Morovis Sur Water Treatment Plant Optimization

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Abstract *— Morovis Sur Water Treatment Plant is one of the many water treatment plants in Puerto Rico which do not fully comply with regulatory requirements established by federal drinking water regulations. Following the methodology established by the Environmental Protection Agency Composite Correction Program, this project evaluates the plant's current performance, defines optimization performance goals and identifies the improvements needed to achieve those goals. Various treatment process improvements are necessary for the plant to fully comply with all applicable regulations. Major performance limiting factors identified were lack of plant process controllability, disinfection unit design less than adequate, lack of plant supervision and policies not clearly communicated to plant personnel. The alternative selected to optimize the plant consists of utilizing current infrastructure and provide the necessary improvements to achieve optimization goals.*

Key Terms *— Drinking Water Regulatory Compliance, EPA Composite Correction Program, Optimizing Water Treatment Plant, Water Treatment.*

INTRODUCTION

The World Health Organization (WHO) estimates that about 10% of diseases globally are attributable to water-quality, sanitation or hygiene related problems. Only 53% and 80% of the global population has access to basic sanitation and a reasonably safe and adequate supply of water, respectively [1]. The Safe Drinking Water Act (SDWA) is the main federal law that ensures the quality of drinking water in the United States. Under SDWA, the Environmental Protection Agency (EPA) is authorized to set standards for drinking water quality and oversees the states, localities, and water suppliers who implement those standards [2]. Currently, there are several water treatment plants in Puerto Rico (PR) that do not fully comply with SDWA regulatory requirements. The Morovis Sur Water Treatment Plant (MSWTP) is one of the water treatment plants in PR that do not fully comply with the SDWA requirements. The plant's raw water source is Rio Grande de Manatí. The quality of the water from this source is variable since the turbidity is affected by erosion caused by rain in the area; therefore raw water supply is highly vulnerable to contamination from surface runoff and must be treated to ensure public health conditions. Various treatment process improvements are necessary for the WTP to fully comply with all applicable regulations. This design project assesses the current plant's performance, evaluates the major unit processes, defines optimization performance goals, identifies and prioritizes the performance limiting factors and identifies the improvements needed to achieve compliance with current drinking water regulations while achieving the optimization goals.

PROBLEM STATEMENT

The main purpose of a water treatment plant is to produce water that complies with drinking water regulatory requirements at a reasonable cost for the customers. In spite of all the regulations and standards that apply to public water systems, the principles of conventional water treatment process have not significantly changed over time.

Existing Facilities

The MSWTP is a conventional surface water treatment plant that provides water supply for approximately 25,000 people in the Morovis Sur service area. It normally operates at approximately 3.0 MGD. The peak instantaneous flow for the plant is approximately 3.86 MGD (~1,350 gpm). Historically the WTP has confronted difficulties achieving compliance with water quality regulations. Primary regulatory non-compliance concern is with Disinfection by Products.

The plant's raw water intake is located approximately two miles from the MSWTP. Secondary and primary polymers and chlorine are injected into the raw water line prior to entering the flocculation unit. Mixing is accomplished strictly by hydraulic turbulence caused by the water flow in the pipe and entering the flocculation unit. The WTP has two flocculation/sedimentation treatment trains. These trains includes: four mixing flocculation chambers and a superpulsator and a flocculator / tube settler unit (two flocculating motors/paddles and tube settlers-currently not being used). The plant is equipped with a mechanical sludge collection system that is inoperable. Following sedimentation the water flows through a 24-inch line to eight dual media filters. These filters were designed to contain 0.51 meters (approximately 24 inches) of anthracite and 0.36 meters (approximately 14 inches) of sand over a 20-inch gravel and underdrain base. The water flows by gravity from the filters to a clear well adjacent to the filters. Chlorine is injected at the inlet to the clear well. Finished water is pumped into the distribution system both before and after entering the concrete ground storage tank. There are two lines that distribute water prior to entering the tank and a third line distributes water after the storage tank.

