

# Arsenic Residuals Treatment to Meet New IPP Limits for Discharges from a Potable Water Membrane Plant

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The city of Clearwater owns and operates a reverse-osmosis water treatment plant (ROWTP) that treats up to 3 million gallons a day (MGD) of water derived from 10 groundwater wells. The treated water provided at the consumer's tap meets or exceeds the Safe Drinking Water Act (SDWA) requirements for water quality.

The plant removes undesired constituents that occur naturally in the well water, a process that produces residuals which are then properly disposed of off site.

Currently, the residuals produced from the treatment plant process are directly discharged to the sanitary sewer system.

The city operates three advanced wastewater treatment facilities (AWTFs) as part of the sanitary system: Marshall Street AWTF, East AWTF, and the Northeast AWTF. Discharging residuals from the treatment plant to the wastewater system is regulated by an industrial wastewater pretreatment program (IPP) in accordance with Chapter 62-625, Florida Administrative Code, and the

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**Table 1  
Arsenic Treatment Methods(1)**

<u>Arsenic Management Method</u>	<u>Applicability</u>
<b><i>Non-Treatment &amp; Treatment Minimization Strategies</i></b>	
Source Abandonment	N/A <sup>(1)</sup>
Seasonal Use	N/A <sup>(1)</sup>
Blending	N/A <sup>(1)</sup>
Sidestream Treatment	Evaluated
<b><i>Enhance Existing Treatment Processes</i></b>	
Enhanced Coagulation/Filtration	Evaluated
Enhanced Lime Softening	N/A <sup>(1)</sup>
Iron/Manganese Filtration	Evaluated
Greensand Media	N/A <sup>(2)</sup>
<b><i>Treatment (Full Stream or Sidestream)</i></b>	
Ion Exchange	N/A <sup>(1)</sup>
Activated Alumina Sorbents (Tigg Corp.)	Evaluated <sup>(3)</sup>
Iron Based Sorbents (US Filter, Severn-Trent)	Evaluated
Coagulation-Assisted Microfiltration (CMF)	N/A <sup>(1)</sup>
Coagulation-Assisted Direct Filtration (CADF)	N/A <sup>(1)</sup>
Oxidation/Filtration	Existing Process
Permanganate	N/A <sup>(1)</sup>
<b><i>Point-of-Use Treatment Program</i></b>	
Activated Alumina	N/A <sup>(1)</sup>
Iron Based Sorbent	N/A <sup>(1)</sup>
Reverse Osmosis	N/A <sup>(1)</sup>

**Notes:**

- (1) These processes are not applicable to the ROWTP, and the process would require significant infrastructure and cost to construct.
- (2) The hydraulic load rate for greensand is 3 to 5 GPM/ft<sup>2</sup>, and the addition of a new prefilter would be required. Potassium permanganate oxidation would be used, followed by a greensand media filter. Because greensand is very fine (16-60 mesh), it was determined to be susceptible to being overloaded with solids and therefore excluded from further consideration.
- (3) Activated alumina is not as efficient as a ferric absorbent.

prescribed industrial wastewater permit.

Changes to the impending IPP permit requirements and the wastewater discharge standards will reduce the level of naturally occurring arsenic allowed to be discharged to the sanitary sewer system from 0.2 mg/L to 0.12 mg/L. The lower limit of 0.12 mg/L was based on calculations performed as the allowable limit of arsenic to either of the AWTFs.

The goals established in this study were to determine cost-effective solution to meet the arsenic limit (0.12 mg/L) and to comply with the industrial pretreatment requirements. Objectives for meeting these goals and the new level of arsenic identified for the IPP include:

1. Evaluating alternatives to treat arsenic and comply with the new discharge limit.
2. Limiting the amount of infrastructure cost to achieve the desired level of arsenic at the IPP discharge point.
3. Identifying the current ROWTP operating conditions affecting arsenic in the waste stream and identifying process improvements that can help meet the new limit.
4. Optimizing the existing chemical treatment process to meet the new limit.
5. Re-evaluating the basis for establishing the limit of arsenic in the city's sanitary sewer system.

