**City of Glendale Water and Power**
141 North Glendale Ave, 4th Floor – Glendale, CA 91206

# Research Effort to Investigate the Feasibility of Microfiltration in the RCF Process for Cr(VI) Removal –
# Pilot Test Plan

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# 1. Introduction

As part of a Water Research Foundation (WaterRF) project, the City of Glendale, California retained CDM (the operator of the Glendale Water Treatment Plant) and Malcolm Pirnie/ARCADIS (Consultant Team) to conduct pilot testing of microfiltration (MF) membranes for removing hexavalent chromium, Cr(VI), to sub-ppb levels in drinking water supplies. The MF pilot units will be tested as an add-on to the current reduction, coagulation, filtration (RCF) demonstration process, in parallel operation with the current granular media filters.

The test objectives include the following:

1) To determine the effectiveness of MF/UF membrane technology for removing total Cr (and hence, Cr(VI) as well) to the sub-ppb levels,

2) To assess whether iron fouling is problematic in direct filtration mode of operation for the RCF process, and

3) To identify design criteria for full-scale MF/UF in a RCF treatment process, which will provide the basis for cost development (which will be performed as an additional effort).

This test plan provides the MF/UF pilot test scope, sampling and monitoring plan, and test schedule.

## 1.1. Cr(VI) Regulatory Trends

Chromium is a naturally occurring element that is typically present in several valence states, with trivalent, Cr(III), and hexavalent, Cr(VI), chromium being the most common. While Cr(III) is an essential nutrient for humans, Cr(VI) compounds have been found to be carcinogenic by inhalation and ingestion. Although naturally occurring Cr(VI) can be reduced to Cr(III) by organic matter in the environment, Cr(VI) released by anthropogenic sources may persist in water and soils that contain low amount of organic matter (Johnson et al., 2006[1]; Loyaux-Lawniczak et al., 2001[2]; U.S. EPA, 1984[3]).

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[1] Johnson, J; Schewel, L; Graedel, T.E. (2006). The contemporary anthropogenic chromium cycle. *Environ. Sci. Technol.* 40:7060-7069.

[2] Loyaux- Lawniczak, S; Lecomte, P; Ehrhardt, J.J. (2001). Behavior of hexavalent chromium in a polluted groundwater: Redox processes and immobilization in soils. *Environ. Sci. Technol.* 35:1350-1357.

[3] U.S. EPA (1984). *Health assessment document for chromium.* Final report. Cincinnati, OH: Environmental Criteria and Assessment Office. EPA 600883014F.

Cr(VI) is currently regulated at the federal level as total chromium with a Maximum Contaminant Level (MCL) of 100 µg/L. The current MCL was based on an allergic dermatitis endpoint rather than cancer[4]. In the past few years, the toxicology of Cr(VI) was re-evaluated in a National Toxicology Program (NTP) study. Based primarily on this study, the U.S. Environmental Protection Agency (USEPA) released its peer-review draft assessment of Cr(VI) toxicology for public comment in September 2010. The document identifies Cr(VI) as a carcinogen through ingestion, such as from drinking water, and proposes a reference dose of 0.0009 mg/kg/day, which is much lower than the current reference dose of 0.003 mg/kg/day for total chromium. The reference dose serves as a predecessor to an MCL. If the proposed Cr(VI) reference dose is finalized at or near that level, a separate MCL at a low parts-per-billion level is possible for Cr(VI).

The State of California currently has a lower MCL of 50 µg/L for total chromium. California State law requires California Department of Public Health (CDPH) to set a Cr(VI)-specific MCL. Adoption of this MCL depends on the CA Office of Environmental Health Hazard Assessment (OEHHA)'s publication of a Public Health Goal (PHG). In July 2011, OEHHA released a final PHG of 0.020 µg/L (parts-per-billion, or ppb) for Cr(VI). Based on this PHG, CDPH will perform cost-benefit analyses to set a Cr(VI) MCL. If the MCL is set at or below single-digit ppb levels, a significant number of sources in California would need treatment technologies for Cr(VI) removal.