Optimization Goals

An assessment of performance at the MSWTP will be conducted to identify whether specific treatment unit process are performing as intended and to determine if the plant can comply with specific performance goals. Despite regulatory requirements it is preferable to measure the plant's performance to stricter parameters such as optimization limits proposed by the EPA Composite Correction Program. Applying stricter parameters will enhance water treatment to provide higher quality drinking water. The optimization performance goals are described below [3].

- Minimum Data Monitoring Requirements: daily raw water turbidity; settled water turbidity at 4-hour time increments from each sedimentation basin; on-line (continuous) turbidity from each filter; one filter backwash profile each month from each filter.
- Individual Sedimentation Basin Performance Goals: settled water turbidity less than 1 NTU 95 percent of the time when annual average raw water turbidity is less than or equal to 10 NTU; settled water turbidity less than 2 NTU 95 percent of the time when annual average raw water turbidity is greater than 10 NTU.
- Individual Filter Performance Goals: filtered water turbidity less than 0.1 NTU 95 percent of the time (excluding 15-minute period following backwashes) based on the maximum values recorded during 4-hour time increments; if particle counters are available, maximum filtered water measurement of less than 10 per milliliter; maximum filtered water measurement of 0.3 NTU; initiate filter backwash immediately after turbidity breakthrough has been observed and before effluent turbidity exceeds 0.1 NTU; maximum filtered water turbidity following backwash of less than 0.1 NTU; maximum backwash recovery period of 15 minutes.
- Disinfection Performance Goals: CT (disinfectant concentration) values to achieve required log inactivation of Giardia and virus; Total Trihalomethanes (TTHM) values less than 0.08ppm and Haloacetic Acids (HAA_5) values less than 0.06ppm; Zero positive samples in bacteriology. Therefore, the objectives of this design project is to evaluate current plant's performance and compare it to the optimization goals, propose different alternatives to achieve the above optimization goals and select the most cost effective alternative that will help the facility achieve

these goals and comply with regulatory requirements.

METHODOLOGY

To achieve the objectives of this project, the following methodology will be followed:

- Assessment of Plant Performance utilizing historical data from plant records from October 2010 through October 2011.
- Review and Trend Charting of Plant Operating Records
- Evaluation of Major Unit Processes based on their capability to handle current peak instantaneous flow requirements. The major unit processes included in this evaluation are: flocculation, sedimentation, filtration and disinfection.
- The areas of design, operation, maintenance and administration will be evaluated in order to identify factors which limit plant's performance. After prioritization of the Performance Limiting Factors, different alternatives will be developed in order to provide potential solutions for the plant to achieve optimization goals.

DATA ANALYSIS AND PROCESS EVALUATION

The assessment was completed for the flocculation, sedimentation, filtration and disinfection treatment processes. The analysis is based on data from plant records from October 2010 through October 2011 and special studies performed during the WTP site visits. The parameters that will be discussed below were chosen in order to evaluate plant's performance compared to optimization goals.

Flow

MSWTP average flow is 2.7MGD with a peak flow of 3.86 MGD (see Figure 1). Plant's production for this period ranged between 0.5 and 3.3 MGD 99.44% of the time. Values exceeding 3.3 MGD only occurred once (0.56% of the time). The improvements that are proposed in this design project are directed towards achieving full compliance at the plant for flows up to 3.86 MGD (peak flow).

