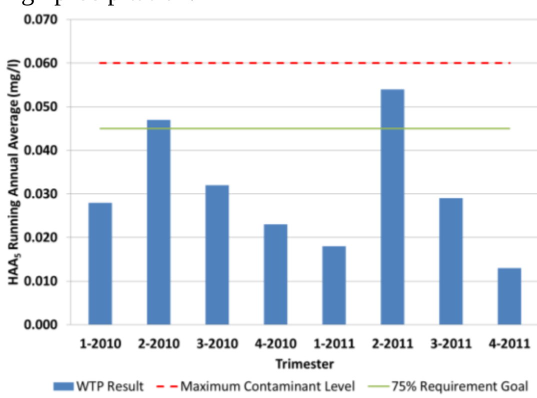

Figure 2
HAA5 Data for Cubuy WTP

TTHM were also evaluated for the period of 2010 to 2011. Figure 3 shows the data obtained for TTHM. This figure shows that the plant did not exceed the MCL. However, the third trimester of 2011 the plant exceeded the requirement goal of TTHM with a value of 0.0758 parts per million (ppm). As previously mentioned, this requirement goal is to indicate that the results are near the MCL.

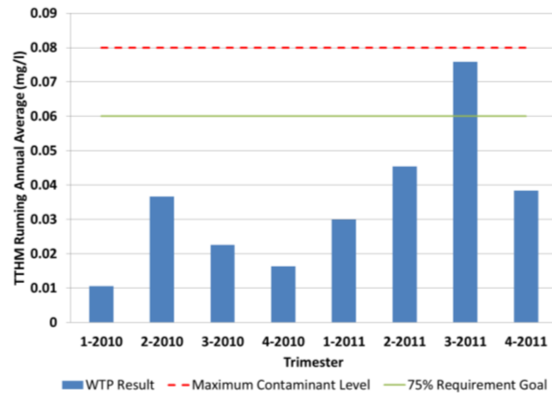

Figure 3
TTHM Data for Cubuy WTP

Turbidity

Turbidity is a measure of the cloudiness of water and it is a key parameter in determining water quality. The turbidity limits established by law are 0.3 Nephelometric Turbidity Unit (NTU) 95% of the time, and not exceeding 1 NTU at any time, except for the first 15 minutes after a filter backwash.

Despite the fact that there are regulatory limits, it is preferable to measure the Plant's performance with stricter parameters, such as optimization limits proposed in the EPA Handbook CPE Manual [5]. Some of EPA's optimization limits considered for the purpose of this evaluation are:

- For a facility to be optimized, the combined filter effluent should be under 0.1 NTU 95% of the time and not exceeding 0.3 NTU at any moment.
- Over filter effluent should be less than 2 NTU when raw water turbidity is 10 NTU or greater. If the average raw water turbidity is less than 10 NTU, then the limit is less than 1 NTU for the clarified water.

Daily turbidity data from the plant was provided by PRASA for the period 2012 through 2013. Figure 4 shows a turbidity profile for the Cubuy WTP. This figure shows turbidity values for raw water, over filters, combined filter effluent compared with the sedimentation effluent goal, regulatory requirement and with the effluent goal. As shown in Figure 4, the Cubuy WTP experienced high turbidity variable spikes in its raw water (pink line) during this period. A WTP should be capable of managing these spikes when operated properly. The 95 percentile of the turbidity values for raw water is 54.22 NTU. Therefore the sedimentation effluent should be less than 2 NTU. As demonstrated in the figure, although the CWTP frequently achieved values less than 2 NTU in the over filters samples (dark red line), some exceedances above this limit were observed. The combined filter effluent (green line) shows values of less than 0.3 NTU. It is important to state that the 95 percentile of combined filter effluent values resulted in 0.3 NTU, which is the regulatory turbidity requirement. However, the combined filter effluent does not achieve the optimized goal of 0.1 NTU 95 percent of time. Also various spikes are over the sedimentation effluent goal.