Several methods have been reported to be available for treating arsenic; they are identified in Table 1. <sup>(1)</sup>

Based on pre-screening analysis, most of these treatment methods were determined to be not applicable to the existing treatment process and were ruled unsuitable based on cost, or they were unsuitable for use in the existing treatment process. Of the 18 reported treatment methods, four were considered

as possible candidates to be further evaluated in this project study:

- ◆ oxidation and filtration
- ◆ sorbents
- ◆ well management
- ◆ gravity settling treatment

Each of these methods appeared to offer potential value for accomplishing the project objectives and goal.

### **Drinking Water Quality & Industrial Pretreatment**

The change to the industrial pretreatment regulation does not affect the drinking water process or the quality of water produced by the plant. Also, the change to the IPP discharge limit does not affect the safety of the water in the distribution system.

The impending change to the industrial pretreatment required an investigation to determine if there were any impacts in the management and disposal of the water plant's residuals and the residuals' ultimate disposition.

Water supplied to the ROWTP is withdrawn through groundwater wells from geological formations that vary in their structure and natural composition, since the wells are strategically located throughout the city to obtain the highest available production capacity. As would be expected, the well water contains many naturally occurring substances such as metals—including calcium, magnesium, trace amounts of iron, and arsenic.

To comply with the maximum contaminant levels (MCLs) identified by the SDWA for potable water, the water treatment plant removes unwanted, naturally occurring substances in the well water. Currently, the MCL for arsenic in drinking water is 0.010 mg/L and the water produced by the plant complies with these SDWA water quality requirements.

### **Industrial Pretreatment Arsenic Limits**

The new 0.12 mg/L arsenic limit allowed to be discharged into the sewer system was approximately 40 percent lower than the existing permitted limit (0.2 mg/L). To comply with the new limit, a pretreatment target criterion was established in this study with an even lower arsenic level to assist in sizing the needed arsenic pretreatment process. The lower target value was established at 0.06 mg/L, or 50 percent lower than the new IPP regulated limit.

The criteria used in selecting the lower target value included:

- ◆ Selection of a pretreatment process design where the regulated limit (0.12 mg/L) will not be exceeded.

◆ Economy of scale.

- ◆ An arsenic target level (0.06 mg/L) that will allow a suitable operating buffer to account for unanticipated change in process variables.
- ◆ A margin, between 0.06 and 0.12 mg/L, that will allow for reasonable factor of safety related to unknowns that can not be readily identified at this level of investigation.

### **Operation of the ROWTP**

The water treatment plant is equipped with four multimedia filters, each comprised of anthracite, sand, and gravel media for removing undesired particles from the raw well water. These filters are located in the process ahead of the membrane system. Once the well water passes through the filters, it is treated again by the membrane filtration system, which removes any remaining undesired substances.

Water treatment chemicals used at the ROWTP are applied to the raw well water. These chemicals comply with NSF 60 Standard requirements. The NSF 60 Standard is the nationally recognized standard for chemicals allowed to be used in drinking water treatment.

The chemicals introduced to the well water in the pipeline ahead of the multimedia filters include both sodium hypochlorite (oxidant) and ferric chloride (coagulant). After chemical addition, the precipitate is collected on the media contained in the filters and subsequently removed from the filter media during backwashing and rinse cycles using treated water.

The constituents removed by the membrane system are typically known as potable water treatment plant byproduct (concentrate). The backwash and rinse water from the multimedia filters and the concentrate from the membrane system comprise the total residuals from the plant containing arsenic. These flows are then piped to a single sanitary sewer (IPP) manhole located next to the plant, then conveyed to the wastewater treatment system via a pump

station. Currently, the residuals receive no additional pretreatment before being discharged to the IPP manhole and wastewater system.