## 1.2. City of Glendale, California Cr(VI) Research Program

Since 2002, the City of Glendale has been leading research to identify and test Cr(VI) treatment technologies for drinking water. Phase I screened a wide range of technologies at the bench-scale for the ability to yield water with single-digit micrograms per liter (ppb) Cr(VI) concentrations. Phase II built upon these findings to test six Cr(VI) treatment technologies at the pilot scale. From these studies, an Expert Panel recommended two technologies for demonstration-scale testing – weak base anion exchange (WBA) and reduction/coagulation/filtration (RCF) using ferrous sulfate. The City of Glendale accepted the Panel's recommendation and is currently in Phase III of the research effort, consisting of demonstration testing a 425-gpm WBA system and a 100-gpm RCF system.

The RCF process uses ferrous sulfate to reduce and co-precipitate chromium with iron oxyhydroxide particles, which are subsequently removed by filtration. An interim aeration step between reduction and filtration is intended to oxidize all of the remaining ferrous iron in solution after the reduction tanks, and also provide more time for coagulation. Chromium removal is intrinsically tied to particle removal by filtration due

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[4] U.S. EPA website: http://water.epa.gov/drink/contaminants/basicinformation/chromium.cfm

to the association of the Cr(III) with the ferric iron particles. Granular media filtration (i.e., anthracite and sand) is currently being tested at the demonstration scale to offer a low-cost means of particle removal. However, granular media filtration has demonstrated considerable fluctuations in filter effluent turbidity and hence chromium removals, thus sub-ppb levels of total Cr have not been consistently achieved. The California PHG at a level of 0.020 ppb and the intention of California to regulate Cr(VI) has raised the question of whether more advanced filtration (i.e., microfiltration) can achieve lower treated water concentrations. The Expert Panel recommended that Glendale test MF to achieve better particle, and hence chromium, removal in the RCF process. MF pilot testing will be approached as an add-on to the current RCF facilities.

## 1.3. Process Flow Diagram

Two MF membrane units will be tested as an add-on to the current RCF facilities, and will be run in parallel. The RCF process diagram is shown in Figure 1-1. The MF membrane units will receive coagulated water (containing ferric but no polymer) from the break tank inserted between the aeration tank and the rapid mix. The effluents from the MF membrane units will be discharged to the sewer.