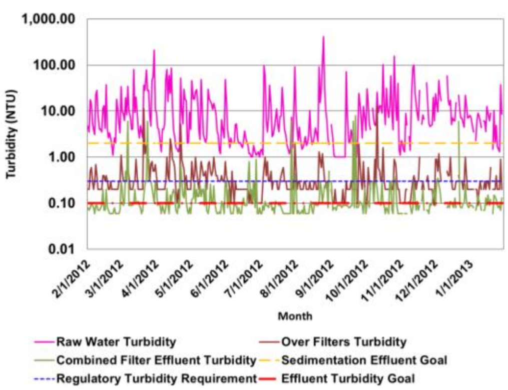

Figure 4
Turbidity Profile of Cubuy WTP

Also the monthly turbidity compliance percentages from the CWTP for the period between 2010 through 2011 were also obtained from PRASA. Figure 5 shows the monthly turbidity removal percentages. It can be observed that the plant achieved 100% compliance for all the period. There was no data available for the months of January through March of 2010.

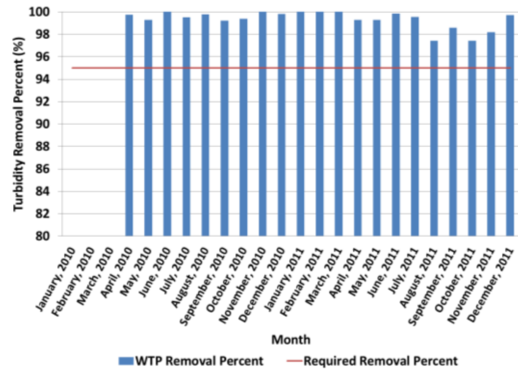

Figure 5
Turbidity Monthly Turbidity Compliance Percentages

Bacteriology

The Total Coliform Rule (TCR) is the Federal regulation under the SDWA that sets MCLs and monitoring requirements for certain biological contaminants [6]. It requires every public water system to periodically collect samples and analyze them for bacteria called coliforms. Total coliforms are a group of closely related bacteria that are generally harmless. Their presence in drinking water suggests that there has been a breach, failure, or other change in the integrity of the water system and pathogens may have entered into drinking water. The number of routine samples required each month, quarter, or year depends on the system size and source water. This information is established by the EPA on the Total Coliform Rule. According to this Rule, Cubuy WTP requires 3 samples per month. These samples are taken in predetermined points in the distribution systems. These points are determined in cooperation with the Puerto Rico Department of Health. The bacteriology results of Cubuy WTP were analyzed for the periods of 2010 through 2011, resulting in positive samples ranged between 2–8. The system incurred in violations in two months, January and February of 2010.

Potential Performance Graph

To assess the Plant’s capacity for managing the peak instantaneous flow a potential performance graph (PPG) was generated. Figure 6 shows the PPG of the Cubuy WTP, showing a peak instantaneous flow of 0.5 mgd.

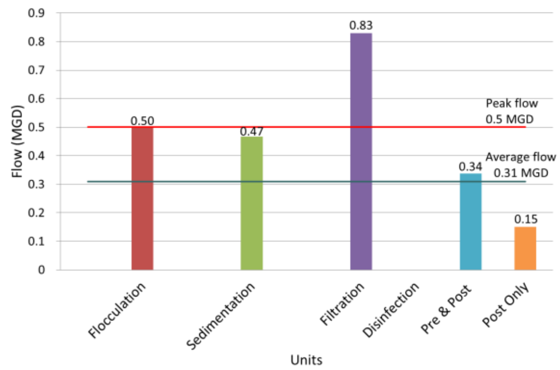

Figure 6
Cubuy WTP Potential Performance Graph

As shown on Figure 6, it can be concluded that the flocculation and filtration units processes has the capacity to handle the peak flow of the Plant, however the sedimentation and disinfection processes does not have capacity to treat the peak flow. The disinfection unit is capable of treat only the 68% of the plant's peak flow. This means that capital improvements are necessary to be able to treat the 0.5 MGD.

CT Evaluation

The CT factor shall be calculated to all surface water system or groundwater systems under the direct influence of surface water. CT represents the concentration of free chlorine residual in mg/l in a contact time in minutes. Once the actual CT is calculated, this number must be compared to a minimum CT value set by EPA. This value is used to illustrate the effectiveness of chlorine to inactivate Giardia cysts.

