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Department of
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L. Scott Baird
Executive Director

DIVISION OF DRINKING WATER
Marie E. Owens, P.E.
Director

March 11, 2020

Clint McAffee
Park City Water System
PO Box 1480
Park City, Utah 84060

Subject: **Exception to R309-525-13(3)(d) Sedimentation, R309-525-15(4) Filtration, and R309-525-15 Filter Backwash Supply** for 3 Kings Water Treatment Project, 3 Kings Water Treatment Plant (TP003); Park City Water System, System #22011, File #12020

Dear Mr. McAffee:

On February 17, 2020, the Division of Drinking Water (the Division) received your request for an exception to Rule R309-525-13(3)(d) Sedimentation, R309-525-15(4), and R309-525-15(a) Filter Backwash Supply regarding the construction of the 3 Kings Water Treatment Plant (3KWTP). According to these rules:

- Sedimentation Rule R309-525-13 (3)(d) states that for tube settlers, the design application rate shall be a maximum of 2 gallons per minute per square foot (gpm/sf).
- Filtration Rule R309-525-15 (4)(a-d) states for mono-media filters at a filter depth of 30 inches
- Filter Backwash Supply Rule R309-525-15 (7)(a)(i) states that a minimum backwash rate of 15 gpm/sf should be used, while providing adequate backwash with minimum media loss. In addition, Rule R309-525-15 (4)(b)(ii) states that the filter media should be able to be effectively washed at backwash rates between 15 and 20 gpm/sf.

A full scale pilot plant operated at the site from April 2016 until October 2016 to demonstrate proof of performance and validate the treatment technology effectiveness to treat mine influenced water from the Judge and Spiro Tunnel water. Park City continued to operate the adsorption testing on Spiro Water Treatment plant until the plant was demolished in late 2019.

The basis for your request for an exception to Rule R309-525-13(3)(d) Sedimentation, R309-525-15(4), and R309-525-15(a) Filter Backwash Supply regarding the construction of the 3 Kings Water Treatment Plant is on the validation testing completed on the various treatment technologies to ensure treatment goals are met and provide equivalent protection for public health to meet the intent of the rule:

- Sedimentation Rule R309-525-13 (3)(d) addressed conventional gravity sedimentation to reduce suspended solids
    - 3KWTP will utilize lamella plate settlers which are simply a different type of settler technology than the tube settlers called out in rule.
    - Pilot studies were conducted on the loading rate for the lamella plate settlers as their loading rate does not directly compare to the loading rate for tube settlers
    - For the 3KWTP, the maximum design plate settler loading rate is 0.4 gpm/sf, based on 95% effective plate area.
    - This plate loading rate is below the recommended maximum lamella plate loading rate of 0.5 gpm/sf at 80% effective plate area (0.4 gpm/sf at 100% effective plate area) defined in the Recommended Standards for Water Works (10 States Standards), Section 4.2.6.d. An excerpt of this section is included in Attachment A of the enclosed document.

- Filtration Rule R309-525-15 (4)(a-d)
    - 3KTWP pilot study compared four combinations of media filtration to find the maximum contaminate removal for suspended solids, manganese, and thallium removal while maintaining turbidity goals:
        - Mono-media: 42 inches of pyrolusite
        - Mono-media: 24 inches of pyrolusite
        - Dual media: 60 inches of anthracite over 12 inches of sand
        - Dual media: 40 inches of anthracite over 20 inches of pyrolusite
    - Results of all for media vessels found that:
        - The 42-inch pyrolusite filter media profile fully removed thallium while the other filter media profiles only partially removed thallium.
        - Filter effluent from all filter media profiles exceeded the goal of less than 0.1 NTU filter effluent turbidity.
        - For the 42-inch pyrolusite filters, filtered water turbidity was between 0.018 NTU and 0.028 NTU for most filter runs between all filter loading rates.
        - The 42-inch pyrolusite filter media profile also terminated on headloss without turbidity breakthrough, while the other filter media profiles terminated on turbidity or a combination of runs terminated on headloss and turbidity.
    - The design filter loading rate of 10 gpm/sf was also selected through pilot testing.
        - Filter loading rates were varied from 5 gpm/sf to12 gpm/sf for the 42-inch pyrolusite media profile.

        - Filtered water turbidity varied minimally between all filter loading rates and median filtered water turbidity far exceeded the goal of less than 0.1 NTU for all filter runs, regardless of filter loading rate. Filter effluent turbidity also exceeded the goal of less than 0.1 NTU during stress tests that included a high filter loading rate stress test, a shutdown stress test, and a high raw water turbidity stress test.
        - A stress test was also performed to simulate the loss of chemical feed at the treatment plant. During the loss of ferric chloride test, the pyrolusite filters operated for over an hour before exceeding 0.1 NTU at filter loading rates at or above 8 gpm/sf and the pyrolusite filter at 6 gpm/sf operated for approximately 5 hours before reaching 0.1 NTU.

- Filter Backwash Supply Rule R309-525-15 (7)(a)(i) states that a minimum backwash rate of 15 gpm/sf should be used, while providing adequate backwash with minimum media loss. In addition, Rule R309-525-15 (4)(b)(ii) states that the filter media should be able to be effectively washed at backwash rates between 15 and 20 gpm/sf.

    - The 3KWTP utilizes a different granular media filter than assumed within the rule. The maximum design filter backwash rate for the pyrolusite filters is 32.8 gpm/sf, which is the backwash rate required, based on the filter media vendor information, to achieve 25% bed expansion at the warmest design temperature (20°C). Achieving between 20 to 30% bed expansion is required for effective cleaning of the filter media and is a typical industry standard (Kawamura, 2000) (Letterman, 1999).
    - All media vessels are self-contained equipment that specifications call out specific measures in place to prevent media loses through secondary capture during bed expansion backwash cycles.

You propose to maintain all Division required operational monitoring requirements, specifically that the turbidity performance standards for the proposed treatment plant will **be less than 0.3 NTU 95% of the time, and shall not exceed 1.0 NTU** (per R309-200-5(a)(ii) and R309-530-9) to maintain the facilities **2.5-log credit for *Giardia lamblia* removal, and 2-log credit for *Cryptosporidium* removal** for the first stage compliance filter.

On this basis, **an exception R309-525-13(3)(d) Sedimentation, R309-525-15(4) Filtration, and R309-525-15 Filter Backwash Supply is hereby granted for the 3 Kings Water Treatment Project.**

Please maintain a copy of this letter with your permanent records for future reference.

If you have any questions regarding this approval, please contact Cheryl Parker, of this office, at (385) 271-7039, or Nathan Lunstad, Engineering Manager, at (385) 239-5974.

Sincerely,

Marie E. Owens, P.E.
Director

CP/nl/as/mdb

Enclosure: 10 States Standards and Relevant Pilot Study Sections

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DDW-2020-004062

Attachment A. Recommended Standards for Waterworks 2018 (Excerpt)

2018 Edition

Recommended Standards for Water Works

Great Lakes – Upper Mississippi River Board of State and Provincial Public Health and Environmental Managers

Illinois Indiana Iowa Michigan Minnesota Missouri
New York Ohio Ontario Pennsylvania Wisconsin

Recommended Standards For Water Works

2018 Edition

Policies for the Review and Approval of Plans and Specifications for Public Water Supplies

A Report of the Water Supply Committee of the
Great Lakes--Upper Mississippi River Board
of State and Provincial Public Health and Environmental Managers

MEMBER STATES AND PROVINCE
Illinois Indiana Iowa Michigan Minnesota Missouri
New York Ohio Ontario Pennsylvania Wisconsin

Published by: Minnesota's Bookstore
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660 Olive Street
St. Paul, MN 55155

4.2.5.11 Water losses

a. Units shall be provided with controls to allow for adjusting the rate or frequency of sludge withdrawal.

b. Total water losses should not exceed:

  1. Five percent for clarifiers;

  2. Three percent for softening units.

c. Solids concentration of sludge bled to waste should be:

  1. Three percent by weight for clarifiers; or

  2. Five percent by weight for softeners.

4.2.5.12 Weirs or orifices

a. The units should be equipped with either overflow weirs or orifices constructed so that water does not travel over 10 feet horizontally to the collection trough or launder.

b. Weirs shall be adjustable~~,~~ and at least equivalent in length to the perimeter of the tank.

c. Weir loading shall not exceed:

  1. 10 gpm per foot of weir length (120 L/min/m) for clarifiers;

  2. 20 gpm per foot of weir length (240 L/min/m) for softeners.

d. Where orifices are used the loading rates per foot of launder should be equivalent to the weir loadings rates and. Shall produce uniform rising rates over the entire area of the tank.

4.2.5.13 Upflow rates

Unless supporting data is submitted to the reviewing authority to justify higher rates, the upflow rates shall not exceed:

a. 1.0 gpm per square foot of area (2.4 m/hr) at the sludge separation line for units used as clarifiers;

b. 1.75 gpm per square foot of area (4.2 m/hr) at the slurry separation line~~,~~ for units used as softeners.

4.2.6 Tube or plate settlers

Settler units consisting of variously shaped tubes or plates which are installed in multiple layers and at an angle to the flow in the sedimentation basin may be used to enhance settling of solids. Proposals for settler unit clarification must demonstrate satisfactory performance under on-site pilot plant conditions or documentation of full scale plant operation with similar raw water quality conditions as allowed by the reviewing authority prior to the preparation of final plans and specifications for approval.

General criteria is as follows:

a. Inlet and outlet considerations - The design shall maintain velocities suitable for settling in the basin and minimize short--circuiting. Inlets to plate settlers shall be designed to evenly distribute the water across the units.

b. Protection from freezing - Although most units will be located within a plant, outdoor installations must provide sufficient freeboard above the top of settlers to prevent freezing in the units. A cover or enclosure is strongly recommended.

c. Application rate for tubes - A maximum rate of 2 gpm per square foot of cross-sectional area (4.8 m/hr) for tube settlers, unless higher rates are successfully shown through pilot plant or in-plant demonstration studies.

d. Application rates for plates - A maximum plate loading rate of 0.5 gpm per square foot (1.2 m/hr), based on 80 percent of the projected horizontal plate area.

e. Flushing lines - Shall be provided to facilitate maintenance and must be- properly protected against backflow or back siphonage.

f. Drainage - Drain piping from the settler units must be sized to facilitate a quick flush of the settler units and to prevent flooding other portions of the plant.

g. Placement - Modules should be placed:

    1. In zones of stable hydraulic conditions; or

    2. In areas nearest effluent launders for basins not completely covered by the modules.

h. Inlets and Outlets - Inlets and outlets shall conform to Sections 4.2.4.b and 4.2.4.d.

i. Support - The support system shall be able to carry the weight of the modules when the basin is drained plus any additional weight to support maintenance personnel and equipment.

j. Cleaning - Provisions should be made to allow the water level to be dropped, and a water or air jet system for cleaning the modules.

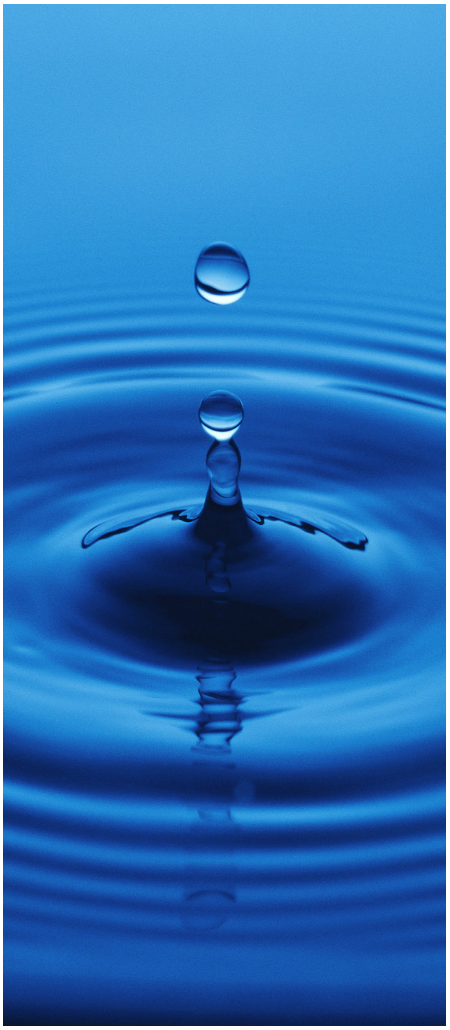
4.2.7 High rate clarification processes

High rate clarification processes may be approved upon demonstrating satisfactory performance under on-site pilot plant conditions or documentation of full scale plant operation with similar raw water quality conditions as allowed by the reviewing authority. Reductions in detention times and/or increases in weir loading rates shall be justified. Examples of such processes may include, but are not limited to, dissolved air flotation, ballasted flocculation, contact flocculation/clarification, and helical upflow, solids contact units, and pulsating clarifiers.

Attachment B. Pyrolox® Media Datasheet

Pyrolox® effectively reduces iron, manganese and hydrogen sulfide from problem water.

Pyrolox®



Pyrolox® is a granular water filtration media used for the removal of hydrogen sulfide, iron and manganese. A naturally mined ore, Pyrolox has been used in water treatment for more than 75 years.

Through a natural chemical reaction, Pyrolox has the ability to help produce clean, high-quality water. Pyrolox filter media works by oxidizing iron, manganese and hydrogen sulfide in problem water. Trapped particulate is then removed from the media bed during the backwash cycle.