### **Process Flow**

The plant was originally designed to remove arsenic from the well water at two locations: the four multimedia filters and the water treatment plant membranes. Ahead of the filters, an oxidant (sodium hypochlorite) is added to the raw well water to convert the arsenic to a form that can be removed by a coagulant. The coagulant (ferric chloride) is applied to the well water ahead of the filters to form a floc. The filters are then used to remove this floc from the water as a precipitate on the filter media. Based on a survey of the literature, the design removal efficiency using sodium hypochlorite and ferric chloride for arsenic removal is expected to be 90 to 100 percent.<sup>(1,2,3)</sup>

Based on the expected arsenic removal efficiency of the multimedia filters, the majority of the arsenic residuals should be removed in the filter backwash and rinse water, so for investigation of residuals treatment options, the focus for removal of arsenic was the filter backwash and rinse water.

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## Residual Water Quality

The residuals water quality contributes to its treatability and ultimately to the way in which the arsenic can be removed before it is discharged to the sanitary sewer system. The backwash and rinse waters from the multimedia filters were identified to contain the predominant quantity of arsenic and were characterized.

## Arsenic Chemistry

The backwash and rinse waters contain soluble arsenic [As] derived from naturally occurring sources. Arsenic can exist in two primary forms: arsenite (a trivalent metallic ion, As (III)) or arsenate (a pentavalent ion, As (V)). Since groundwater can be void of oxygen, the arsenic found in well water should predominate in the form of arsenite.

Both arsenite and arsenate exist in four different species. The speciation changes by dissociation in water and is pH dependent. The kinetics of dissociation for each species is essentially instantaneous.<sup>(1)</sup>

Obtaining the desired arsenic species is essential for its removal by first oxidation to change its valence state and then coagulation using ferric chloride and precipitation on the multimedia filters. A negative surface charge on the ion surface facilitates removal by precipitative processes such as oxidation-coagulation-precipitation.

Arsenite [As(III)] is neutral at pH levels 6 to 9. Ions with neutral surface charges are not easily removed from water. Arsenate (V) is negative valence state (-1 or -2) at pH levels 6 to 9 and can be removed by precipitative processes, using positive valence coagulant

(ferric chloride).

Before the precipitative processes can be applied, As(III) must be converted to As(V) by adding an oxidizing agent such as chlorine. The ROWTP currently utilizes chlorine in the form of sodium hypochlorite for this conversion. Once the conversion of arsenite to arsenate occurs, ferric chloride is then added to precipitate the negatively charged arsenic ion complex.

The chlorine added to the raw water is not used to adjust pH, but rather as an oxidant for conversion of arsenite to arsenate. Not including chlorine demand by other constituents in the water, the stoichiometric oxidant demand is about 0.95 mg of chlorine (as Cl<sub>2</sub>) per mg of As(III).<sup>(1)</sup> The reduction-oxidation reaction for chlorine (as hypochlorite) is provided in the following equation:



## Development of Alternatives

The short list of arsenic removal strategies previously identified was evaluated. These alternatives were developed based on the understanding that the predominant source of arsenic to be removed for pretreatment was derived from the multimedia filter backwash and rinse water; and they are expected to meet the arsenic treatability objective of 0.06 mg/L.

As a first step in the course of evaluating alternatives, the chemical addition was checked. This check also included confirmation that the existing filter operation was optimized for removal of chemical (ferric chloride) precipitate.

## Oxidation & Filtration

The chlorine dose required for optimal conversion of arsenite to arsenate was a function of existing chlorine demand and the chlorine residual needed to attain the best possible conversion. Chlorine dose for conversion of arsenic was found to be within range of the existing equipment.

Field sample results indicated that a chlorine residual at the multimedia filters of 0.3 mg/L (total) and 0.22 mg/L (free) attained approximately 80 percent conversion. Field tests indicated that increasing the chlorine dose and residual did not improve the conversion of arsenite to arsenate.