To effectively determine the CT value for Cubuy WTP, the facility was divided by chlorine injection points. The first group includes the flocculation and sedimentation units, while the second group includes the filters and the distribution tank. Once the contact time is calculated (volume divided by the flow rate), it is necessary to adjust this time with a baffling factor. The baffling factor to be assigned is based on the description of CPE Manual, 1998. The actual CT is the sum of the CT's obtained for group 1 and 2.

Table 1 shows the calculations performed for the CT evaluation in each unit processes. The CT values for the 3-log inactivation of Giardia lamblia Cysts (CT 99.9) and the 4-log inactivation for viruses (CT 99.99) are 157.7 and 2.4, respectively. These values are taken from the CPE Manual based on the pH and temperature of the Plant, as established by EPA.

To compare the compliance of the actual CT value for the facility with the value required by EPA, a ratio is calculated. If the ratio is greater or equal to 1.0, adequate disinfection is provided.

Table 1
CT Calculation of Cubuy WTP Existing Conditions

	Floculation	Sedimentation	Filtration	Distribution Tank
Volume	12,925.44	26,198.00	12,925.44	75,000.00
Flow rate (gpm)	347.22	347.22	347.22	347.22
Theoretical Detention	37	75	37	216
Baffling Condition	Average	Unbaffled (mix flow)	Average	Unbaffled (mix flow)
Factor	0.5	0.1	0.5	0.1
T_{10} (min)	18.6	7.5	18.6	21.6
Disinfectant	0.1		0.8	
pH	7.6			
Temp (°C)	23			
CT Value	2.6		32	
			CT Total	35
			CT 99.9	157.7
			CT 99.99	2.4
			Giardia lamblia Ratio (99.9)	0.22
			Viruses Ratio (99.99)	14.49

It can be observed in Table 1, the CT value for Cubuy WTP is 35. This ratio value is under the CT required for 3-log inactivation for Giardia lamblia Cysts, but complies with the 4-log inactivation for viruses.

Filter Assessment

The objective of the filter assessment is to understand limiting factors affecting the filtration process [7]. This unit is particularly important because is the final barrier for removing microorganism of the treatment plant. The test performed to the Cubuy WTP included instantaneous turbidity profile through treatment processes, filter backwash assessment and filter recovery evaluation. It was intend to measure the media expansion of the filter during backwash evaluation. This test consists in measuring the expansion of the filter media during the high rate filter backwash. However it could not be completed because after completed the back wash process the water was turbid and the measuring device cannot be appreciated. The assessment was performed to filter No. 1.

Proper maintenance of filters is essential to preserve the integrity of the filter as constructed. Technical resources consider a filter to be adequately clean when the spent backwash water turbidity is in the range of 10-15 NTU [8].

The backwash process was performed on automatically, and lasted only five minutes. It was observed mudballs were formed on the top of the media. The presence of mudballs in the filter media is an indication of inadequate filter backwashing over time. The backwash process resulted on a turbidity of 21.3 NTU, therefore after finished the backwash the filter was unclean.

Another criterion to assess plant optimization is the filter recovery period. This period is comprised by the 15 minutes following a filter backwash. Ideally it is required that the filter recuperate in 15 minutes. During this period it is desirable that the turbidity in the filtered water does not exceed 0.3 NTU and that it stabilizes at less than 0.1 NTU in less than 15 minutes [9].

The turbidity resulted on approximately 0.25 NTU which is higher than the expected stabilization value of 0.1 NTU.

Evaluation of Alternatives

Three alternatives were evaluated to identify improvements in the Cubuy WTP to provide the 1.0-log removal requirement for Cryptosporidium of the LT2ESWTR. In addition, other rehabilitation activities not associated with the LT2ESWTR have been included.