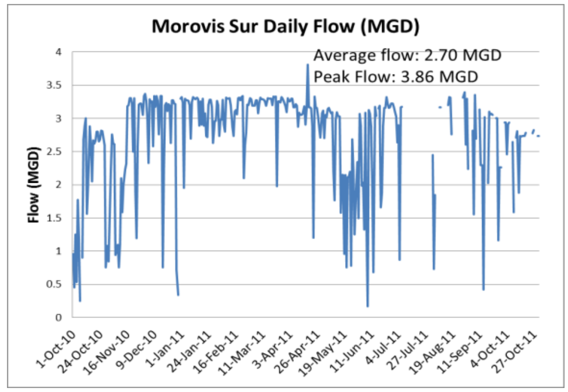

Figure 1

MSWTP Flow Profile

Turbidity

Figure 2 shows the maximum daily recorded raw water and combined filter effluent turbidities plotted against time on a semi-log graph. The raw water turbidity has an average of 179.6 NTU and ranged from 2 NTU to 2,140 NTU. The performance optimization criteria establish a settled water goal of <2 NTU 95 percent of the time. At the MSWTP, settled water turbidity is not a parameter that has been measured to date, therefore, it is unknown if the settled water optimization goal of <2 NTU 95% of the time is achieved by the plant.

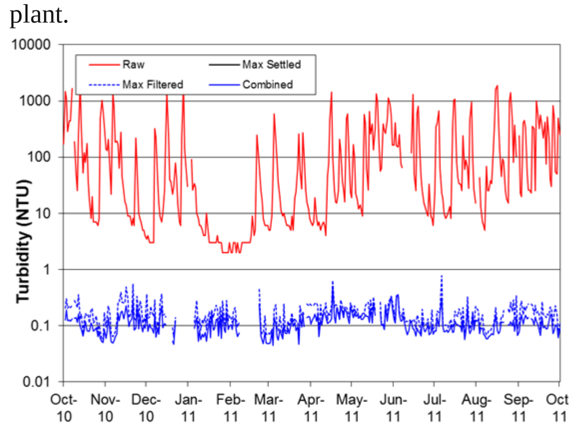

Figure 2

MSWTP Turbidity Profile

Values of less than 0.1 NTU were obtained in the combined filter effluent. The MSWTP complied with the regulatory limit, obtaining 96.41% of samples under 0.3 NTU. However, the plant only obtained 46.69% of the samples under 0.1 NTU, thus some improvements are needed to reach the optimization goals.

Chemical Feed Equipment

Raw water turbidity fluctuates a lot in the MSWTP; therefore coagulant feed rates must be adjusted as necessary to achieve desired results. Currently operators do not perform Jar Tests to determine the exact coagulant dosage required. The coagulant feed pump is manually adjusted. Operators stated that chemical dose rates and feed pump adjustments were based "on experience". Chlorine gas is fed at the head of the plant and at the inlet of the contact tank.

Turbidimeter Calibration Verification

There is a portable turbidimeter located at the control room which the operators calibrate on a daily basis using standards and they record these values. Also the plant has turbidimeters at the effluent of each individual filter effluent but one of the Optimization Goals for the Minimum Data Monitoring Requirements is to have at least one filter backwash profile each month from each filter. Currently PRASA does not gather information regarding filter backwashing practices for the filters at the plant. The monitoring of the filter backwashing practices would allow the water treatment plant to better assess the performance of each individual filter.

Sludge Treatment System (STS)

The existing STS is out of service and it has been reported to be under capacity. The waters discharged from the two pulse bed clarifiers, tube settling tank, and the filter backwash waters bypass the STS. Currently all the components of the STS are out of service most of them because malfunctioning.

Disinfection

Since chlorine is the disinfectant applied at the MSWTP, in order to inactivate the pathogenic microorganisms, the chlorine reacts with the natural organic matter in the water and forms disinfection by products (DBP). WTPs can control DBPs by three methods: removal of DBP precursors (i.e., natural organic matter), modifying chlorination strategy, or removing DBPs after formation, (most difficult process) [4]. In general, DBP formation will decrease as the removal of total organic carbons (TOCs) increases. Studies have found that adding chlorine downstream in the source water treatment process (e.g., adding after sedimentation) results in a reduction of DBP formation. However, some plants use the addition of chlorine to promote other pollutant removals prior to sedimentation (e.g., iron removal, manganese removal, taste/odor control, and color removal) [5].