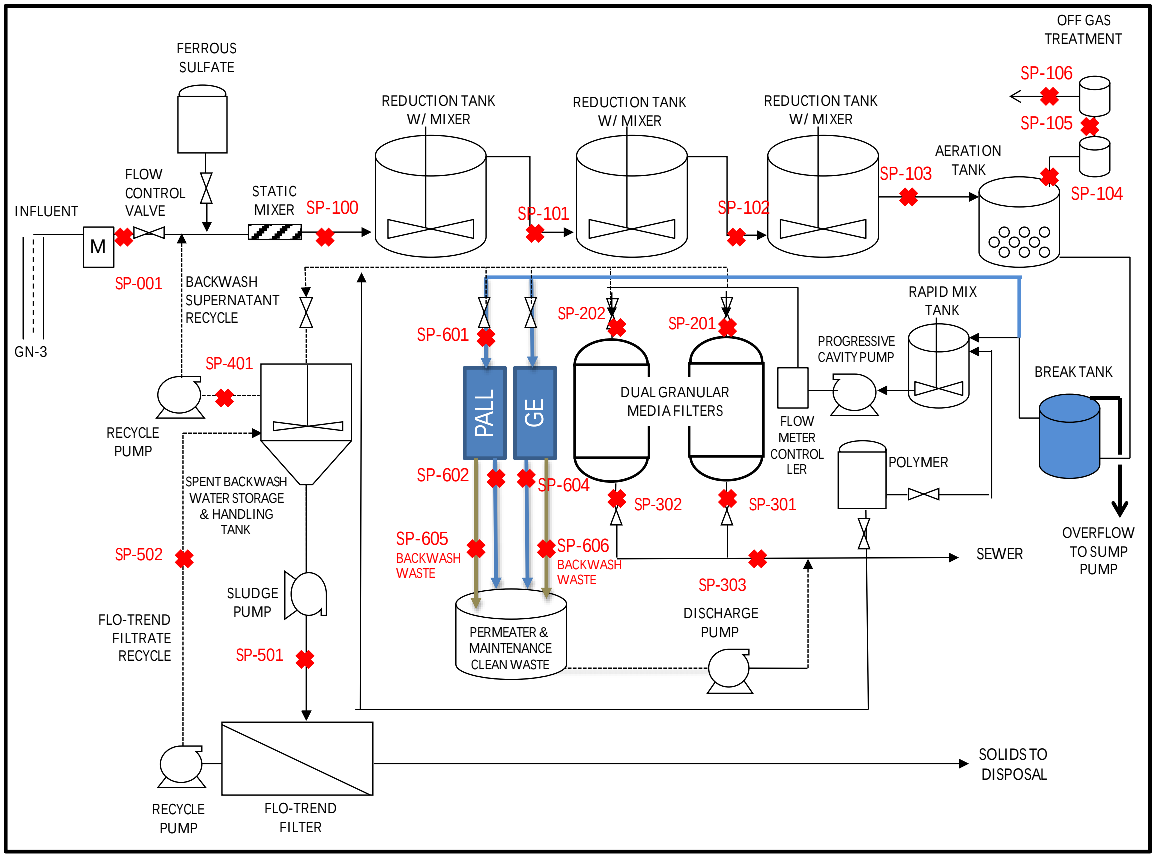

Figure 1-1: RCF Process Flow Diagram Showing Integration of MF Pilot Units

## 1.4. Source Water Supply and Quality

Table 1-1 summarizes the anticipated feed water quality to the MF units. Turbidity, ferrous and total iron, temperature, Cr(VI) and total Cr, are currently not monitored at the aeration effluent (i.e. potential MF takeoff location). Total Cr concentrations in the raw water are provided instead of aeration effluent. Ferrous iron, Cr(VI), and total iron monitoring results at the aeration influent are provided instead of aeration effluent. Ferrous iron concentrations at aeration effluent are expected to be lower than at aeration influent.

Note that the total iron concentrations in Table 1-1 reflect operational conditions with a Fe:Cr(VI) mass ratio of 25:1 and Cr(VI) concentrations of approximately 80 ppb. In addition to the 25:1 Fe:Cr(VI) ratio, a higher Fe:Cr(VI) mass ratio of 50:1 will also be tested during the MF pilot study, which is expected to result in doubling of the total iron concentration in membrane feed water.

A low influent Cr(VI) water source will be identified with CDM's help, using a combination of North wells. Raw water quality data for the identified water source will be gathered and analyzed, if available. In addition, membrane feed water quality data will be gathered during the MF pilot test as described in Section 4.1.