To maintain and further augment the long-term performance and removal capacity of the media, an oxidant feed of some type is recommended. This will maintain the media and enhance removal capacity. Chlorine injection (options include chlorine, sodium hypochlorite, or calcium hypochlorite) immediately up stream of the filter feed is a simple way to meet this recommendation. Other acceptable oxidants include air injection, potassium permanganate, sodium permanganate, etc. **Hydrogen peroxide is specifically prohibited for use as an oxident.**

It is important that Pyrolox media is backwashed properly to ensure adequate bed expansion and continued service life.

It is recommended that Pyrolox be installed with an underbed and be backwashed daily. Individual application requirements may vary.

ADVANTAGES

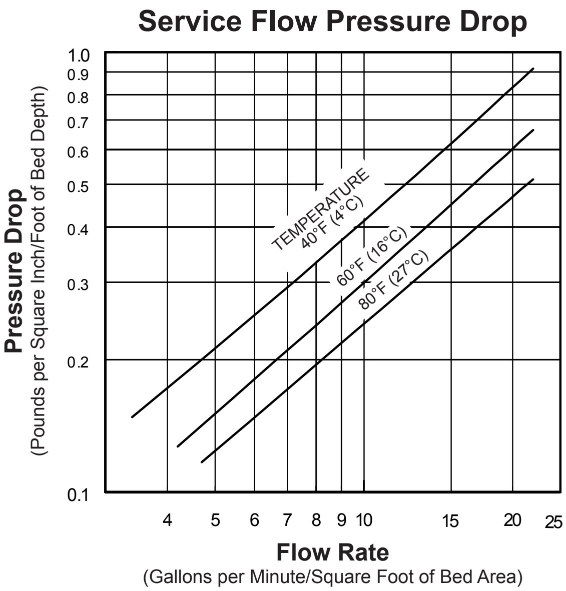
- Effective reduction of iron, manganese and hydrogen sulfide
- Durable media with long service life

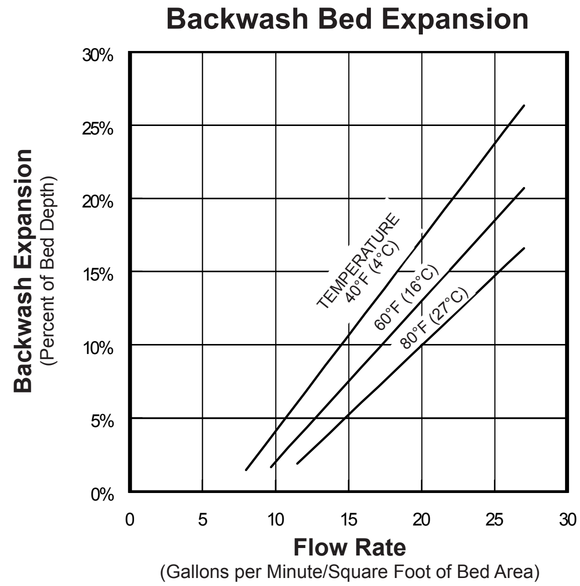
PHYSICAL PROPERTIES

- Color: Black
- Bulk Density: 120 lbs./cubic foot
- Mesh Sizes: US 8 x 20, US 20x40, UK 18/44
- Specific Gravity: 3.8
- Packaging: 60 lb. bags, 2,000 or 2,205 lb. super sacks

CONDITIONS FOR OPERATION

- pH: 6.5-9.0
- Bed Depth: Suggested depth 18 inches. Dependent on application and water quality.
- Backwash Flow Rate: 25-30 gpm/sq.ft.
- Freeboard: 40% of bed depth (min.)
- Underbed: Garnet #8, #8-#12. #3 Silica. Other materials are also suitable but must keep media from migrating downward and be heavy enough to remain in place during backwash.
- Service flow rate: 5 gpm/sq. ft.





Certified to NSF/ANSI Standard 61

Pyrolox® is manufactured by
Prince Minerals Inc., Quincy, IL.

ORDER INFORMATION

Part No.	Description	Cu. Ft./Bag	Wt./Cu. Ft.*	Bags/Pallet	Weight/Pallet	Pallet Dimensions
A8005	Pyrolox®	0.5 (60 lbs.)	120 lbs.	50	3050 lbs.	42″ x 42″ x 43″

*Weight per cubic foot is approximate.

The information and recommendations in this publication are based on data we believe to be reliable. They are offered in good faith, but do not imply any warranty or performance guarantee, as conditions and methods of use of our products are beyond our control. As such, Clack makes no express or implied warranties of any kind with respect to this product, including but not limited to any implied warranty of merchantability or fitness for a particular purpose. We recommend that the user determine whether the products and the information given are appropriate, and the suitability and performance of our products are appropriate, by testing with its own equipment. Specifications are subject to change without notice.

The information and recommendations given in this publication should not be understood as recommending the use of our products in violation of any patent or as a license to use any patents of the Clack Corporation.

The filter medias listed in this brochure do not remove or kill bacteria. Do not use with water that is microbiologically unsafe or of unknown quality without adequate disinfection before or after the system.

Clack will not be liable under any circumstance for consequential or incidental damages, including but not limited to, lost profits resulting from the use of our products.

LENNTECH
info@lenntech.com .
www.lenntech.com .

Attachment C. Pilot Testing Report Section 4.4 to 4.5 (Excerpt)

4.4 Turbidity Removal Through Oxidation, Clarification, and Filtration

Both Spiro Tunnel and Judge Tunnel are classified as groundwater sources for drinking water. However, PCMC has decided to establish more conservative drinking water quality goals that match the USEPA's Surface Water Treatment Rule for conservative planning. Specifically, this pilot study gathered data to demonstrate that this facility conforms to Utah Admin Code Rule R309-525 for Facility Design and Operation: Conventional Surface Water Treatment.

The pilot process of clarification and filtration represents a conventional surface water treatment process. The 42 inches of pyrolusite media column must be approved through R309-525-15 (4) (e.):

> *R309-525-15. Filtration.*
>
> > *(4) Media Design.*
> >
> > > *(e) Other Media Compositions and Configurations: Filters consisting of materials or configurations not prescribed in this section will be considered on experimental data or available operation experience.*

Pyrolusite is a manganese dioxide ore typically used in drinking water treatment. Pilot testing was performed using a deep bed filter with 42 inches of two types of pyrolusite media with 0.43 to 0.5 mm effective size (ES) and 1.48 to 1.56 uniformity coefficient (UC) pyrolusite. Appendix C includes a sieve analysis of the pyrolusite media that confirms the ES and UC of the media. This media configuration has performed exceptionally well in terms of turbidity removal and metals removal.

Loading rates for pyrolusite filter runs ranged from 5 gpm/sf to 12 gpm/sf throughout the course of the pilot study. From April 29 through October 31, 2016, this media configuration operated through various upstream conditions and set points, with 247 filter runs completed during optimal operating conditions. All but five of 247 filter runs in optimal conditions terminated due to the accumulation of 20 feet of headloss. The five filter runs that terminated due to reaching 0.1 NTU effluent turbidity did so during a period of elevated influent turbidity near the end of the pilot study. During pilot operations, the filter runs were stopped if any filter effluent measured 0.1 NTU for over 15 minutes or when the filter reached 29 feet of headloss, the maximum reachable headloss for each filter at the pilot plant. All UFRV calculations were based on 20-feet of headloss accumulation, which occurred prior to the terminal headloss of 29 feet. Typical filter effluent turbidity from the deep-bed pyrolusite filters was 0.023 NTU.

During the majority of the pilot testing period, the raw water turbidity was very low. From April 1 to October 31, 2016, the MIW pilot plant influent saw thirteen turbidity spikes, and the most severe spike saw raw water turbidity reach 999 NTU. A turbidity reading of over 15 NTU was defined as a "turbidity spike" for both Judge Tunnel and Spiro Tunnel waters. Table 4-3 presents a summary of the turbidity spikes seen through the pilot study. During the highest of these spikes, settled water turbidity briefly reached a maximum of 7.6 NTU. Throughout these spikes, the 42-inch pyrolusite media maintained an effluent turbidity of less than 0.1 NTU at all times. During the highest turbidity spikes, filter run length decreased in duration through the 42-inch pyrolusite media due to faster headloss accumulation when polymer doses were increased above 1.0 mg/L. However, the unit filter run volumes (UFRVs) of the filter runs during the turbidity spikes were comparable to other filter runs during normal operation. Filter performance is discussed in Section 4.5.

Thus, the deep bed pyrolusite filters saw minimal effects of the turbidity upsets experienced through the pilot plant and the filters maintained filter effluent turbidities of less than 0.1 NTU. Throughout the seven turbidity spikes, the deep bed pyrolusite filter performance indicated that both the Long-Term 2 Enhanced Surface Water Treatment Rule and the DDW Alliance's most stringent filtered water turbidity goals of less than 0.15 NTU 95 percent of the time will be met during elevated inlet turbidity conditions.

The periods of elevated turbidity showed that the pilot plant can produce high quality finished water in high turbidity upset conditions up to turbidities of 994 NTU. At full-scale, further optimization of chemical dosing and process operation through clarification is recommended during high turbidity events.

Table 4-3: Summary of Turbidity Spikes

Date of Turbidity Spike	Maximum Spiro Raw Water Turbidity (NTU)	Maximum Settled Water Turbidity (NTU)	42-inch Pyrolusite Filter Loading Rates (gpm/sf)	Ferric Chloride Dose Range (mg/L)	Polymer Dose Range (mg/L)
5/3/2016	146	7.6	5 and 6	10	0.75
5/27/2016	54	6.5	2	12 – 30	0.75 – 1.0
6/16/2016	37	2.8	5 and 6	8	1.0 – 1.5
8/11/2016	15	3.1	6 and 12	8	0.75
8/17/2016	73	4.1	6	8	0.75
9/19/2016	49	4.2	6, 8, and 10	10 – 20	0.75 – 1.0
9/20/2016	84	3.9	6, 8, and 10	10 – 12	1.0
9/21/2016	91	3.5	6, 8, and 10	8 – 12	0.75 – 1.5
9/26/2016	20	3.2	6, 8, and 10	8 – 10	0.75 – 2.0
9/27/2016	24	3.4	6, 8, and 10	8	0.75 – 1.0
9/28/2016	999	7.5	6, 8, and 10	8 - 15	0.75 – 3.0
9/29/2016	37	4.3	6, 8, and 10	8 - 10	1.0 – 2.0
10/5/2016	19	7.1	6, 8, and 10	10	1.0 – 2.0

Figure 4-23 through Figure 4-25 present Spiro raw water turbidity, pilot influent turbidity, settled water turbidity, and filter effluent turbidity through three turbidity spikes seen at the pilot plant. Filters “PY-01,” “PY-02,” and “PY-07” all contained 42 inches of 0.43 to 0.50 mm ES pyrolusite. “PY-01” and “PY-02” contained one type of pyrolusite media and “PY-07” contained a different type of pyrolusite media. Appendix C shows the pyrolusite media sieve analysis for both media types. Pilot influent turbidity was measured at the inlet of the flocculation and sedimentation pilot skid and varied from Spiro raw water turbidity based on the Spiro to Judge blend at the time of spike.

In addition to the filters with 42 inches of pyrolusite, three other media profiles were tested. Specific information on each media type is shown below in Section 4.5. Media profiles tested included 60 inches of anthracite over 12 inches of sand, 40 inches of anthracite over 20 inches of pyrolusite, and 24 inches of pyrolusite. Table 4-4 presents a comparison of metals removal and turbidity removal performance of the four media profiles. When compared, the 42 inches of pyrolusite filter media performed the best in terms of metals removal of all filter media profiles. The 42 inches of pyrolusite filter media also consistently terminated due to headloss accumulation and did not typically terminate due to reaching 0.1 NTU filter effluent turbidity.

Table 4-4: Comparison of Filter Media Profiles

Parameter	42-inch Pyrolusite	60-inch Anthracite over 12-inch Sand	24-inch Pyrolusite	40-inch Anthracite over 20-inch Pyrolusite[b]
Metals Removal	Full removal of thallium	Partial removal of thallium	Partial removal of thallium	Partial removal of thallium
UFRV (gal/sf)[a,c]	11,600	6,000 – 17,000	5,500 – 13,000	23,100
Termination	Headloss	Turbidity	Headloss/ Turbidity	Turbidity
Median Turbidity (NTU)[c]	0.023	0.02 – 0.06	0.02 – 0.05	0.016

a- Unit Filter Run Volume calculated based on the volume of water produced per square foot of filter area from the conclusion of filter-to-waste through termination of the filter run. Filter run termination could be from either headloss or turbidity.

b- Anthracite over pyrolusite media was evaluated at a polymer dose of 2 mg/L, which was found to be the optimal polymer dose for maximizing filter run lengths with this media configuration.

c- Single UFRV and turbidity values represent the median value and a range of UFRV or turbidity values represents the range for that media.

For each filter run, a filter effluent turbidity and headloss profile was created. As per the Pilot Testing Protocol, filter runs ended at either 0.1 NTU filtered water turbidity or if filter headloss accumulation exceeded 20-feet.