The additional benefit from these dosing tests was their contribution to the pro-active management of chemical use. This proactive management assured that chemicals applied were not overfed and applied according to the variable chlorine demand (which may vary with different wells in service). Dosing management means that staff will actively monitor the dose needed to obtain the target range of approximately 0.3 mg/L total chlorine residual and 0.22 mg/L free chlorine residual, as required for arsenic conversion.

The multimedia filters were checked to determine if their operation was consistent with original plant design parameters. Water samples were taken upstream and downstream of the chlorine injection point to see if the chlorine (sodium hypochlorite) level introduced to the well water was adequate for maximizing the conversion of arsenite to arsenate.

The ratio of As(III) to As(V) was identified in the sampling. The benefit from obtaining this information was that it would help determine the optimum chlorine dose, based on the well water in use. The chlorine demand by the well water was reported by operations staff to be in a range of 4 to 5 mg/L as total chlorine.

After the optimal chlorine dose was determined for conversion of arsenite to arsenate, sampling was performed to confirm the optimal dose of ferric chloride to be applied. Ferric chloride as a coagulant is used for removal of As(V).

The ferric chloride dose was changed by staff from 0.5 to 2.0 mg/L, in 0.5 mg/L increments. Sampling for arsenic was then performed to identify the optimum amount of arsenic removed at each level of ferric chloride dose. Using this method confirmed the optimum coagulant dose for arsenic removal for the well water used.

Field sampling for arsenic before and after the filters was performed between February and March 2006. As expected, the results indicated that conversion of arsenite to arsenate will not occur at a chlorine dose

of about 6 mg/L. This low chlorine dose was equivalent to the chlorine demand of the well water (demand of about 4 to 5 mg/L) and therefore would not allow an adequate chlorine residual needed to make a suitable conversion possible.

At a chlorine dose of 12.9 mg/L where the oxidation by chlorine converts with a ratio  $(As(III)/As(V)) = 34.5/9.3 = 3.4$ . The conversion from As (III) to As (V) was approximately 82.6 percent with a total chlorine residual of 0.3 mg/L and a free chlorine residual of 0.22 mg/L.

To confirm the dosing, an increase in the chlorine dose was made to 15 mg/L. The results did not indicate that the conversion of As(III) to As(V) was improved. At 15 mg/L chlorine dose, the As(III)/As(V) ratio was 3.4 with only a 70.9 percent conversion.

Throughout the test, it was noted that the multimedia filters could not be checked to confirm their hydraulic performance or for comparison to the original design flow parameters. Currently, the filters do not have flow measurement instrumentation or control valves to throttle effluent flow.

From surveillance inspections, it was noted that the flow through each of the filters may be imbalanced upon increased headloss or as a result of a filter's individual piping arrangement. Also, acute changes in the flow

regime through a filter may upset the accumulated precipitate and result in inadvertent release of arsenic floc through the anthracite and sand media bed to the effluent side of the filter. Because filter operation must be carefully controlled and the flow evenly distributed to assure the highest possible removal performance, flow measurement and flow control valves should be provided.

Within the accuracy of the lab results and the number of samples taken, the data indicated that the optimal chlorine dose for conversion of arsenite to arsenate appeared to occur where the total chlorine residual ahead of the multimedia filters was about 0.3 mg/L and the free chlorine residual was 0.22 mg/L.

During the same sample period, ferric chloride was dosed at varied levels between 0.5 and 2.0 mg/L in 0.5 mg/L increments, and at a constant chlorine dose of 6 mg/L. The results of the sampling indicated that a ferric chloride dose of 2.0 mg/L provided for the removal of arsenic in the effluent of multimedia Filter No. 3 at an efficiency of approximately 69.5 percent. At this dose of 2.0 mg/L, however, the level of iron in the effluent was notably higher when compared to the other ferric chloride dose levels.