Alternative No. 1 – Optimization of Existing Facility

The LT2ESWTR provides a 0.5-log removal credit if the combined filter effluent (CFE) turbidity measurements taken for any month are less than 0.15 NTU in at least 95 percent of the measurements. An additional 0.5-log removal credit is awarded if the individual filter effluent (IFE) turbidity measurements are less than 0.15 NTU in at least 95 percent of the values recorded in each month, excluding the 15 minute period following return to service from a filter backwash; and no individual filter has an IFE measured turbidity greater than 0.30 NTU in two consecutive measurements taken 15 minutes apart. This alternative will focus on meeting the LT2ESWTR requirements by the optimization of the combined and individual filter performance.

Based on the PPG included in Figure 6, the existing filters have a treatment capacity of 0.83 MGD, which results in the need to provide an additional filter unit to achieve the desired 4.0 gpm/ft^2 with one unit out of service because with only one filter the filtration ratio is approximately 4.82 gpm/ft^2 which is higher than the desired. By providing an additional filter of the same dimensions of the existing units (9 ft long by 8 ft wide), the maximum capacity of the filters would be 2.21 MGD. With the new filter unit, the loading rate of the filters at the maximum flow of 0.5 MGD would be 1.60 gpm/ft^2 with all units in operation, and 2.41 gpm/ft^2 with one unit out of service. These loading rates result in a robust system that should be able to achieve the additional 1.0-log removal credit by meeting the CFE and IFE turbidity criterion included in the LT2ESWTR. To optimize the system, the existing filters should also be rehabilitated and upgraded as part of the alternative. Rehabilitation activities shall include: replacement of underdrain, filter media and addition of an air scouring system, along with instrumentation to provide the operator the necessary information to optimize the operation of these units.

To address non-compliance events recorded for the HHA5 and TTHM, it is recommended to reduce the disinfection achieved by pre-chlorination in the facility and provide additional contact time to achieve a higher degree of disinfection via post-chlorination reducing the bacteriology. At the maximum flow of 0.5 MGD, and considering a temperature of 23°C, pH of 7.6 and chlorine concentration of 0.8 mg/l, the required CT to achieve a 3-log inactivation of Giardia with post-chlorination only would be 157.7, resulting in a contact volume of approximately 100,000 gallons. Therefore the construction of a new tank of 0.1 million gallons it is recommendable. Table 2 shows the cost estimate of the Alternative No. 1.

Table 2
Alternative 1 – Cost Estimate

Items	Cost
New Tube Settlers in Sedimentation Basin	$ 36,100.00
New Continuous Sludge Removal System	$ 48,100.00
New Filter	$ 36,100.00
Rehabilitation of existing Filters	$ 72,200.00
New Contact / Distribution Tank (0.1 MG)	$ 130,000.00
New Control System and Instrumentation	$ 18,100.00
Sub-Total	**$ 340,600.00**
Site work & Yard Piping (5%)	$ 17,100.00
Electrical Work (8%)	$ 27,300.00
Construction Cost Sub-Total	$ 385,000.00
Overhead & Profit (18%)	$ 69,300.00
Total Construction Cost	$ 454,300.00
Total Investment Cost	**$ 708,800.00**

Alternative No. 2 – Optimization of Existing Facility + UV System

This alternative considers the same improvements explained on Alternative No. 1, but also includes installation of a UV reactor upstream of the new contact / distribution tank. The improvements proposed in Alternative 1 are necessary because the water quality needed in the UV influent is important to avoid reactor fouling due to raw water contaminants. The UV system will have the capacity of treating the peak flow of 0.5 MGD, and should provide enough dose to meet the required 1.0 log removal credit. This unit will be constructed after the existing combined filter effluent. This alternative could provide a 1.0-log removal credit; which should be sufficient to meet the LT2ESWTR requirements for the Cubuy WTP, even if the plant fails to meet the CFE or IFE turbidity criterions for filter optimization described under Alternative No.1.

An advantage of the UV disinfection system would meet both Giardia and Cryptosporidium inactivation requirements, resulting in a reduction of the contact tank volume required to meet with disinfection requirements. Even with a UV system, chlorine use will still be required in the facility, mainly to achieve virus inactivation, and to maintain the minimum required residual chlorine in the distribution system. Table 3 shows the cost estimate of the Alternative No. 2.