The following conclusions can be drawn from the turbidity performance during the pilot study as well as Figure 4-23 through Figure 4-25 and Figures F-1 through F-247 in Appendix F:

- 42 inches of 0.43 to 0.50 mm ES pyrolusite performed the best of all filters tests, providing robust metals removal as well as excellent turbidity removal.
- In 247 filter runs of optimized treatment conditions, most runs with 42 inches of pyrolusite media terminated on headloss, always maintaining a filtered water turbidity of less than 0.1 NTU. Five filter runs terminated on turbidity during periods with elevated influent turbidity.
- Filter runs terminated after 20 feet of headloss accumulation with turbidities in the 0.02 to 0.05 NTU range.

Figure 4-23: Turbidity Spike of 146 NTU (maximum) on May 3, 2016, Filter Loading Rates of 5 and 6 gpm/sf

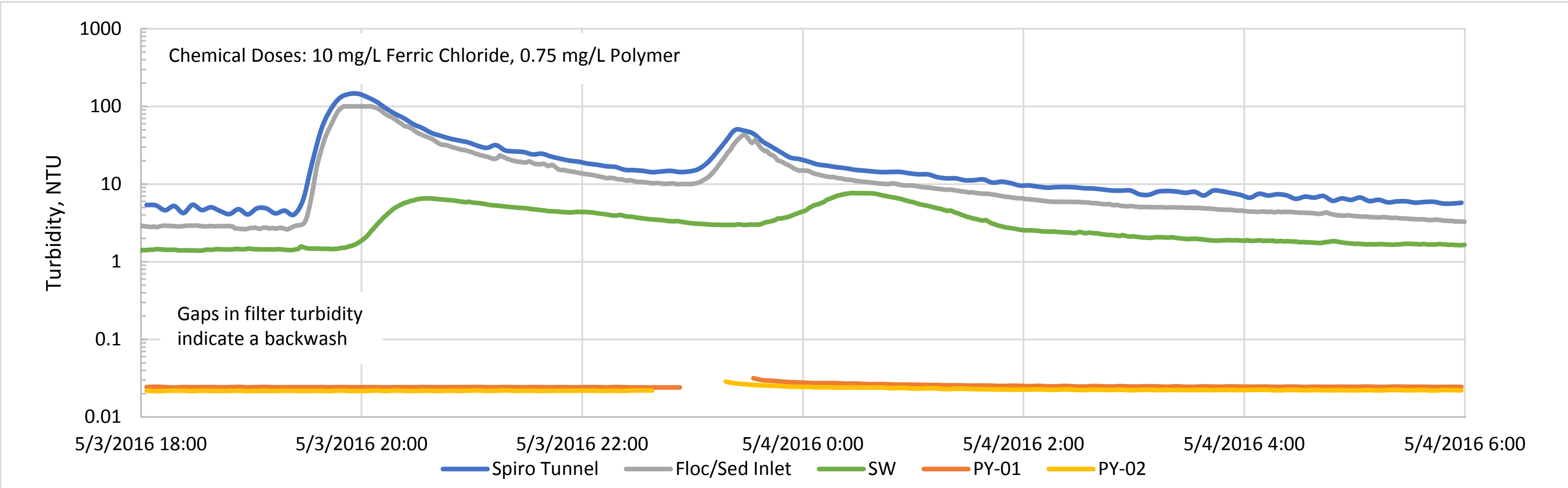


Figure 4-24: Turbidity Spikes of 45, 65, and 91 NTU (maximum) on September 19 through 22, 2016, Filter Loading Rates of 6, 8, and 10 gpm/sf

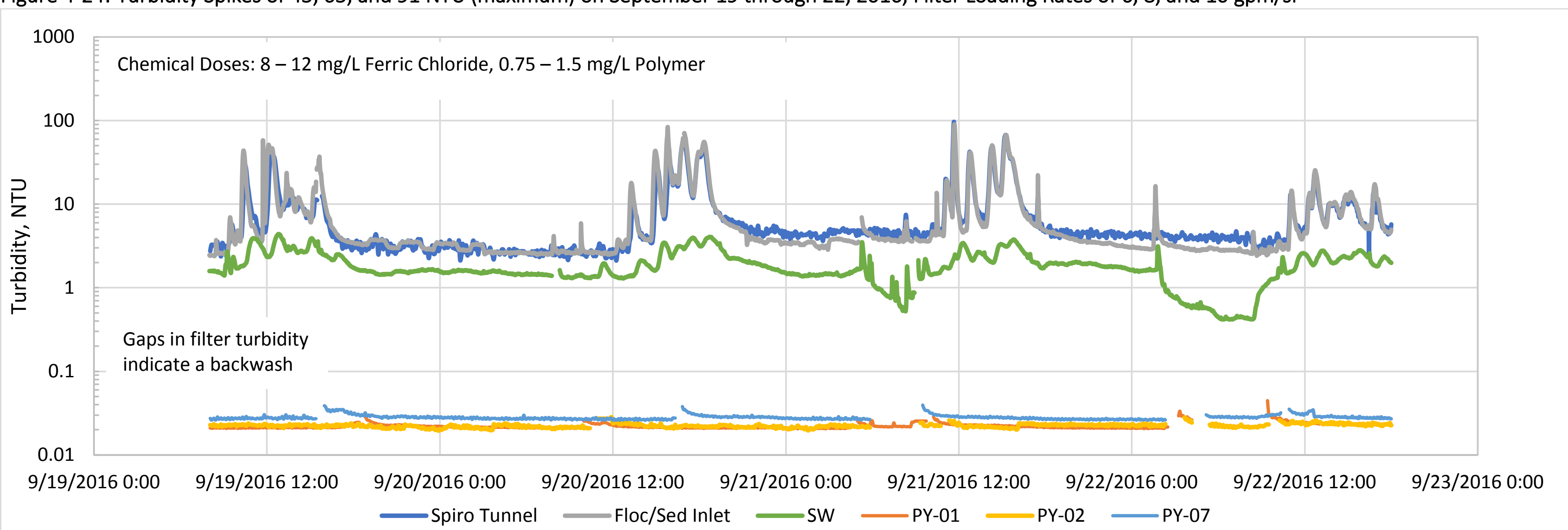
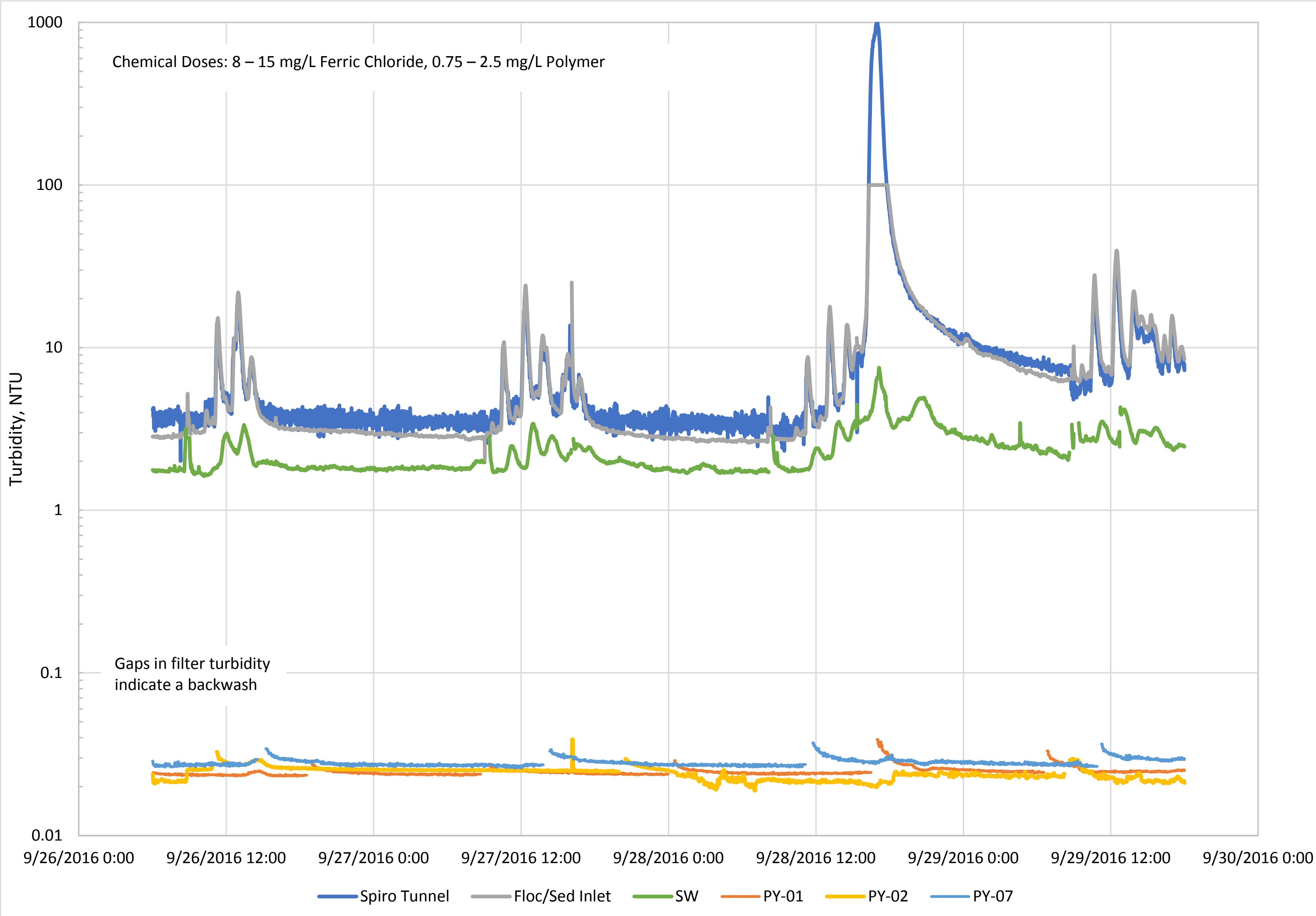


Figure 4-25: Turbidity Spikes of 20, 21, 999, and 38 NTU (maximum) on September 26 through 29, 2016, Filter Loading Rates of 6, 8, and 10 gpm/sf



4.5 Filter Performance

Throughout the pilot study, evaluations of metals and turbidity removal of four filter media profiles aided in the selection of the best filter media to be used for full-scale operations. The four filter media profiles and number of filter runs performed are as follows:

- 501 filter runs using three separate filter columns with 42 inches of 0.43 to 0.50 mm ES pyrolusite media from two different media suppliers
- 134 filter runs using two separate filter columns with 60 inches of 1.25 to 1.35 mm ES anthracite over 12 inches of 0.55 to 0.65 mm ES sand
- 42 filter runs using one column with 40 inches of 1.25 to 1.35 mm ES anthracite over 20 inches of 0.43 mm ES pyrolusite
- 16 filter runs using one column with 24 inches of 0.43 mm ES pyrolusite media

Of the 501 runs performed with the pyrolusite media, 247 filter runs occurred during optimal treatment conditions and their effluent turbidity and UFRV analysis is included below. The first 42 filter runs for both the pyrolusite column PY-01 and the pyrolusite column PY-02 were excluded because they were during the pilot commissioning phase. Other excluded filter runs included those occurring during mechanical difficulties and during experimental periods (e.g., loss of chemical feed, changes in upstream conditions, insufficient or excess polymer). Table 4-5 presents a summary of filter runs PY01-43 though PY01-251, filter runs PY02-43 through PY02-165, and filter runs PY07-01 through PY07-83. Appendix F includes filter run profiles for these 248 pyrolusite filter runs. The filter runs that are shown and that were included in the data summary that follows are those 247 filter runs that constitute “steady state” filter runs with optimized treatment conditions.

The data summarized below in Table 4-5 and illustrated in Figure 4-26 and Figure 4-27 are based on filter runs from three 42-inch pyrolusite filter columns. The filter analysis used 13 filter runs at 5 gpm/sf, 66 filter runs at 6 gpm/sf, 60 filter runs at 8 gpm/sf, 99 filter runs at 10 gpm/sf, and 9 filter runs at 12 gpm/sf. One single filter run at 7 gpm/sf was also performed with a UFRV of 14,078 gallons per square foot (gal/sf) and a median turbidity during the run of 0.019 NTU.

Table 4-5: Summary of Filter Performance

Filter Loading Rate	Number of Runs Analyzed	*Lower Quartile*[a,b]		*Median*[b]		*Upper Quartile*[a,b]	
		UFRV	**Median Filter Effluent Turbidity**	**UFRV**	**Median Filter Effluent Turbidity**	**UFRV**	**Median Filter Effluent Turbidity**
5 gpm/sf	13	12,098	0.018	14,220	0.021	15,127	0.021
6 gpm/sf	66	7,449	0.022	9,730	0.023	12,303	0.025
8 gpm/sf	60	6,653	0.023	8,076	0.024	9,992	0.027
10 gpm/sf	99	5,901	0.020	8,084	0.021	9,164	0.024
12 gpm/sf	9	10,498	0.020	10,986	0.020	11,159	0.020

a- The lower quartile represents the 25th percentile of data and the upper quartile represents the 75th percentile of data.
b- UFRV values are in gallons per square foot (gal/sf), and median filter effluent turbidity values are in NTU.