While an increase in ferric chloride apparently improved the arsenic removal, there was concern that increased iron levels

could impede membrane performance. At a ferric chloride dose of 1.0 mg/L, Filter No. 2 notably exhibited an arsenic removal efficiency of 62.5 percent. Based on these sample results for arsenic and iron levels in the effluent, it was determined that the iron levels in the effluent should be continuously monitored during operations to confirm that the membrane performance was not affected.

To help confirm efficient operation, it was determined that the multimedia filters should be equipped with individual flow monitoring, turbidity monitoring, and control valves. The installation of this equipment would help confirm that flow was in accordance with design parameters, resolve any imbalance of flow caused by increased headloss of the media and piping arrangement, confirm suitability of backwashing and cleaning, and stabilize the flow regime based on changes in flow and pressures in the piping system.

### ***Sorbents (Iron Based Hydroxide & Activate Alumina Media Material)***

Iron-based hydroxide media are proprietary and were evaluated as a possible substitute for the existing anthracite and sand media. These proprietary media are typically

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used in an adsorption-type process to remove arsenic and other heavy metals from water. Pre-oxidation would not be required for arsenic adsorption removal applications. Once the iron-based hydroxide media have exhausted their adsorption capacity, they would be removed from the process and replaced with new media.

The application and use of this proprietary media performance depends strongly on the quality of water being treated and the flow rate. Activated alumina has been reported as a potential sorbent for arsenic in certain applications. The use of activated alumina as a media sorbent was known, however, to be less efficient for sorption of arsenic when compared to iron based hydroxide sorbents, and its application for arsenic was not widely known to be in use. Sorbents such as iron based hydroxide materials were eliminated from further consideration for use as a treatment alternative based on the city's desire to not use a proprietary material in this application.

### **Optimization of Well Operation**

The groundwater from the wells was identified as the source of arsenic in the water treatment plant residuals. An evaluation was made to determine if alternating well usage or strategic use of well combinations could help reduce the amount of arsenic required to be treated. Based on the need to maximize water production from each of the wells in the system, it was determined that there was no advantage identified for further investigation of well operations as a means to reduce the level of arsenic in the raw water.

### **Gravity Settling & Solids Management**

Data from American Water Works Association Research Foundation (AWWARF) indicated that chemical conditioning using a coagulant (ferric chloride) provides for the removal of arsenic, and that a conventional settling overflow rate of 0.25 gpm/ft.<sup>2</sup> may reduce arsenic to below 10 µg/L. While this overflow rate was considered extremely low, it provided a target for gravity settling. The literature indicated that gravity settling alone (no chemical addition) may be able to reduce arsenic solids to below 50 µg/L for direct discharge applications to public landfills.<sup>(2)</sup>

The gravity-settling treatment option for handling the backwash and rinse waters required an analysis of the solids that would be produced. Sampling data taken May 22-24, 2006, indicated that the solids ranged from 4.4 to 2,349 mg/L. Estimates of the solids produced at full scale range from 40 to 190 pounds (dry) solids per backwash

(20,000 gallons). Using this criterion, the amount of solids produced per week would range from 320 to 1,520 pounds (dry) solids per week (eight backwashes).

This estimate included and accounted for the addition of lime at approximately two cubic feet per backwash. An estimate was made for the depth of the solids blanket and was based on staff observations of an Imhoff cone that was filled from the bottom to approximately one-quarter of the overall depth.

Notably, during the solids testing, the decant water from Imhoff cone test was analyzed for arsenic. The arsenic level ranged from 0.04 to 1.4 mg/L and was found greater than the limit of 0.12 mg/L. From these preliminary tests, it was determined that the decant water may require additional treatment to comply with the arsenic limit.