Table 3
Alternative 2 – Cost Estimate

Items	Cost
New Tube Settlers in Sedimentation Basin	$ 36,100.00
New Continuous Sludge Removal System	$ 48,100.00
New Filter	$ 36,100.00
Rehabilitation of existing Filters	$ 72,200.00
New Contact / Distribution Tank (0.1 MG)	$ 130,000.00
New Control System and Instrumentation	$ 18,100.00
New UV System	$ 60,100.00
Sub-Total	**$ 400,700.00**
Site work & Yard Piping (5%)	$ 20,100.00
Electrical Work (8%)	$ 32,100.00
Construction Cost Sub-Total	$ 452,900.00
Overhead & Profit (18%)	$ 81,600.00
Total Construction Cost	$ 534,500.00
Total Investment Cost	**$ 833,900.00**

Alternative No. 3 – Optimization of Existing Facility + Membrane System

This alternative is similar to Alternative No. 1 but also includes installation of a pre-engineered membrane package plant for polishing to the combined filter effluent. The membrane system will have the capacity of treating the peak flow of 0.5 MGD. Membrane systems can receive 1.0 log removal credit after challenging testing demonstrated with integrity tests.

This unit will be constructed after the existing combined filter effluent. This alternative could provide a 1.0-log removal credit; which should be sufficient to meet the LT2ESWTR requirements for the Cubuy WTP, even if the plant fails to meet the CFE or IFE turbidity criterions for filter optimization described under Alternative No. 1. This provides a safety factor in terms of compliance with the new regulatory requirements making easier the plant operation. Table 4 shows the cost estimate of the Alternative No. 3.

Table 4
Alternative 3 – Cost Estimate

Items	Cost
New Tube Settlers in Sedimentation Basin	$ 36,100.00
New Continuous Sludge Removal System	$ 48,100.00
New Filter	$ 36,100.00
Rehabilitation of existing Filters	$ 72,200.00
New Contact / Distribution Tank (0.1 MG)	$ 130,000.00
New Control System and Instrumentation	$ 18,100.00
New Membrane System	$ 480,800.00
Sub-Total	**$ 821,400.00**
Site work & Yard Piping (5%)	$ 41,100.00
Electrical Work (8%)	$ 65,800.00
Construction Cost Sub-Total	$ 928,300.00
Overhead & Profit (18%)	$ 167,100.00
Total Construction Cost	$ 1,095,400.00
Total Investment Cost	**$ 1,708,900.00**

SELECTION OF ALTERNATIVES

In order to encourage the objectivity and uniformity of the analysis, the mean weighted average method has been used for the selection of the recommended alternative. The criteria considered in the comparison were: Net Present Value (NPV); Which alternative provides greater reliability to the system; Complexity of the proposed alternative in terms of both construction and operation; The impact that the project will have on the environment.

A scale from 0 thru 5 was used, 5 meaning fully compliance to the criterion and 0 no compliance.

A description of the items that were considered for each of the criterion used for the evaluation is presented below:

- Net Present Value - As expected, after analyzing capital and O&M costs for each alternative it was concluded that the filter optimization alternative presented the best NPV, which is lower than the other alternatives that considered the filter optimization with additional barriers to meet the LT2ESWTR requirements. Among the other alternatives, the alternative to use the UV system as the additional barrier to meet the LT2ESWTR requirements resulted in the lower NPV, followed by the membrane system.
- Reliability - This criterion considered the reliability of the system to obtain the credits required by the LT2ESWTR. The most reliable alternatives were the membrane and UV, even if the plant fails to meet the IFE and CFE turbidities on any given month. Finally, the filter optimization alternative is the least favored since the compliance is dependent on the monthly results of the IFE and CFE turbidities, without having an alternate mean to obtain removal credits.
- Complexity - For this criterion the highest ranking was awarded to the filter optimization alternative since it represent the lowest amount of construction activities for this reason less complicated. When considering the magnitude of the construction activities, Alternative No.1 would be followed by Alternative No. 2 the installation of the UV system and finally Alternative No. 3 the membrane system because it requires the construction of the unit and will need a challenging test to receive the treatment credit.
- Environmental Impacts - For this criterion, the highest rankings were issued to the filter optimization and the UV system, since this alternatives contemplates the construction of new structures outside of the existing PRASA property limit but when compared with Alternative No.3 required the less additional space, in areas that have not being impacted. The Alternative No.3 received the lower ranking because it will impact an additional area. All alternatives will require the demolition of existing structures and an assessment to determine the presence of asbestos and lead based paint.