Figure 4-26: Filter Run UFRV

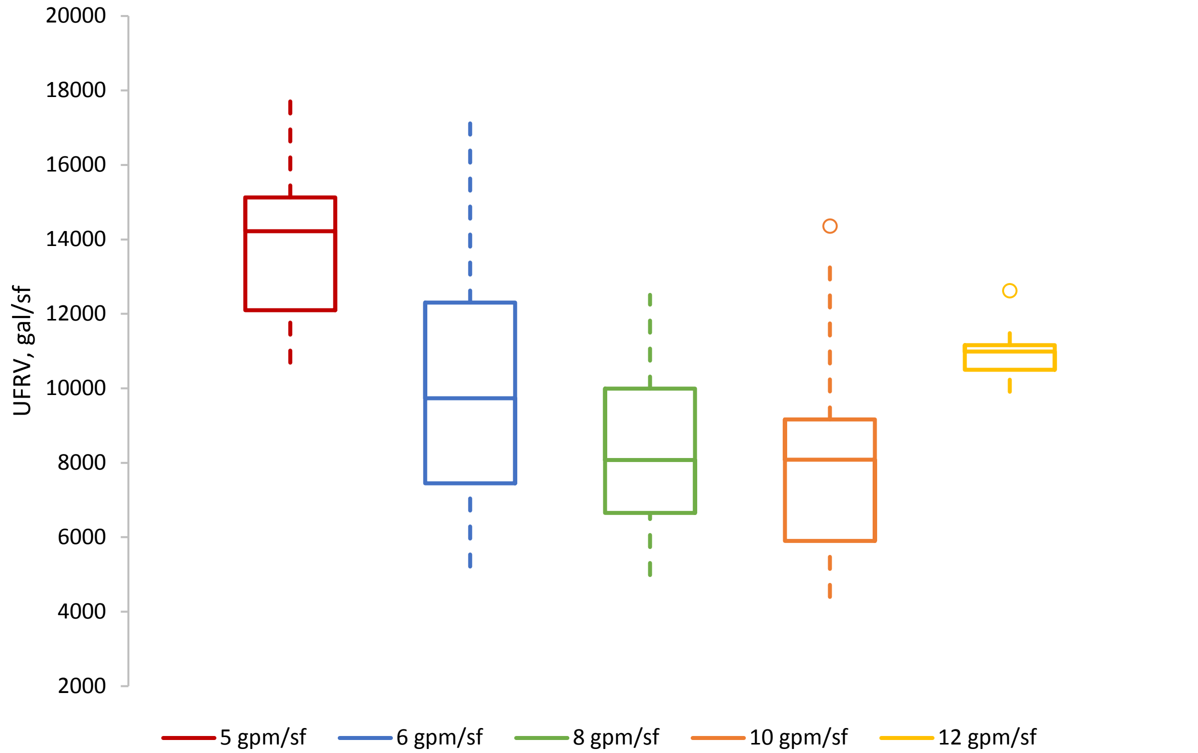
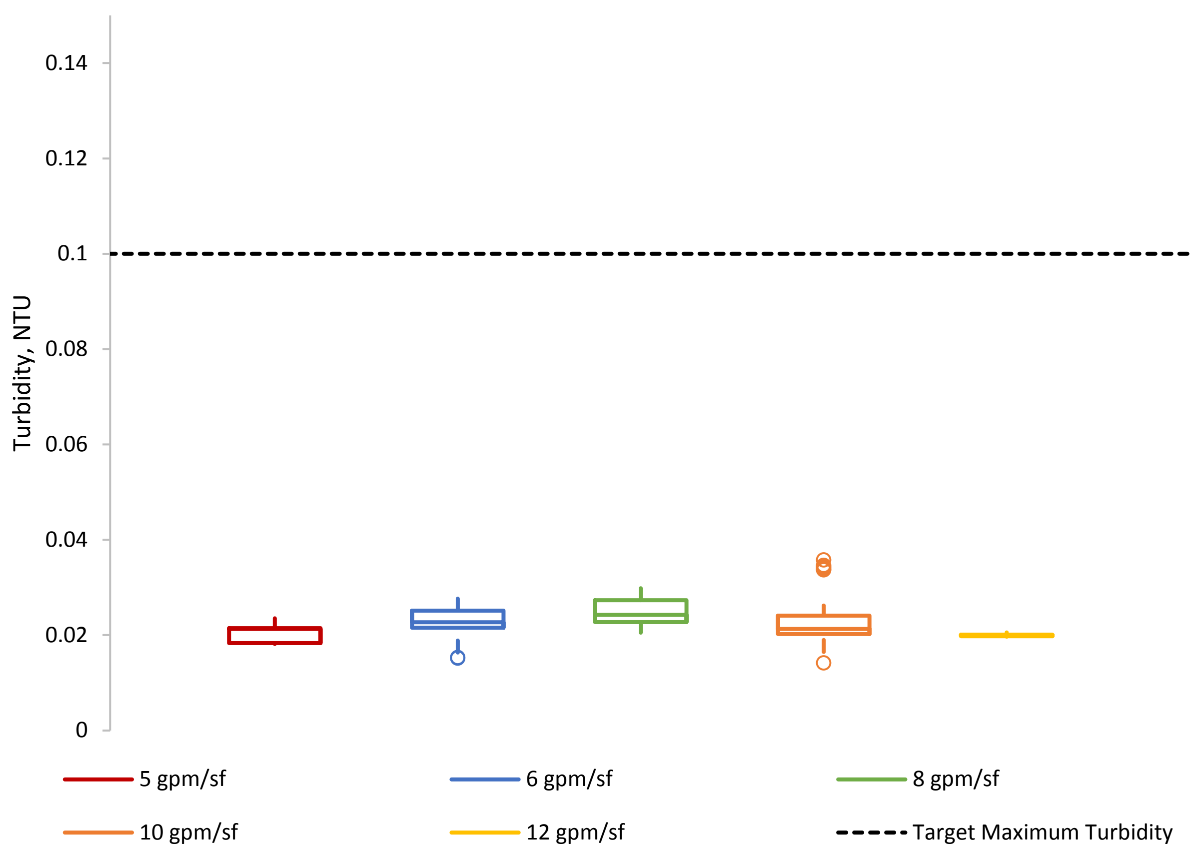


Figure 4-27: Median Turbidity of Filter Runs



From Figure 4-27 and Table 4-5, filtered water turbidity varied minimally between all filter loading rates tested from 5 to 12 gpm/sf, with a filtered water turbidity between 0.018 and 0.028 NTU for most filter runs. Figure 4-27 shows that all filter runs with the 42-pyrolusite filter media far exceeded the goal of less than 0.1 NTU filter effluent turbidity. Additionally, most optimized filter runs terminated due to headloss, regardless of filter loading rate. Five filter runs terminated due to turbidity in October 2016 during a period of elevated influent turbidity.

Figure 4-26 and Table 4-5 indicate UFRVs between 4,400 gal/sf and 18,000 gal/sf. The figure also shows that UFRVs were slightly higher at a 5 gpm/sf filter loading rate compared to UFRVs at filter loading rates of 6, 8, 10, and 12 gpm/sf. However, UFRV represents an operational consideration, and the implications of the slightly lower UFRV will be factored in with the future construction cost for different loading rates in selecting a design value. Metals removal data also showed equivalent removal of manganese and thallium across all filter loading rates.

4.6 Solids Dewatering and Dewatering Filtrate Water Quality

Throughout pilot testing, pilot operators routinely drained settled solids from the clarifier and discharged them to the sanitary sewer. Periodically, samples of the clarifier underflow were collected for settling tests and simulated thickening in a 30-gallon container. The thickening simulation achieved solids concentrations of 2.0 to 3.3 %. Samples of the thickened solids were collected in order to send to Andritz Separation for analysis of alternative dewatering processes.

Additionally, two settling tests were conducted in an unstirred 2000-mL graduated cylinder and indicated that minimal additional settling occurred in samples with no polymer addition. For example, in the first settling test, only 100 mL of clear supernatant was observed after 3 hours and in the second test, only 135 mL of clear supernatant was observed after 3 hours.

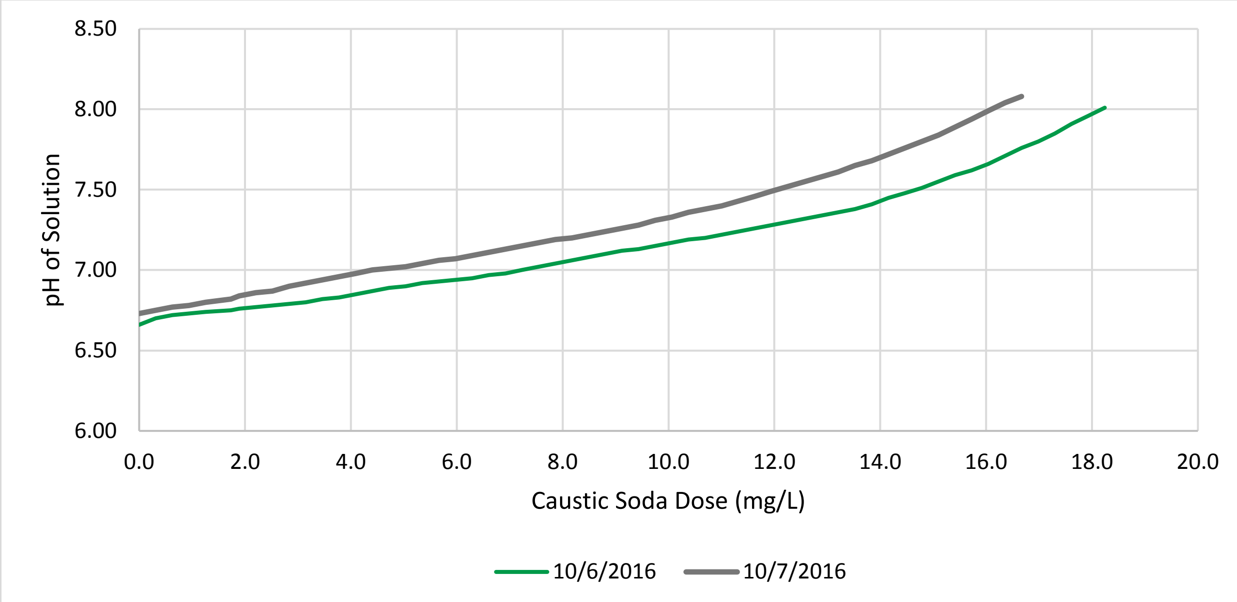
In October 2016, sludge grab samples were taken while draining sludge from the clarifier. Three sludge samples were taken each day for six days. The sludge samples drawn included a sample at the initial draw of sludge from the clarifier, a composite sample of the total daily sludge volume, and a sample at the final draw of sludge before the water ran clear. These 18 sludge samples were measured for total suspended solids (TSS) to compare the initial and final TSS concentration to the composite sample TSS concentration. Figure 4-28 indicates that the composite samples can be used as an estimate of all solids wasted from the pilot sedimentation basin, since the TSS concentration of the composite was close to the average of the initial and final sample TSS concentrations. Therefore, the metals concentrations in the composite sludge samples, shown below in Table 4-6, will be used to estimate percent of metals captured through clarification. Concentrations of radionuclides including uranium, gross alpha, gross beta, radium-226, and radium-228 a single composite sludge sample will also be included in Table 4-6 after data is received.

After sampling, the composite sludge samples settled for 24 hours, and the resulting supernatant was sampled for metals concentrations. Table 4-7 shows the metals in the supernatant and composite sludge samples. The supernatant metals concentrations were lower than the sludge metals concentrations by more than an order of magnitude, which confirms the sludge contains most of the metals by mass.

From TSS analyses of the initial draw sludge samples, the samples ranged from 0.8 to 1.6 percent solids, indicating that some thickening occurred in the floc/sed pilot unit. Composite sludge samples ranged from 0.4 to 0.7 percent solids. During conceptual design, more typical values for percent solids will be used for conservatism of solids process design.

Attachment D. Pilot Testing Report Section 4.9 (Excerpt)

Figure 4-31: Finished Water Stability Test



4.8.7 Disinfection Considerations

The pilot operations team conducted a chlorine residual decay test during the pilot study to aid in the future design of the chlorine disinfection basin for the full-scale water treatment plant. For the test, the operations team collected two liters of pH 6.5 Metsorb® titanium-dioxide adsorption media effluent, and adjusted pH to 7.6, and then dosed with a 1.24% sodium hypochlorite solution to obtain a chlorine residual of 1.5 mg/L. Chlorine residual and pH of the water were measured at two-hour increments for six hours and then measured again after 24 hours. Table 4-14 below indicates that there was minimal decay of chlorine residual after a 24-hour period.

Table 4-14: Chlorine Decay Test Results

Time[a]	Chlorine Residual[b]	pH
0	1.64	7.70
2	1.63	7.69
4	1.57	7.73
5.5	1.56	7.77
24	1.42	8.00

a- Time measured in hours
b- Chlorine residual measured in mg/L Cl_2

4.9 Challenge Tests

One key objective for the MIW pilot plant operation was to perform various challenge tests in order to understand the robustness of the treatment process, particularly with regard to risk of stream discharge compliance issues. Between August and September 2016, the pilot operations team performed testing through several challenges to demonstrate treatment in less than ideal conditions. The challenge tests conducted included:

- Filter challenge tests
- A 48-hour shutdown and a 72-hour shutdown

- Periods of ceasing to add chemicals used at the pilot plant, including caustic soda, sodium hypochlorite, ferric chloride, and polymer
- Elevated turbidity in the source waters (as described previously)

4.9.1 Filter Challenge Tests

Filter challenge tests included a high loading rate "stress test" and a test in which the filter loading rate was changed rapidly. These tests were conducted to identify any changes in filtered water quality that could occur if the filter loading rate changed to accommodate a higher or lower plant flowrate.