Figure 3 shows that the plant does not seem to be confronting problems achieving the required removal of TOC (removal ratio ≥1) since TOC removal ratio values for this period range between 1.16 and 1.46.

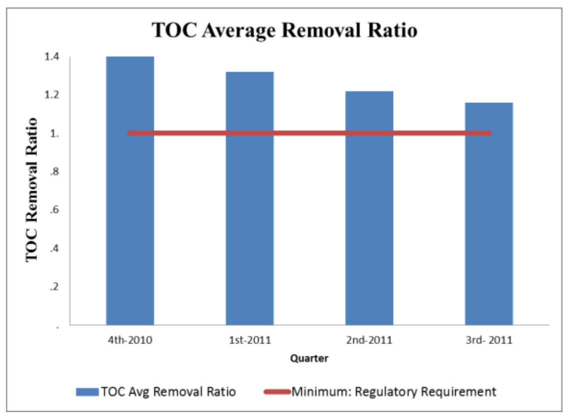

Figure 3

MSWTP Quarterly Average TOC Removal Ratio

Other parameters evaluated are Total Trihalomethanes (TTHM) and Haloacetic Acids (HAA_5). THMs are formed through the reactions of hypochlorous acid (HOCl) with natural organic matter in the presence or absence of bromide [6]. TTHMs and HAAs are a class of DBPs that have been implicated in a number of human health risks (cancer and noncancer risks). The regulatory maximum allowable limits of these compounds are 0.08 parts per million (ppm) and 0.06 ppm on an annual running average for TTHM and HAA_5, respectively. The plant had one permit violation for HAA5 during one trimester and TTHM regulatory limits were achieved consistently as shown in Figures 4 and 5.

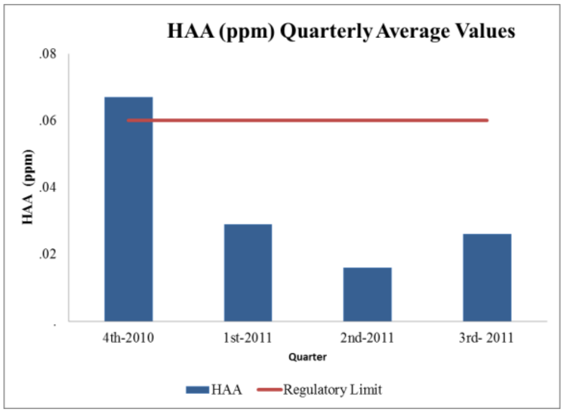

Figure 4

HAA5 Quarterly Average Values

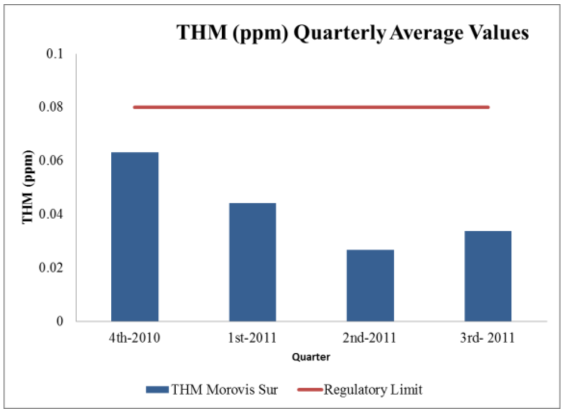

Figure 5

THM Quarterly Average Values

Total Coliform Rule

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 Total Coliform Rule (TCR) is the Federal regulation under the SDWA that sets maximum contaminant levels (MCLs) and monitoring requirements for certain biological contaminants. The number of routine samples required each month, quarter, or year depends on the system size (population serving) and source water. MSWTP required 30 samples per month from October 2010 to April 2011 (minimum samples required per month for a system serving a population of 25,001-33,000 people) and 25 samples per month from May 2011 to October 2011 (minimum samples required per month for a system serving a population of 21,501-25,000 people). The samples are taken in predetermined points in the distribution systems. These points are determined in cooperation with the Puerto Rico Department of Health. The MSWTP system incurred in bacteriology violations during three months: October 2010, February and July 2011.