Ultimately, the processes evaluated for treatment of arsenic in the backwash/rinse water included a combination of gravity settling, solids collection, solids pumping, lime addition, and solids management. This treatment alternative was broken down into four options with different equipment arrangements and included:

#### **Option 1 – Gravity Settling/Decant / Solids Management On-site**

A new gravity thickener would be provided with decant equipment. Solids would be thickened on-site in a new building and the solids would be hauled to the landfill.

#### **Option 2 – Gravity Settling/Haul Solids to AWTF**

A new gravity thickener would be provided with decant equipment. The settled solids would be collected and hauled to the city's AWTF and temporarily stored in a new holding tank. The AWTF would thicken the solids and haul the solids to the landfill.

#### **Option 3 – Tube Settling/Haul to Solids AWTF**

New pre-cast concrete holding tanks would be provided with inclined plates. The settled solids would be pumped out by a truck, hauled to the city's AWTF, and temporarily stored in a new holding tank. The AWTF would thicken the solids and haul the solids to the landfill.

#### **Option 4 – Tube Settling/Decant- Iron oxide/Haul to AWTF**

This option is similar to Option 3; however, decant from the pre-cast concrete holding tanks would be treated by use of iron-based media to reduce the arsenic in the decant water discharged to the IPP manhole.

Once the solids were produced in the

gravity thickener, it was necessary to investigate how these solids would be managed. From a literature search, it was determined that it was important to maintain ferric chloride solids with a pH higher than neutral. This high pH ensured that the arsenic would not unbind from the arsenic solids matrix and leach. Lime addition would help to provide stable solids suitable for landfill application.<sup>(3)</sup>

Further bench scale testing would be needed to confirm that ferric chloride solids would be stable by the addition of a small amount of lime. The suitability for disposal of solid waste is covered by EPA 40 CFR, Part 261, Toxicity Characteristic Leaching Procedure (TCLP), which includes a contaminant limit for arsenic of 5 mg/L.<sup>(5)</sup>

The goal for disposal of arsenic-laden solids (water plant residuals) was the public landfill. Should the arsenic leach from the solids and exceed the permissible TCLP value, it must be disposed of as hazardous waste.

During the course of the study, several operational changes were made to the chemical feed for both chlorine and ferric chloride. In addition, sand and anthracite media were added to the multimedia filters to meet the design depth. Upon completion of these operational adjustments, continuous field sampling was completed in the IPP manhole.

#### **Single Skid Sample Results:**

In October 2006, 24-hour flow proportional composite sample results were taken in the IPP manhole. Based on these composite results, the discharges to the manhole were found to be below the limit of 0.12 mg/L.

#### **Two Skid Sample Results:**

In July 2006, hourly sample results were taken in the IPP manhole. Based on the average of these hourly results, the discharges to the IPP manhole were also found to be below the limit of 0.12 mg/L.

### **Summary**

The IPP pretreatment limits for arsenic will be reduced from 0.2 to 0.12 mg/L. Residuals management options have been evaluated for removal of arsenic prior to the discharge of water plant residuals to the sanitary sewer system. This evaluation has included research of the literature, analysis of sampling data, and discussion with equipment manufacturers.

The objective established for this study was to treat the backwash and rinse water from the multimedia filters, since this water contains the highest levels of arsenic within the flow streams to the sanitary sewer system.

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The project goal was to reduce the discharges of arsenic to the sanitary sewer system to below the required discharge limit of 0.12 mg/L.

To accomplish the goal, 18 residuals management treatment methods were evaluated and six candidate treatment methods or alternatives were identified. Of those six candidate methods for treatment, three methods—sorbents, oxidation and filtration (optimize existing multi-media filters), and gravity settling—were ultimately shortlisted. For the gravity settling treatment method, four options were developed, which included different equipment configurations.

Because of cost, risk, and perception for the inability to obtain the material when needed, sorbent media were eliminated from consideration. Only two sources of supply for the proprietary material were generally known, and the city did not want to procure proprietary iron hydroxide media.