In the high loading rate stress test, one 42-inch pyrolusite filter's loading rate was changed from 10 to 12 gpm/sf for approximately 4 days to evaluate both turbidity removal and metals removal. Filter performance remained constant throughout the high rate stress test. While at 12 gpm/sf, the pyrolusite filter achieved UFRVs between 10,000 and 12,600 gal/sf and maintained a median filter run turbidity of 0.02 NTU, both of which were consistent with performance at a 10 gpm/sf loading rate. Additionally, the pyrolusite filter completely removed manganese and thallium during the high loading rate stress test. It should be noted that the filter loading rate of 12 gpm/sf represented the highest possible filter loading rate with the pilot equipment.

Turbidity removal of the pyrolusite filters was also evaluated when loading rates were changed mid-run. For each 42-inch pyrolusite filter, loading rates were changed for two hours and then returned to the previous loading rate. The first 42-inch pyrolusite filter was changed from 10 to 5 gpm/sf, the second pyrolusite filter changed from 6 to 10 gpm/sf, and the third pyrolusite filter changed from 8 to 11 gpm/sf. All filter loading rate changes were made two hours into their respective filter runs and lasted for 2 hours before returning the filters to their original loading rates. Filter effluent turbidity and filter run UFRVs remained similar for all pyrolusite filters throughout the duration of the test.

4.9.2 Shutdown Challenge Tests

The pilot operations team conducted a 48-hour shutdown test in late August 2016 and a 72-hour shutdown test in early September 2016 to determine any effect on water quality when bringing the treatment processes back online after a period without treatment. In each test, the pilot plant processes were shutdown for the time period indicated, with no flow through several unit process. At the end of the 48-hour shutdown test, flow was returned to the pilot plant. Sampling through the treatment process immediately followed the end of the shutdown test after placing the filters and adsorption columns back in service.

Both metals removal and turbidity removal were evaluated in the 48-hour shutdown test. For this test, water continued to run through the flocculation/sedimentation skid throughout the test, but water to all filters and adsorption media was turned off. Sodium hypochlorite, caustic soda, ferric chloride, and polymer continued to be fed to the oxidation and flocculation/sedimentation skids throughout the test. Samples were taken through the process before shutdown.

After bringing the pilot plant back online after the shutdown, filters operated normally for 15 minutes before backwashing. Sampling of all filter effluent occurred at 5 minutes and 12 minutes after each filter came back online as well as 15 minutes after backwashing the filters. Metals removal remained consistent through all 42-inch pyrolusite columns before and after the 48-hour shutdown test.

The 40-inch anthracite over 20-inch pyrolusite column saw no change in metals removal before and after the test except for the removal of thallium. Thallium was detected in the effluent at levels greater than the stream discharge permit level after 5 minutes and 12 minutes of filter operation after coming back online. The anthracite over pyrolusite filter effluent was not sampled after backwashing.

The 72-hour shutdown test focused on turbidity performance through sedimentation and filtration as well as time to bring the pilot plant back online. No sampling for metals occurred before or after the

72-hour shutdown. In this test, no water flowed through clarification, filtration, or adsorption over a 72-hour period. The pilot plant was brought back online incrementally, with flow to flocculation and sedimentation increased from 3 to 6 gpm after 2.5 hours of operation. Settled water turbidity dropped to below 1.5 NTU after 30 minutes of operation and remained below 1.5 NTU throughout the startup period. All filters were backwashed immediately after startup. Effluent turbidity of all filters dropped below 0.03 NTU within 20 minutes of normal operation after backwash and remained there throughout the filter runs. The Metsorb® media saw an increase in antimony removal two days after the shutdown, most likely due to the resting period during the 72-hour shutdown.

4.9.3 Chemical Drop Tests

The chemical drop tests consisted of ceasing to add a treatment chemical for a period of approximately 12 to 16 hours to demonstrate the effect on treatment of an interruption in dosing of each treatment chemical. Tests were conducted individually, dropping caustic soda, sodium hypochlorite, ferric chloride, and polymer over a number of tests. For the tests, the pilot operations team turned off each chemical, except polymer, overnight and brought them back online the next morning. Before returning the chemical feed, sampling through the process occurred to determine any effects on metals removal.

Polymer was unintentionally halted several times throughout the course of the study for up to 12 hours at a time. An evaluation of turbidity removal during these periods is shown below.

4.9.3.1 Caustic Soda

When the caustic soda feed was stopped, pH in the settled water basin dropped to 7.4 from pH 8.2. Through filtration, pH dropped from 8.0 to 7.5. Adsorption influent pH dropped slightly from pH 6.5 to pH 6.4 in the low-pH adsorption columns and from pH 7.6 to 7.4 in the ambient-pH adsorption columns.

Due to the pH-dependent nature of cadmium and zinc removal, the loss of caustic soda resulted in elevated cadmium and zinc levels through clarification and filtration. Zinc levels through the pyrolusite effluent exceeded the SDP and cadmium levels through the pyrolusite effluent reached values near the SDP, showing the importance of maintaining a pH of 8.0 or above through filtration. During the test, pyrolusite filter effluent had approximately four times the cadmium and ten times the zinc concentrations that would typically be loaded onto the Metsorb® titanium-dioxide adsorption media. Both cadmium and zinc were removed to levels at or near the detection limit through Metsorb® media. Table 4-15 shows cadmium and zinc concentrations through the process during the test compared to median concentrations from pilot study data. These results demonstrate the criticality of the multiple metals removal barriers provided with post-filter Metsorb® adsorption.

Table 4-15: Cadmium and Zinc Removal Without Caustic Soda Feed

Sample Locations	Cadmium[c,d]		Zinc[c,d]	
	Without Caustic Soda	Median Value	Without Caustic Soda	Median Value
Laboratory Detection Limit	0.1	0.1	5	5
Influent	0.8 (0.7)	0.8 (0.7)	310 (260)	310 (280)
Settled Water	0.6 (0.5)	0.5 (0.2)	250 (190)	140 (40)
Post-Filtration[a]	0.4	0.1	210	20
Post-Adsorption[b]	ND	ND	20	10
MCL	5	5	5000	5000
SDP	0.42	0.42	198	198

a- Concentration reported is the average of all filter effluent concentrations in similar operating conditions.

b- Concentration reported is the maximum concentration of all adsorption effluent samples to provide the most conservative estimate.
c- All values are in µg/L. Dissolved concentrations are in parentheses.
d- A value of ND indicates a concentration below the laboratory detection limit.

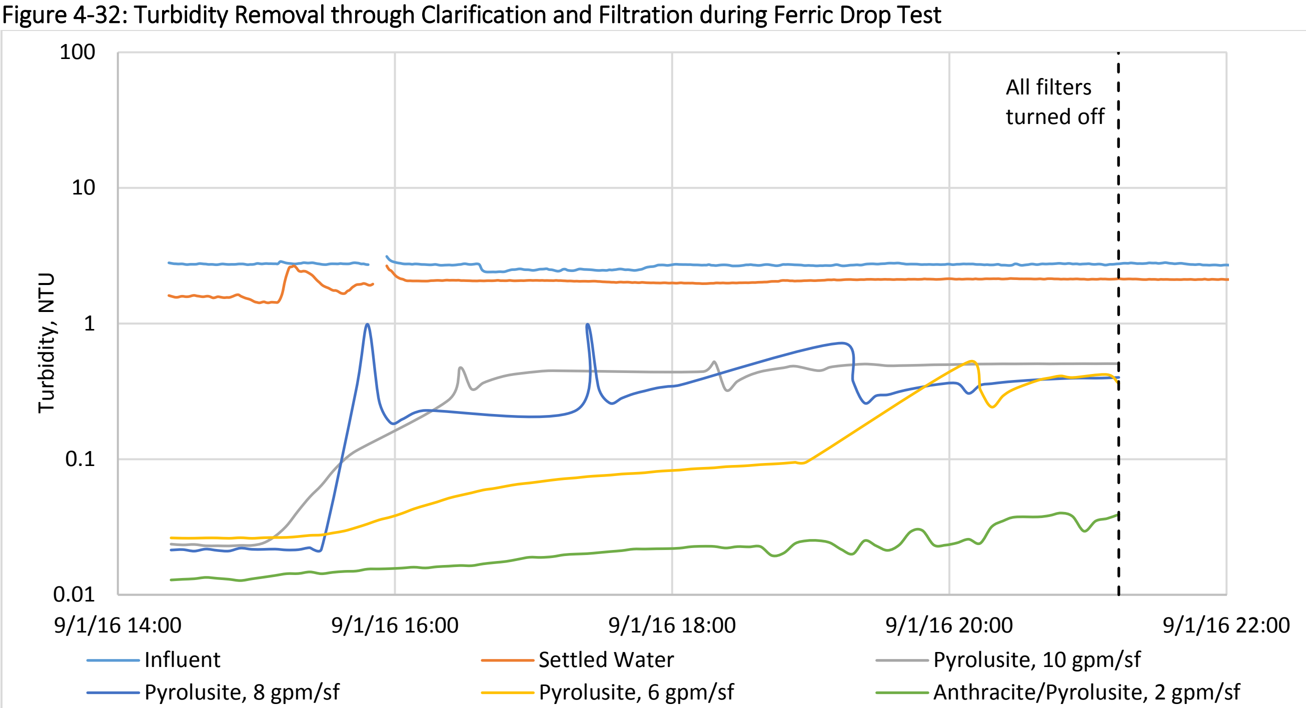
4.9.3.2 Sodium Hypochlorite

The loss of sodium hypochlorite was expected to affect both the pre-oxidation process and the pyrolusite filter media performance. Removal of manganese and thallium through pyrolusite media relies on the media retaining a positive chlorine residual. Despite the temporary stop in chlorine dosing, the pyrolusite filters completely removed thallium and manganese to below the laboratory detection limit throughout the interruption of 18 hours in chlorine dosing. Longer periods without chlorine dosing may have a greater impact. Continuous chlorine dosing is recommended at full-scale.

4.9.3.3 Ferric Chloride

The loss of ferric chloride affected both metals removal and turbidity performance. Without ferric chloride, settled water turbidity increased to 2.5 NTU after 50 minutes. Figure 4-32 shows that the 42-inch pyrolusite filters at 10 gpm/sf and 8 gpm/sf filter loading rates operated for approximately one hour before they could no longer maintain effluent turbidities of less than 0.1 NTU. The 42-inch pyrolusite filter at 6 gpm/sf operated for approximately four hours before consistently reaching effluent turbidities above 0.1 NTU. The 40-inch anthracite over 20-inch pyrolusite filter was operating at a 2 gpm/sf loading rate and was turned off after seven hours of operation along with the other filters. It reached a maximum effluent turbidity of 0.04 NTU at seven hours of operation without ferric chloride. The loss of ferric chloride also resulted in a reduction of arsenic and lead removal through clarification.

Figure 4-32: Turbidity Removal through Clarification and Filtration during Ferric Drop Test



4.9.3.4 Polymer

Polymer feed to the pilot was unintentionally stopped five times throughout May and June, 2016. In all five instances, the polymer feed stopped overnight and the pilot operators saw that the polymer was not feeding into the rapid mix basin the next morning. The exact time that the polymer stopped feeding to the system is unknown in all five instances. After discovering the loss of polymer feed, the pilot operators reinstated polymer feed by repositioning the feed tube in the peristaltic feed pump and by trimming the feed tubing inlet or outlet to remove any clogging of polymer in the tubing. All five instances occurred while a small diameter polymer feed tube was used; it was replaced with a larger diameter tubing in June 2016 and polymer feed was able to run continuously after the switch. During polymer stoppage, settled water turbidity increased from less than 2.0 NTU to a maximum of 3.3 NTU. Pyrolusite filter run times and UFRVs decreased slightly and median filter effluent turbidities increased slightly during periods of polymer loss. All pyrolusite filter runs terminated due to headloss accumulation during the periods of polymer feed loss. Filter run UFRVs and median filtered water turbidities for the filter runs during loss of polymer feed are indicated as black squares on the filter run summaries shown below in Figure 4-33 and Figure 4-34. The plots below show that pyrolusite filters can still produce low turbidity filtered water without a polymer feed for a period of 12 hours or less.