CT Evaluation

Chlorine residuals are important to ensure the microbial safety of distributed drinking water. Requirements for disinfection of drinking water are defined in the Surface Water Treatment Rule (SWTR). According to the rule, treatment including disinfection must reliably achieve at least a 3-log (99.9%) removal and/or inactivation of Giardia Lamblia Cysts and a 4-log (99.99%) reduction and/or inactivation of viruses prior to the delivery of water to the first consumer. A control parameter considered and specified in the SWTR is the CT concept (the product of the disinfectant residual concentration (mg/L) and contact time (min) measured at peak hourly flow) [7]. This value depends on water pH, temperature, free chlorine concentration and desired log inactivation.

To effectively determine the CT value for MSWTP, the facility was divided by chlorine injection points. In this facility pre-chlorination is practiced and it is applied into the raw water line prior to entering the flocculation unit. The post-chlorination is injected at the entrance of the Contact Tank. Due to the pH and temperature used to calculate the CT value, the 3-log inactivation for Giardia Lamblia Cysts (CT 99.9) and the 4-log inactivation for viruses (CT 99.99) values established by the EPA are 90 and 2, respectively [8].

The CT was calculated based in the following assumptions or sampling: peak hourly flow of 3.86 MGD; baffling factor of 0.1 for the flocculation unit, 0.5 for the superpulsators and 0.7 for the filtration unit; baffling factor of 0.5 for the Contact Tank; maximum measured pH of 8.0; minimum water temperature of 20°C; chlorine residual concentration of 1mg/L for the flocculators and superpulsators; a measured chlorine residual concentrations of 0.35 mg/L in the filters effluent and 1.95 mg/L in the Contact Tank effluent.

To compare the compliance of the actual CT value for the facility with the value required by EPA, a ratio of CTactual/CT99 is calculated. If ratio is ≥1 then adequate disinfection is provided. Calculated CT value for MSWTP is 50. This value is under the CT required for 3-log inactivation for Giardia Lamblia Cysts with a calculated CTactual/CT99 ratio of 0.56. For the 4-log inactivation for viruses a ratio value of 25.11.

Performance Assessment Summary

A summary of the major unit process evaluation for the plant is shown as a Performance Potential Graph (PPG) in Figure 6. The PPG shows the treatment potential from the perspective of capability (adequate size to treat peak instantaneous operating flow) of existing treatment processes to achieve optimized performance levels.

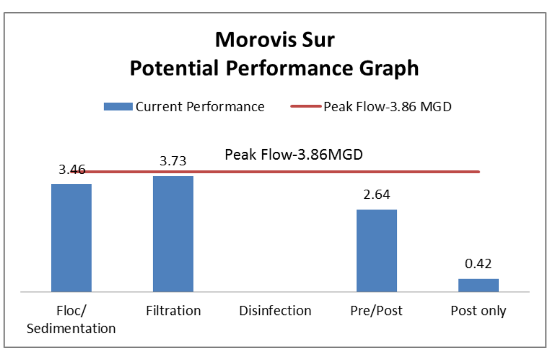

Figure 6

MSWTP Potential Performance Graph

Flocculation/Sedimentation

The objective of the flocculation process is to provide sufficient time and energy for the development of floc particles that can be removed in the sedimentation and filtration process. The flocculation units were evaluated based on the available hydraulic detention time and a single stage since the baffles were removed. Based on the single stage configuration and a water temperature of greater than 0.5° C, a minimum hydraulic detention time of 20 minutes was used for the evaluation.