Table 5 presents the ranking gave to alternatives for all the evaluated criteria, and compared the obtained weighted average by criteria.

Table 5
Evaluation of Alternatives

Criterion	Weight	Alternative	Score	Weighted Score
NPV	0.25	I	5	1.25
		II	3	0.75
		III	1	0.25
Reliability	0.3	I	1	0.3
		II	5	1.5
		III	5	1.5
Complexity	0.2	I	4	0.8
		II	3	0.6
		III	1	0.2
Environmental Impact	0.25	I	3	0.75
		II	3	0.75
		III	2	0.5

Table 6 shows that Alternative No. 2 (Optimization of Existing Facility + UV System) obtained the highest ranking, with a total score of 3.6, closely followed by Alternative No. 1 (Optimization of Existing Facility), with a total score of 3.1. As mentioned previously, Alternative No. 2 would allow the plant to meet the LT2ESWTR even if the plant fails to meet the IFE and CFE turbidity limits for any given month, thus resulting in a highly reliable system.

Table 6
Evaluation of Results

Alternative	Total Score
I	3.1
II	3.6
III	2.5

Conclusion and Recommendations

The objective of this design project was to identify the improvements required in the Cubuy WTP to bring the plant into compliance with the LT2ESWTR and other enforcement activities applicable to the facility. The analysis included gathering raw water data of the facility to determine if the existing sizing of the treatment units is adequate and an evaluation of the plant's current compliance status.

After evaluating each of the alternatives, it was determined that the Optimization of Existing Facility with the UV system, which resulted in the second lowest NPV, provided a higher degree of reliability. As a result, it is recommended to implement the construction of a project to optimize the operation of the filters, while providing a UV system that would guarantee the required 1.0-log credit even if the IFE and CFE turbidities are not in compliance with the LT2ESWTR requirements. The total construction cost for the recommended alternative was estimated at $534,500, with an investment cost of $833,900 which is obtained multiplying the Total Construction Cost by a factor of 1.56.

The selected alternative provides solution to the problems identified in the Cubuy WTP; which are exceedances in bacteriology, DBP's and not compliance with CT requirements. Also, the facility does not achieve optimization goals. The selected alternative will provide the required Cryptosporidium oocysts removal required by the ESWTRLT2, and will improve the treatment process, which will result in the solution to the identified problems. This alternative offers the most reliable and practical solution. Also, when considering that with time, the regulation will become stricter, UV disinfection is an alternative that have the capability of be expanded with minor changes that will not represent a high investment from PRASA.

References

[1] EPA, "Long Term 2 Enhanced Surface Water Treatment Rule Toolbox Guidance Manual", 2010.

[2] EPA, "LT2ESWTR Source Water Monitoring for Systems Serving Less Than 10,000 People Factsheet", 2006.

[3] Idaho Department of Environmental Quality, "Implementation Guidance for the Long-Term 2 Enhanced Surface Water Treatment Rule", 2007.

[4] EPA, Fact Sheet - Long Term 2 Enhanced Surface Water Treatment Rule, 2005.

[5] EPA, "Optimizing Water Treatment Plant Performance Using the Composite Correction Program", 1998.

[6] EPA, "Total Coliform Rule", 2010.

[7] Bureau of Water, "Filter Assessment Manual", 2003.

[8] Kawamura, Susumu, "Integrated Design and Operation of Water Treatment Facilities" Second Edition, John Wiley and Sons, Inc., 2000.

[9] AWWA, "Optimum Backwash of Dual Media Filters and Granular Activated Carbon Filter-Adsorbers with Air Scour", 1990.