Figure 4-33: Filter Run UFRV during Polymer Drop

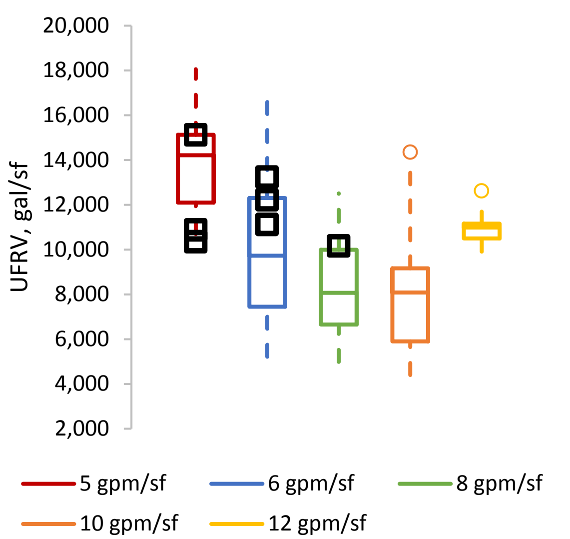
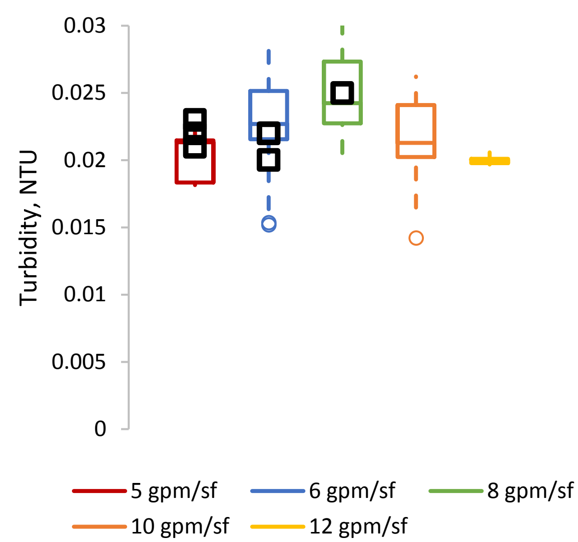


Figure 4-34: Median Turbidity of Filter Runs during Polymer Drop



4.9.3.5 Summary of Chemical Drop Tests

The chemical drop tests indicated that, in an emergency, interruptions to caustic soda, sodium hypochlorite, and polymer dosing can be tolerated for up to 12 hours without a significant impact on finished water quality. For stream discharge, zinc concentrations may become critical if caustic soda dosing is interrupted. The tests also indicated that the process can continue to operate for a short period of time without ferric chloride until an operator is able address the loss in chemical feed.

4.10 Taste Test

At the conclusion of the pilot study, adsorption effluent at both a 2:1 Spiro to Judge blend ratio and a 4:1 Spiro to Judge blend ratio were collected and compared to the taste of two water sources from Salt Lake City and two sources from the Park City distribution system. Effluent from one pH 6.5 Metsorb® column was sampled for the adsorption effluent samples. Both samples were pH adjusted to pH 7.6 and disinfected with sodium hypochlorite at a chlorine residual of 1.5 mg/L after 30 minutes of contact time to provide more than 0.5 log reduction in *Giardia* and a much more than the SWTR's 2.0-log reduction in viruses. All samples were taken the day before the test and refrigerated to maintain a similar temperature. A facilitator numbered the samples and served them to six taste testers in order to maintain a blind taste test. Figures 4-36 and 4-37 show the taste testers trying the various waters. The taste testers ranked the samples from best to worst and rated them on an absolute scale. Figure 4-35 presents the average rating given to each sample and indicates that all sample waters were observed to be fairly similar in taste. The Metsorb® effluent with a 2:1 Spiro to Judge blend received the highest rating, followed by water collected from the CH2M office near Salt Lake City. After the waters were

Jacobs

Memorandum

Supporting Information to BODR

Attachment E. Pilot Testing Report Section 4.2 (Excerpt)

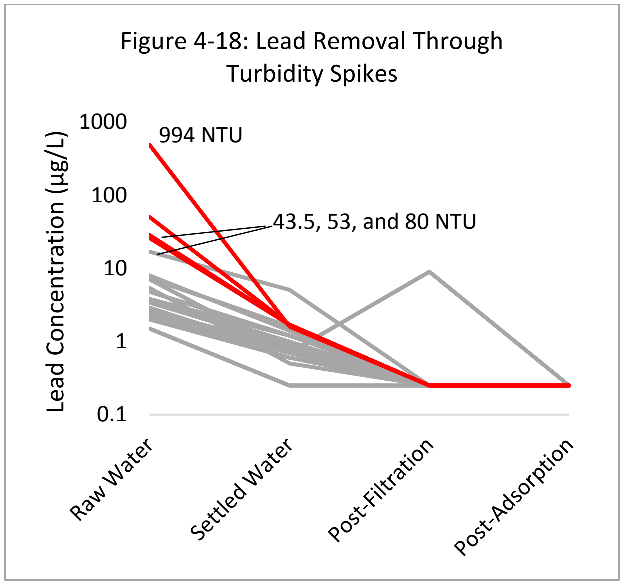


Table 4-1: Spiro Tunnel Upset Raw Water, Settled Water, and Filtered Water Mercury Concentrations

Analyte	Spiro Tunnel Upset, 730 NTU			Spiro Tunnel Upset, 850 NTU			MCL or SMCL	SDP
	Raw Water[a,b]	**Settled Water[a]**	**Filtered Water[a]**	**Raw Water[a,b]**	**Settled Water[a]**	**Filtered Water[a]**		
Mercury (ng/L)	19.4	0.25	0.25	93.7	0.25	0.25	2,000	12

a- All concentrations presented are total mercury concentration. Values represent a sample of Spiro Tunnel upset water taken during the "999 NTU" turbidity spike on September 28, 2016.

4.2 Metals Removal Through Adsorption

In the pilot plant treatment train, filtered water from two 42-inch pyrolusite filters was collected in a common filter effluent basin and fed to the adsorption process. The loading rates of these filters varied, but for the majority of time one filter operated at 10 gpm/sf and one filter operated at 6 gpm/sf. Filtered water turbidity remained below 0.1 NTU throughout operation. If a filter effluent reached 0.1 NTU, the filter would automatically backwash.

Adsorption was identified as the primary mechanism for antimony removal. Through bench-scale testing, three adsorption media were recommended for the pilot study, as follows:

- Titanium dioxide media: Metsorb®, provided by Graver Technologies.
- Ferric oxide media: Bayoxide® E33, provided by AdEdge Technologies.
- Ferric hydroxide media: GFH®, provided by Evoqua Water Technologies.

More detailed information about each adsorption media can be found in Appendix C.

Adsorption media exhaustion curves developed during pilot operation show antimony concentration versus bed volumes (BVs) treated for the column midpoint and column effluent sample points.

There were several phases of testing with the adsorption columns. They are summarized below.

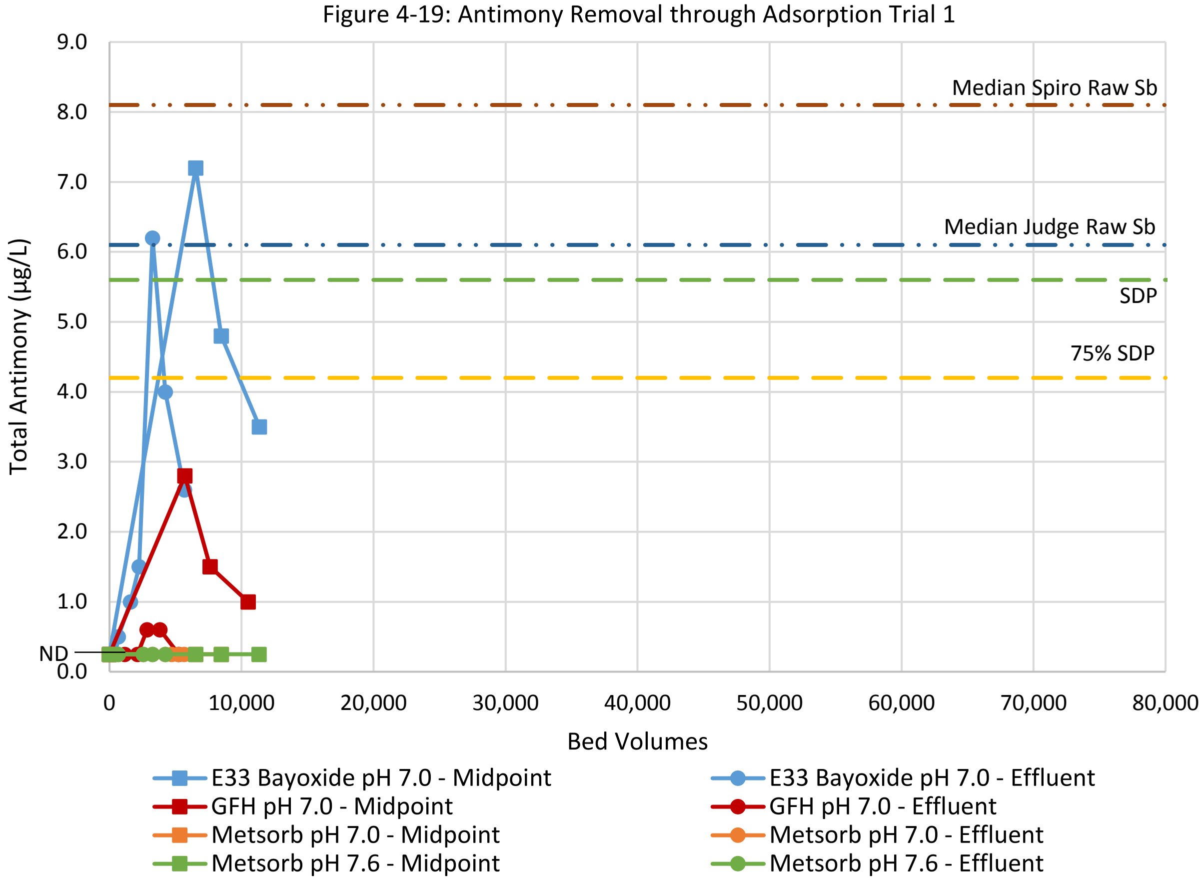
4.2.1 Trial 1

During the initial trial, four test conditions were evaluated:

- Adsorption Column 1: Metsorb® at pH 7.0
- Adsorption Column 2: Bayoxide® E33 at pH 7.0
- Adsorption Column 3: GFH® at pH 7.0
- Adsorption Column 4: Metsorb® at pH 7.6

Samples were collected at the midpoint and the effluent of each column. The two sample points represented empty bed contact times (EBCTs) of 3.0 and 6.0 minutes. During this initial trial, the pH rose from the target of 7.0 to a pH of 8.0 due to difficulties encountered with the acid feed. When the pH increased, there was an immediate increase in the antimony levels detected in the Bayoxide® E33 and GFH® products. This effect can be seen in Figure 4-19 from 3,000 to 5,500 bed volumes for the effluent series and between 6,000 to 11,000 bed volumes for the mid-point series. The pH increase did not have a detectable effect on the Metsorb® columns.

Figure 4-19: Antimony Removal through Adsorption Trial 1



4.2.2 Trial 2

Based on the observation of pH effect in Trial 1, the test conditions were modified during the second trial. Trial 2 represents a continuation of Trial 1 for all columns, with all columns containing the same media as Trial 1. Trial 2 test conditions included:

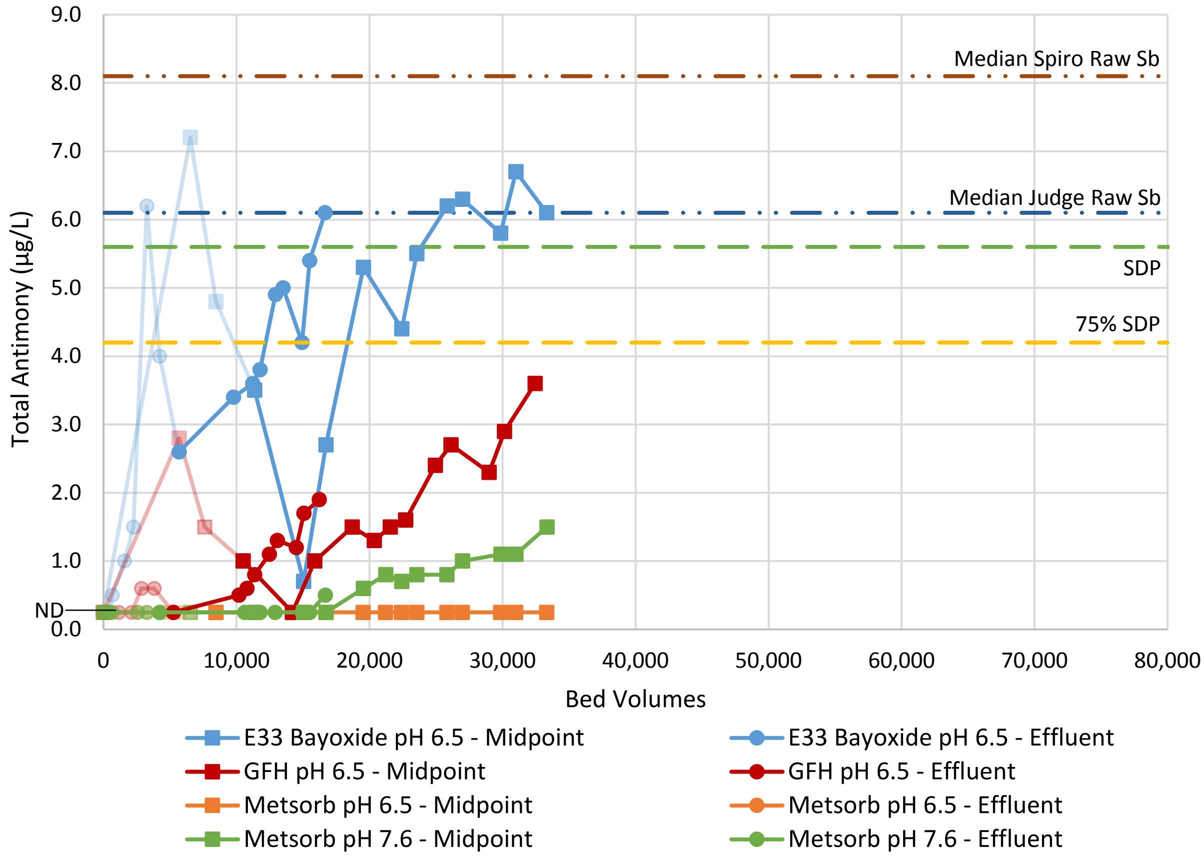
- Adsorption Column 1: Metsorb® at pH 6.5
- Adsorption Column 2: Bayoxide® E33 at pH 6.5

- Adsorption Column 3: GFH® at pH 6.5
- Adsorption Column 4: Metsorb® at pH 7.6

Additionally, the loading rate on the column was increased. Samples were collected at the midpoint and the effluent of each column. The two sample points represented EBCTs of 2.5 and 5.0 minutes.