The sedimentation process is commonly assessed by using surface overflow rates appropriate for basin configuration, size, depth, and best professional judgment of the evaluator. The MSWTP flocculation/sedimentation process was rated at 3.46 MGD based upon a surface overflow rate of 1.5gpm/ft^2 and 20 mins hydraulic detention time.

The potential performance graph shown in Figure 6 was developed using surface areas and volumes of equipment currently being used. In 2007 a parallel flocculation/tube settler unit was installed increasing the flocculation/sedimentation capacity by 1 MGD. Therefore when this module is in operation the actual rated capacity of the MSWTP flocculation / sedimentation unit is 4.46 MGD which is above the required to treat peak instantaneous operating flow as seen in Figure 7.

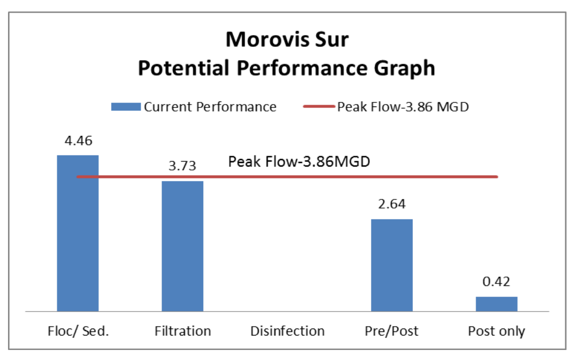

Figure 7

MSWTP Potential Performance Graph adding Flocculator/tube Settler Unit

Filtration

Filtration is the final barrier in the plant for particle removal. Normally dual media filters are capable of 4 – 6 gpm/ft^2, therefore, based upon the total surface area of the filters (4 in service) and a surface loading rate of 4.0 gpm/ft^2 filtration capabilities was rated at 3.73MGD.

Disinfection

The final microbial protection barrier in the plant is disinfection. The disinfection process was assessed based on Surface Water Treatment Rule requirements for 3-log removal and/or inactivation of Giardia Lamblia Cysts and 4-log removal/inactivation of viruses. The Giardia inactivation requirement is the most stringent disinfection criterion when free chlorine is used as a primary disinfectant; therefore, it was used as the basis of the disinfection evaluation. MSWTP disinfection process was rated at 2.64 (4 filters in service). The performance potential evaluation includes both pre- and post-chlorination. Disinfection is not adequate for all conditions of flow, temperature and pH given the current requirements of 3-log Giardia inactivation.

In summary, the limitations at the MSWTP would need capital improvements to achieve optimization goals.

Performance Limiting Factor

The areas of design, operation, maintenance, and administration were evaluated in order to identify factors which limit performance. Each of the factors were classified as A, B, or C according to the following guidelines:

- A – Major effect on a long-term, repetitive basis;
- B – Moderate effect on a routine basis or major effect on a periodic basis;
- C – Minor effect.

In developing this list of factors limiting performance, 50 potential factors were reviewed and their impact on the performance of the MSWTP was assessed. A total of 8 factors, 6 A factors and 2 B factors, were identified. Between the "A" performance limiting factors found are the following: lack of plant operability/process controllability/application of concepts by operator; less than adequate design of unit processes (e.g. disinfection); lack of pre-sedimentation; lack of administration policies and supervision at plant site. Under "B" performance limiting factors found are the following: less than adequate plant coverage by operators; lack of corrective maintenance.

The identification of factors limiting performance are provided to support the MSWTP achieve optimization performance goals and improve overall system reliability. Achieving this level of treatment and reliability has been demonstrated to be the best approach to provide maximum public health protection from microbial pathogens.

Evaluated Alternatives

The alternatives considered in this design project provide potential solutions to the deficiencies identified at the plant in order to comply with the optimization goals. The considered alternatives are the following:

- Alternative I: Optimization of existing facilities.
- Alternative II: Abandon the existing plant and build a new one.