### **Opinion of Probable Cost**

An opinion of probable cost is presented for the three treatment methods to remove arsenic from water plant residuals: sorbents, oxidation and filtration (optimize existing multimedia filters), and gravity settling (the four gravity settling options). The most attractive alternative identified for meeting immediate project goals and objectives—and the lowest apparent cost identified—was the option to improve the existing filters at a cost of approximately \$753,000.

Action items were developed and identified for the operations staff, including a wide array of operational conditions such as confirming the level of anthracite and sand in each filter. If any media are found missing or depleted, the media should be replaced in-kind according to the design depths.

Once a month, the amount (feed rate) of chemicals added to the raw well water should be checked because the quality of well water may vary according to each well or combination of wells used. The chlorine demand may be affected and the chemical dosing should be adjusted as required.

Once every five years, operations staff should completely remove all media and support stone in the filters and check the laterals to confirm that they are in good operating condition. The importance of filter operations was emphasized, as staff should routinely check the timing for duration of the filter backwash and rinses. Optimal backwash and rinse times may be confirmed by additional sampling.

Based on the use of multiple wells and their respective water quality, operations staff should adjust the chlorine dose to obtain a target residual of 0.3 mg/L total chlorine and

a free chlorine residual of 0.22 mg/L at the location as the water enters the filters. Routinely, optimization of the ferric chloride dosing should be repeated at an initial targeted dose range of 0.5 to 1.0 mg/L ferric chloride. Operations staff should monitor the level of arsenic, iron, ferric chloride dose, and chlorine residual to identify the desired ferric chloride dose between 0.5 and 1.0 mg/L.

Acute changes in the filters' operation were believed to impact their performance significantly. When filters were taken out of service, the remaining operational filters were subject to swings in flow during the filter cycle. Flow swings may unsettle the accumulated floc within the media bed and result in an inadvertent release of precipitate.

Operation of new filters after a completed backwash and rinse cycle must be managed to reduce the potential for filter bed disturbances. Filters returned to service after cleaning should be filtered to waste for a period of time. The optimal time for filtering to waste or "seasoning" a filter is unique to each water system, quality of water filtered, and type of filter. The desired timing for seasoning the filters before returning them to service can be easily confirmed by additional sampling at a short time interval (minute).

The backwash and rinse flow control valve should be evaluated further to confirm that the flow rate provided to each filter is in accordance with the design parameters. This evaluation would include consideration for installation of a highly accurate backwash water control valve and motor operator, and also control logic to address appropriate backwashing of the filters.

An evaluation should also be performed to investigate controlling the rate of flow with control valves at each individual filter. The differences in piping arrangement, filter head loss, and alternating from one filter to another were believed to create significant variation in flow to the other on-line filters, resulting in non-uniform filtering, and may potentially exceed the filter's design hydraulic load rate.

Included in this rate of flow study was an evaluation to assess requirements for replacing flow meters and/or integrating them into the programmable logic controller to automatically adjust the flow rate through each filter.

The air scour system will be evaluated to determine if improvements can be made to optimize the system. Also, an assessment is needed to confirm the removal of air from each filter and the backwash piping. This assessment should include a confirmation for the sizing of air release valves.

This study was valuable to help identify the treatment alternatives that could be applied for compliance with the new arsenic

limit. The study was used as a management tool to help in the decision-making process and was based primarily on desk top evaluation of the arsenic removal technologies known while considering the existing treatment equipment.

Currently, the operation of the existing filters will comply with the new arsenic limit, but the current arsenic treatment capability is at the limit of the existing system's capability to remove arsenic. The recommendations made in this study have been found important for improving current treatment plant operations with respect to arsenic treatment and providing guidance for treatment of arsenic in the future. The findings will be included in and provide the basis for an additional engineering evaluation which will help identify and implement the corrective measures to improve the existing multimedia filters' performance for arsenic treatment.

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