During the second trial, a correction in the removal of antimony through the Bayoxide® E33 and GFH was observed. This indicated that antimony removal is influenced by pH. Since the stream discharge permit limit pH range is between 6.5 and 9.0, pH was not adjusted below 6.5. Figure 4-20 shows antimony concentrations at the midpoint and effluent of all adsorption columns. The shaded lines represent results from Trial 1 and the non-shaded lines represent results from Trial 2.

Figure 4-20: Antimony Removal through Adsorption Trial 2



Though removal increased for Bayoxide® E33 and GFH at the more acidic pH values during Trial 2, both media continued to show breakthrough, as indicated by Figure 4-20. The Bayoxide® E33 media was the first media whose effluent exceeded PCMC's goal of 75 percent of the SDP. Based on the pilot data, Bayoxide® E33 media at pH 6.5 would need to be changed every 12,000 to 18,000 bed volumes.

The GFH media continued to show breakthrough as well. Through extrapolation, it was estimated that GFH media at pH 6.5 would need to be changed every 29,000 to 50,000 bed volumes.

4.2.3 Trial 3 – Antimony Removal with Metsorb® Titanium Dioxide Media

On August 17, 2016, new Metsorb® media replaced both the Bayoxide® E33 and GFH® media. Test conditions for the Trial 3 were modified with the media replaced to the following:

- Adsorption Column 1: Metsorb® at pH 6.5 (same media as Trial 1 and 2)
- Adsorption Column 2: Metsorb® at pH 6.5 (new media)

- Adsorption Column 3: Metsorb® at pH 7.6 (new media)
- Adsorption Column 4: Metsorb® at pH 7.6 (same media as Trial 1 and 2)

Based on finished water quality modeling, for the purpose of the pilot study, it was assumed that finished water would leave the future MIW treatment plant at approximately pH 7.6 to achieve a target calcium carbonate precipitation potential (CCPP). To evaluate the treatment benefits of depressing to pH 6.5 for adsorption and then elevating the pH back to 7.6, test columns were run at both pH 6.5 and pH 7.6 for comparison. These conditions were maintained through the remainder of the pilot study.

Antimony levels in the effluent of both Metsorb® columns operating at pH 6.5 stayed below the laboratory detection limit throughout the duration of the pilot study. Metsorb® columns operating at pH 7.6 saw detectable levels of antimony at both the effluent and the mid-point sample points of the Metsorb® columns.

At the conclusion of this pilot study, in the column mid-point at pH 7.6, antimony levels reached a maximum of 2.6 µg/L at 37,000 bed volumes, which is less than half of the stream discharge permit limit.

Results for the Metsorb® media at pH 6.5 are presented in Figure 4-21. Since most of the data points in Figure 4-21 were at the laboratory detection limit, few quantifications can be drawn, other than the adsorption media life will be much longer than originally anticipated, resulting in significant O&M cost savings for PCMC. However, if the data from the mid-point of Adsorption Column 1 with Metsorb® at pH 6.5 were extrapolated to 75 percent of the SDP, it would result in approximately 170,000 bed volumes between media changes.

Figure 4-22 presents results for the Metsorb® media at pH 7.6. There is no data after approximately 35,000 bed volumes for the midpoint of the Metsorb® column at pH 7.6. In August 2016, half of the Metsorb® media was unintentionally removed from the column. The flow rate to the column was adjusted to maintain an effluent EBCT of 5 minutes, but samples could no longer be taken from the midpoint sample point. From the data in Figure 4-22, media replacement is expected between 66,000 and 91,000 bed volumes at pH 7.6. This indicates that there is a significant improvement that could be obtained by lowering to pH 6.5 for adsorption. Further cost comparisons using the results will be completed during conceptual design.

Near the end of the pilot study, the two Metsorb® columns at pH 7.6 were operated at pH 6.5 for three days to determine if lowering the pH would increase adsorption media life. The columns were returned to pH 7.6 after three days and were sampled again to determine any effects on the adsorption media exhaustion curve shape. Figure 4-22 shows that antimony concentrations were reduced by up to 1.6 µg/L when pH dropped, indicating that reducing adsorption feed pH from 7.6 to 6.5 can increase metals removal. The figure also shows that antimony concentrations returned to previous values once pH was returned to 7.6.

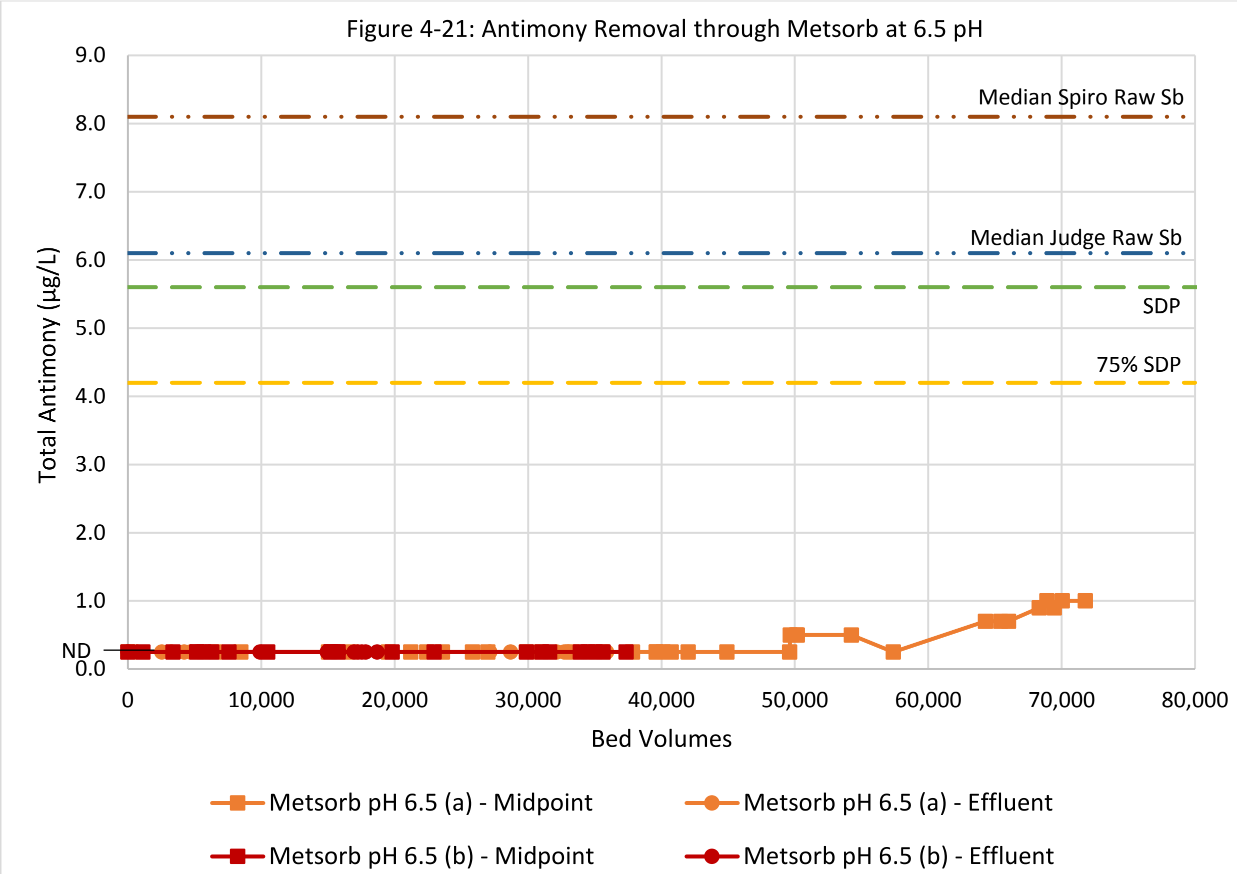


Figure 4-21: Antimony Removal through Metsorb at 6.5 pH
Median Spiro Raw Sb
Median Judge Raw Sb
SDP
75% SDP
Total Antimony (µg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ND
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Bed Volumes
Metsorb pH 6.5 (a) - Midpoint
Metsorb pH 6.5 (a) - Effluent
Metsorb pH 6.5 (b) - Midpoint
Metsorb pH 6.5 (b) - Effluent

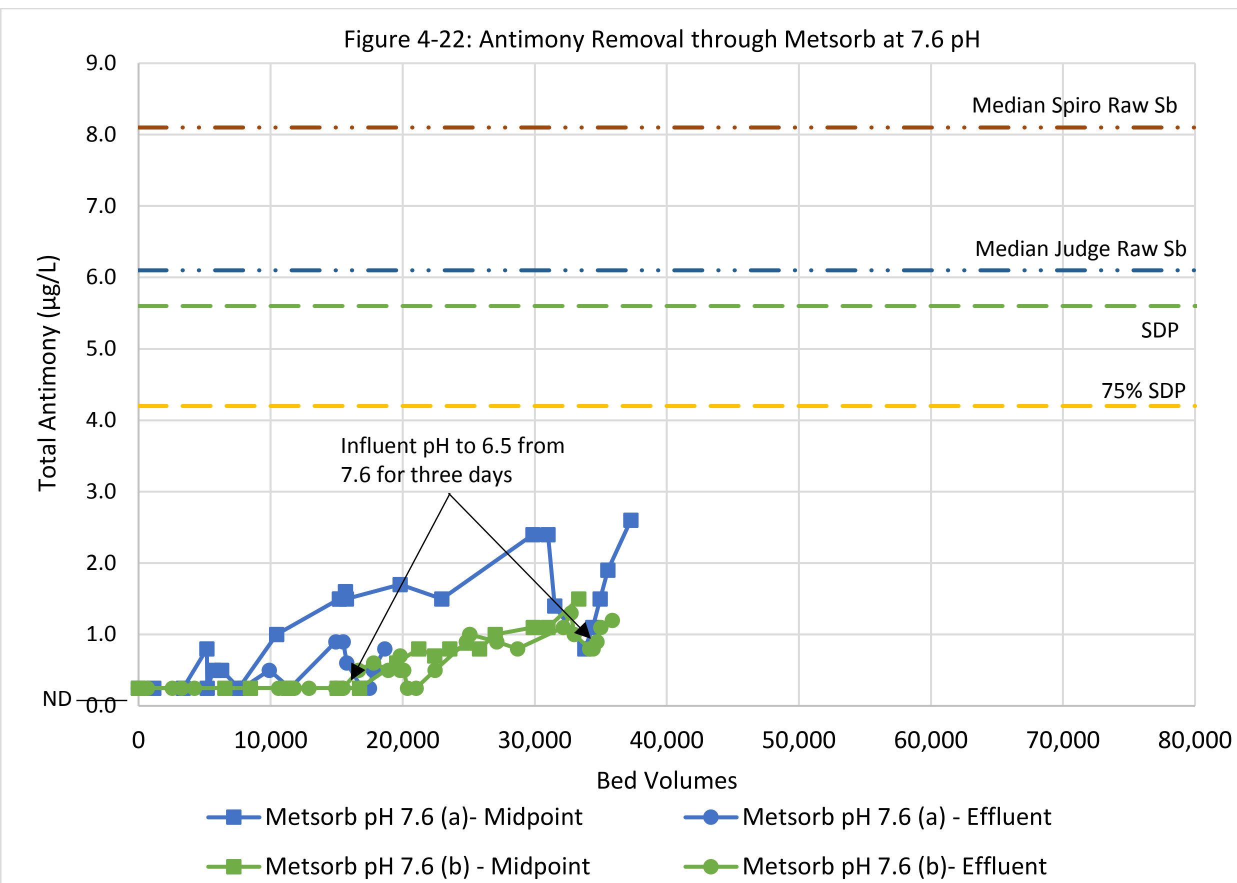


Figure 4-22: Antimony Removal through Metsorb at 7.6 pH
Median Spiro Raw Sb
Median Judge Raw Sb
SDP
75% SDP
Influent pH to 6.5 from
7.6 for three days
Total Antimony (µg/L)
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
ND
0.0
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
Bed Volumes
Metsorb pH 7.6 (a)- Midpoint
Metsorb pH 7.6 (a) - Effluent
Metsorb pH 7.6 (b) - Midpoint
Metsorb pH 7.6 (b)- Effluent

4.2.4 Additional Considerations

In addition to antimony, several other metals were sampled regularly in the adsorption columns' effluent. All adsorption midpoint and effluent samples for all adsorption media saw no detection of either lead or thallium throughout the pilot study.

Arsenic and cadmium were detected once at the midpoint and arsenic was detected once at the effluent of the first Metsorb® column at pH 6.5. All arsenic and cadmium detections from the first Metsorb® column at pH 6.5 were above the respective laboratory detection limits, but less than the MCL and SDP limits. Iron was detected once at both the midpoint and effluent of the GFH® column, twice at the effluent of the Bayoxide® E33 column, and once at the midpoint of the second Metsorb® column at pH 6.5. Manganese was detected once at both the midpoint and effluent of the first Metsorb® column at pH 6.5, once at the midpoint of the second Metsorb® column at pH 6.5, twice at both the midpoint and effluent of the GFH® column, twice at the effluent of the Bayoxide® E33 column, and twice at both the midpoint and effluent of the first Metsorb® column at pH 7.6. Most iron and manganese detections were below their respective SMCLs and all detections corresponded with either the period of difficulty with pH adjustment in the adsorption feed or the turbidity spikes seen in September 2016. Selenium was not removed through adsorption and was typically measured between 2.5 and 2.9 µg/L in the adsorption column effluent.