Alternative I: Optimizing Existing WTP

Alternative I consists of using the existing infrastructure at MSWTP and provide the necessary improvements to optimize the plant to achieve goals described in the "Optimization Goals" section. This alternative considers the addition of the following components:

- Installation of inline turbidimeters at the exit of each superpulsator;
- Installation of a raw water inline TOC analyzer and also at the filter combined effluent;
- Replacement of superpulsator sludge discharge actuator number 2 (the existing actuator is broken and needs replacement);

- Installation of continuous monitoring for raw water alkalinity and pH;
- Installation of particle counters in each filter effluent;
- Provide filters backwash process controllability, the existing filters need to have the capability for controlling backwash flow into the filters;
- Rehabilitation of all filters, although there are 8 existing filters, some of them have not been rehabilitated recently and need improvements;
- Replacement of plant influent flow meter, the existing flow meter is out of service and needs replacement;
- Replacement of influent turbidimeter, current turbidimeter is out of service;
- Relocation of distribution line exiting Chlorine Contact Tank to after Distribution Tank to ensure complete chlorine contact time, currently there is a distribution line that exits the chlorine contact tank prior to the entrance to the distribution tank.

Cost Estimate of Alternative I

The preliminary construction cost estimate for Alternative I is based on costs obtained from vendors of the recommended equipment for this alternative. The installation cost represents a 15% of the equipment cost, which typical percent paid for installation of equipment. Operation and maintenance (O&M) costs for this alternative were assumed to be five percent of total estimated construction costs for the monitoring equipment and one percent of the total estimated construction cost for pipelines. The breakdown of the costs can be seen in Table 1.

Impact of Alternative I in Plant Performance

The alternative was evaluated making a new PPG and new CT calculations while taking into consideration the proposed improvements. Figure 8 depicts the PPG for MSWTP with the improvements proposed in this alternative compared with the current configuration. The figure shows that the WTP increases the rated capacities for filtration and disinfection. If all of the filters are rehabilitated and are placed in service the new rated capacity of the filtration area would be 7.46 MGD.

In the case of disinfection, the proposed capacity is rated as 7.38 MGD for combined pre and post-disinfection. The post disinfection capacity increases from 0.42 to 5.15 MGD. The rated capacity for both disinfection scenarios, with or without pre-chlorination, can manage the average and peak flow for the facility. Therefore, the pre-chlorination could be eliminated, but it is recommended to move the pre-chlorination point after the sedimentation basin. Relocating the pre-chlorination point will reduce the probability of forming disinfection by-products and it will help meeting the TTHM and HAA_5 regulatory requirement.

Table 1

Alternative I Cost Estimate

Task	*Cost*
Improvements to filters (optimization and controls)	$368,000
Replace superpulsator sludge discharge valve/actuator #2	$3,000
Replace plant influent flow meter with recorder and display at control room	$20,000
Replace influent turbidimeter	$19,000
Installation of inline turbidimeters at the exit of each superpulsator	$19,000
Installation of a raw water inline TOC analyzer	$41,000
Installation of combined filter effluent inline TOC analyzer	$41,000
Installation of continuous monitoring for raw water alkalinity	$15,000
Installation of continuous monitoring for raw water pH	$3,000
Installation of particle counters in each filter effluent	$125,000
Relocate water distribution line from exit of contact tank to exit of distribution tank	$100,000
Construction Cost Subtotal	***$754,000***
General Administrative Project Costs	$75,400
Overhead, Profit, Construction Tax	$310,950
Total Construction Cost	***$1,064,950***
Annual Operation and Maintenance Costs:	
Monitoring Equipment	*$14,150*
Pipeline	*$1,000*

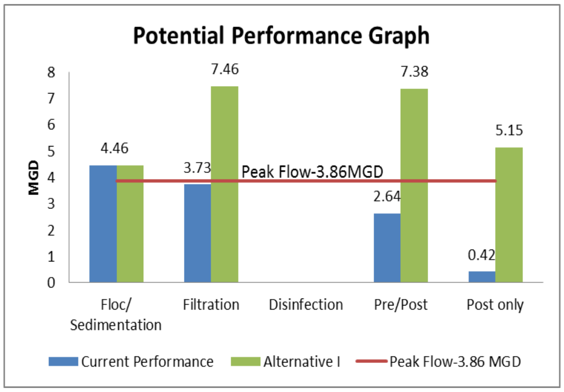

Figure 8

PPG for Improvements under Alternative I

CT Evaluation

CT calculations for the disinfection improvements proposed in this alternative indicate that the facility will comply with the requirements of 3-log removal for Giardia Lamblia and 4-log removal for viruses. The ratio of CTactual/CT99 calculated for Giardia Lamblia is 1.71 and for Viruses 76.92. Since ratios are ≥1 adequate disinfection is provided.

Alternative II: Building a new WTP

Alternative II considers the elimination of the existing WTP and building a new one. MSWTP is currently complying with most of the water quality parameters established by the regulating agencies. The deficiencies in the treatment processes can be corrected with improvements to the existing plant and do not warrant the abandonment of the existing facility. Also, the construction of a new facility may cost approximately $8MM, according to cost estimates from PRASA. For this reason, the construction of a new WTP is considered an unnecessary expense that makes this an unreasonable alternative to solve the current issues.

Alternative I Plus Operational and Maintenance Recommendations

Alternative I describe the capital investment needed to achieve optimization goals but there are also some operational and maintenance recommendations that should be implemented in order to improve even further the MSWTP performance. Following is a list of operation and maintenance recommendations per Qasim (2000):

- Standard Operating Procedures: MSWTP needs good standard operating procedures to successfully achieve process controllability. The development and use of SOPs minimizes variation and promotes quality through consistent implementation of a process or procedure within the organization, even if there are temporary or permanent personnel changes.
- Flocculation Processes: Perform jar test of raw water daily when significant raw water quality changes are experienced. Adjust coagulant dosages accordingly.
- Sedimentation Processes: Test the turbidity of the superpulsator effluent on a regular basis and whenever the water quality or flow rate changes.
- Filtration Processes: Each filter should be drained and inspected annually. Condition of the media is the prime concern. Collect one filter backwash profile each month from each filter.
- Disinfection: Monitor the combined and total chlorine residual daily. Excess variations may indicate equipment malfunction
- Administration/Others: Management should require formal and frequent reporting of Preventive Maintenance practices and critical parts inventory status. There should be a training plan supported by a budget that assigns resources and provides adequate training opportunities. This training plan should be enforced on a formal reporting on the status of individual training, certification and overall training needs.

Conclusion

Various improvements at MSWTP are needed in order to achieve compliance with federal and state drinking water regulations. The approach utilized to optimize the performance of this WTP follows the methodology developed by the EPA known as the Composite Correction Program. This project establishes optimization goals, identifies plant's limiting factors and the required improvements to achieve these optimization goals. Since the plant is complying with most of the water quality parameters, the most cost effective alternative to achieve optimization goals was identified and also some operational and maintenance recommendations were made. The proposed project increases the WTP rated capacities for the critical units at peak flow conditions. The peak instantaneous operating flow was used since unit process performance is projected to be most challenged during these peak loading events and it is necessary that high quality finished water be produced on a continuous basis.

RECOMMENDATIONS

Since this design projects assess only the water quality aspect of the facility, to obtain a complete optimized system other sections of the facility should be optimized. For total system optimization, further research is recommended to assess the entire water system focusing in three main components:

- Evaluation and upgrade of the sludge treatment system of the facility;
- Assessment of the conditions of the intake facilities of the plant;
- Study the conditions of the storage and distribution systems are highly recommended.

These studies should improve process reliability in the WTP and also increase the confidence in the water service.

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