Zinc was detected often at both the midpoint and effluent of the Metsorb® columns at pH 6.5 and at the midpoint and effluent of the GFH® and Bayoxide® E33 columns at pH 6.5. Zinc was also detected at the midpoint and effluent of the Metsorb® columns at 7.6 pH when the pH was reduced to 6.5 for several days. Most zinc detections were below the stream discharge permit limit. However, three zinc samples were detected at levels near or above the SDP limit during periods of very low influent pH. The first Metsorb® pH 7.6 column influent dropped to pH 2 for several hours in early July and the influent to the GFH®, Bayoxide® E33, and Metsorb pH 6.5 columns dropped to pH 3 for approximately 10 hours in mid-July due to an experimental error. After these occurrences, the influent pH issue was resolved and no further influent pH issues occurred. These results indicate that there may be a zinc release potential with all adsorption media used under very low pH conditions. If pH 6.5 or 7.6 is maintained, then the zinc release is not expected to be of concern.

The following conclusions can be made based on the data gathered on metals removal through adsorption:

- Adsorption with titanium dioxide media, ferric oxide media, and ferric hydroxide media removed antimony to below the stream discharge permit limit level. The media replacement frequency was estimated at:
  - 66,000 to 170,000 bed volumes for titanium dioxide media
  - 22,000 to 18,000 bed volumes for ferric oxide media
  - 29,000 to 50,000 bed volumes for ferric hydroxide media
- Antimony was removed by all media at an EBCT of 2.5 minutes.
- Antimony removal at a pH of 6.5 will result in the ability to treat significantly more bed volumes before exhaustion compared to operation at pH 7.6.
- Lowering pH from 7.6 to 6.5 for three days increased antimony removal in both pH 7.6 Metsorb® columns. Media exhaustion curves for both pH 7.6 Metsorb® columns returned to pre-6.5 pH levels once pH was returned to pH 7.6.

Both GFH® and Bayoxide® E33 media were tested with the Toxicity Characteristic Leaching Procedure (TCLP) after removal from the process to verify proper disposal requirements. Metsorb® adsorption media will undergo the TCLP after further testing of the media (as described in Section 6) is completed.

TCLP results for GFH® and Bayoxide® E33, shown below in Table 4-2, are below the TCLP regulatory limits as defined by the Resource Conservation and Recovery Act (RCRA) limits for hazardous solid waste by an order of magnitude or more. These results indicate that both media can be considered non-hazardous waste.

Table 4-2: GFH and Bayoxide® E33 Media TCLP Results

Analyte[a]	GFH Media	Bayoxide® E33 Media	RCRA Limit
Mercury, TCLP	0.0007	0.0007	0.2
Arsenic, TCLP	0.25	0.25	5
Barium, TCLP	0.28	0.17	100
Cadmium, TCLP	0.025	0.025	1
Chromium, TCLP	0.025	0.025	5
Lead, TCLP	0.1	0.1	5
Selenium, TCLP	0.001	0.025	1
Silver, TCLP	0.025	0.025	5

a- All values are total measurements in µg/L.

4.3 Whole Effluent Toxicity (WET) Testing

Two WET tests were conducted throughout the pilot study: one in the spring, during the time that has historically coincided with higher flow conditions, and one in the fall, during the time that has historically coincided with lower flow conditions. These tests matched the regulatory compliance requirements of the UPDES permits. Both WET tests used Metsorb® titanium dioxide media effluent. The first WET test used a blend of 2:1 Spiro-to-Judge water at an adsorption influent pH of 7.0 and the second WET test used a blend of 4:1 Spiro-to-Judge water at an adsorption influent pH of 6.5. The pilot treated water passed the first and second WET tests for survival and reproduction of *Ceriodaphnia dubia* (water flea) and *Pimephales promelas* (fathead minnows). Appendix D contains a summary of results from both WET tests.

As previously discussed, Spiro Tunnel water has a hardness of 470 to 500 mg/L as $CaCO_3$ and, when blended with Judge Tunnel water, has a hardness of 370 to 445 mg/L as $CaCO_3$, depending on the blend ratio. The control water used in the WET test had a hardness of approximately 100 mg/L as $CaCO_3$. Therefore, PCMC had an additional control sample of 400 mg/L as $CaCO_3$ hardness synthetic water tested during the first WET test to determine if elevated hardness levels alone could affect the survival and reproduction of either *Ceriodaphnia dubia* or *Pimephales promelas.* The high hardness control WET test passed for survival and reproduction of *Pimephales promelas* as well as survival of *Ceriodaphnia dubia* but failed for reproduction of *Ceriodaphnia dubia*.

Elevated levels of total dissolved solids (TDS) in the water can interfere with the WET test results. In the first WET test, conductivity ranged from 745 to 812 µS/cm in the sample pilot effluent water and 1,155 to 1,222 µS/cm in the synthetic high hardness water. Using conductivity as a surrogate, the synthetic high hardness water had higher levels of (TDS) than the pilot effluent sample water. This indicates that if the TDS of the tunnel water were to rise significantly, there may be an increased risk of not passing a future WET test.

WET testing for Spiro and Judge Tunnel raw waters was considered but ultimately not pursued because the UPDES permit does not require WET tests on raw water. Furthermore, any raw water WET test results were not expected to impact the current process selection.

Attachment F. MetSorb® Media Datasheet

Graver Technologies

Filtration | Separation | Purification

MetSorb® HMRG

Effective, Low-Cost Adsorbent for Removal of Heavy Metals

MetSorb® HMRG and HMRP adsorbents utilize a patented material to adsorb both forms of arsenic as well as a wide range of contaminants in water. Empty bed contact times as low as 10 seconds achieve high removal efficiencies. The material affords a higher capacity and a lower level of ion interference than competitive iron and alumina based products.

MetSorb® HMRG media's adsorptive capacity is 7-12 grams of arsenic per kilogram of HMRG adsorbent in drinking water applications with a pH range of 6.5-8.5. Much higher adsorptive capacities have been measured, up to 400 g/kg, in industrial treatment applications.

Adsorbent Product Features/Benefits

- Removal of heavy metals to meet drinking water standards
- High adsorbent capacity requiring less frequent replacement
- Fast kinetics to work effectively at high flow rates
- Nonhazardous disposal as solid waste

Contaminants

- Arsenic III
- Arsenic V
- Cadmium
- Copper
- Antimony
- Lead
- Mercury
- Uranium
- Zinc
- Selenium

Applications

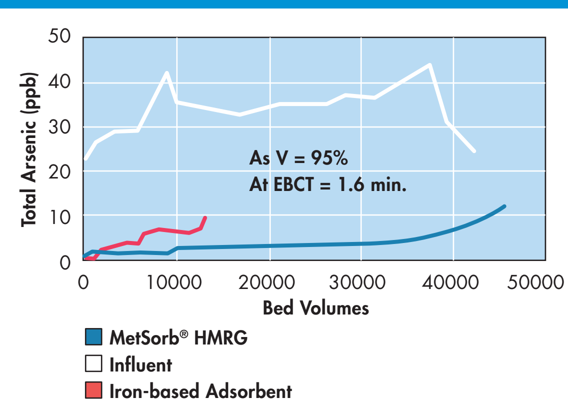
- Commercial and industrial treatment units for drinking water or contaminated water
- Municipal water treatment
- Carbon blocks
- Cartridges for pitchers
- Faucet mounted and countertop devices
- Household point of entry treatment units

.

MetSorb® HMRG Adsorbent Specifications

	HMRG Granular
Appearance	*White granules*
Moisture Content	*<10%*
Bulk Density	*0.65 grams per cc (40 lb/ft3) milliliter*
Other	*Free Flowing*
Particle Size	*–16/+60 U.S. mesh (other sizes available)*

SMALL COLUMN TEST RESULTS

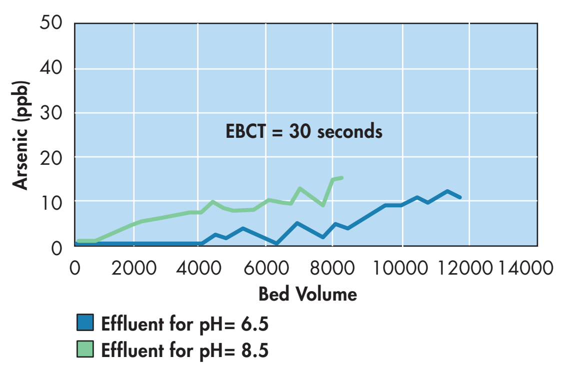


Comparison of HMRG adsorbent with iron-based adsorbent.

BATCH TEST DATA-ADSORPTIVE CAPACITY MetSorb® HMRG

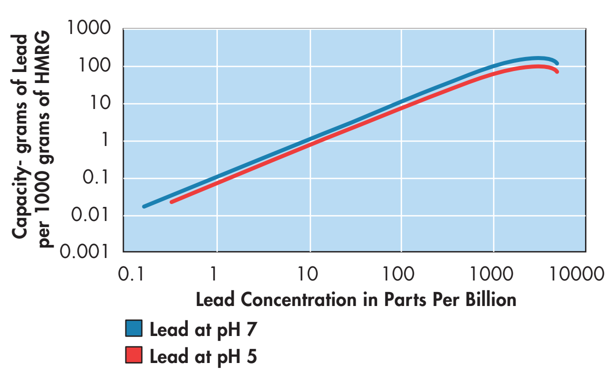
Metal	Initial Concentration	Final Concentration
Arsenic V	*50 ppb*	*<2 ppb*
Arsenic III	*50 ppb*	*5 ppb*
Cadmium	*1,000 ppb*	*24 ppb*
Copper	*500 ppb*	*5 ppb*
Lead	*1,000 ppb*	*18 ppb*
Mercury	*500 ppb*	*26 ppb*
Zinc	*500 ppb*	*12 ppb*

ARSENIC REMOVAL DATA - NSF 53



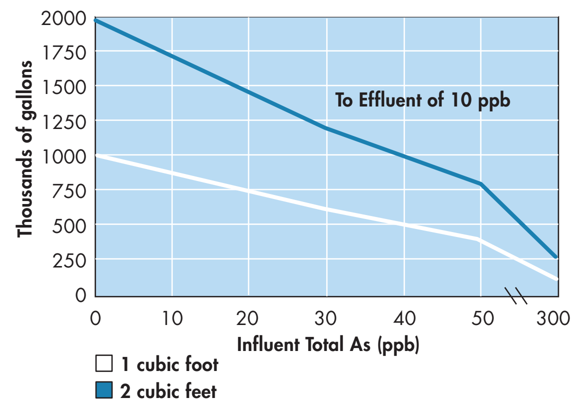
Testing was done under the conditions specified by the NSF Standard 53 for Arsenic. Results at a pH of 6.5 and a pH of 8.5 are shown in the graph above.

LEAD ADSORPTION ISOTHERM



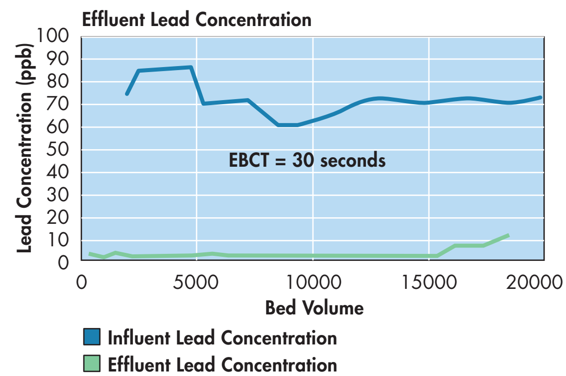
Adsorption isotherms for lead between pH 5 and 7 are nearly identical.

ARSENIC TREATMENT CAPACITY VS. ARSENIC INLET LEVELS



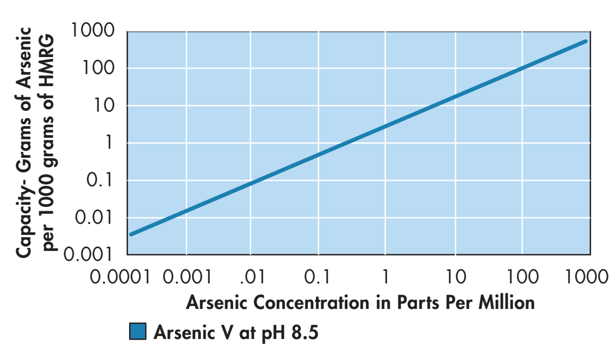
Treatment capacity as a function of tank size.

LEAD REMOVAL COLUMN DATA



Lead removal by MetSorb® HMRG adsorbent in column test; 30 seconds EBCT.

ARSENIC ADSORPTION ISOTHERM



The above graph shows the adsorption isotherm for Arsenic V at pH 8.5.

For more information

MetSorb® HMRG Customer Service: **1-800-533-6623**

Member of:

NSF/ANSI Std 61 D040211

American Water Works Association
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Water Quality Association   Rural Water Association

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