**Table 1-1. Anticipated MF Membrane Feed Water Quality**

| Parameter | Monitoring Location | Average | Range |
|---|---|---|---|
| Total Cr (ppb) | Raw Water | 74 | 64 – 80 |
| Cr(VI) (ppb) | Raw Water | 76.6 | 65-85 |
| Total Cr (ppb) | Aeration Influent | 78.4 | 76-84 |
| Cr(VI) (ppb) | Aeration Influent | 0.15 | ND (<0.025) to 0.38 |
| Total Iron (mg/L as Fe) | Aeration Influent | 1.76 | 1.01 – 2.69 |
| Ferrous Iron (mg/L as Fe) | Aeration Influent | 0.44 | ND (<0.02) – 0.44 |
| Temperature (°C) | Aeration Influent | 21 | 20 – 23 |
| Turbidity (NTU) | Currently no data available for MF/UF feed location | | |
| pH | Aeration effluent (MF Feed) | 7.8 | 7.6 – 8.0 |
| 1,1-Dichloroethane (1,1-DCA, ppb) | Aeration effluent (MF Feed) | 2.2 | 1.6 – 3.0 |
| 1,1-Dichloroethylene (1,1-DCE, ppb) | Aeration effluent (MF Feed) | 37 | 19 - 72 |
| 1,2-Dichloroethane (1,2 DCA, ppb) | Aeration effluent (MF Feed) | 1.3 | 1.1 – 1.7 |
| Carbon tetrachloride (ppb) | Aeration effluent (MF Feed) | 7.4 | 4.3 – 10.0 |
| Chloroform (trichloromethane, ppb) | Aeration effluent (MF Feed) | 4.6 | 3.5 – 5.8 |
| cis-1,2-Dichlorethylene (1,2-DCE, ppb) | Aeration effluent (MF Feed) | 3.6 | 2.7 – 4.3 |
| Tetrachloroethylene (PCE, ppb) | Aeration effluent (MF Feed) | 14 | 9 – 16 |
| Trichloroethylene (TCE, ppb) | Aeration effluent (MF Feed) | 447 | 300 – 510 |
| Total Trihalomethanes (TTHM, ppb) | Aeration effluent (MF Feed) | 4.6 | 3.5 – 5.8 |

## 1.5. Treated Water Quality Goals

Table 1-2 lists project treated water quality goals which will also be used as a benchmark for the membrane treatment system. The project goals are more rigorous than the minimum standards to meet regulatory requirements. In addition, the ability of the MF units to achieve Cr(VI) and total Cr concentrations below the goals will be evaluated to assess the limits of treatability.

**Table 1-2: Treated Water Quality Goals**

| Parameter | Monitoring Location | Treated Water Quality Goals |
|---|---|---|
| Turbidity (NTU) | MF treated water | <1.0 NTU for 100 percent of 4-hr observations;<br>≤0.15 NTU in at least 95 percent of samples each month and is never ≥0.3 NTU in two consecutive 5-minute apart measurements |
| Cr(VI) (ppb) | MF treated water | <1.0 ppb in at least 95 percent of monitoring samples each month |
| Total Cr (ppb) | MF treated water | <1.0 ppb in at least 95 percent of monitoring samples each month |
| Total Iron (mg/L as Fe) | MF treated water | <0.05 mg/L based on monthly average |

## 1.6. Pilot Test Objectives

The objectives of the pilot study are to:

1) To determine the effectiveness of MF/UF membrane technology for removing total Cr (and hence, Cr(VI) as well) to the sub-ppb levels,

2) To assess whether iron fouling is problematic in direct filtration mode of operation for the RCF process, and

3) To identify design criteria for full-scale MF/UF in a RCF treatment process, which will provide the basis for cost development (which will be performed as an additional effort).

# 2. Pilot System Description

This section provides a description of the proposed RCF microfiltration pilot systems.

## 2.1. Overview

Two pilot testing units will be added to existing RCF facility at the City of Glendale's water treatment plant. Glendale issued a Request for Proposals (RFP) for MF vendors and selected two systems, including one pressure MF system from Pall and one submerged UF system from GE/Zenon. Note that the GE/Zenon submerged system is technically considered to be ultrafiltration (UF) due to the smaller pore size than typical microfiltration membranes.

The proposed pilot system will include:

- Pre-treatment (using existing pre-treatment consisting of reduction with ferrous sulfate and aeration)
- Break tank/ equalization tank
- Pall pressure MF system
- GE/Zenon submerged UF system, to be operated in parallel with Pall MF system
- Chemical cleaning solution collection and neutralization tank

All of the chemicals used in the pilot study will conform to the American National Standards Institute/National Sanitation Foundation (ANSI/NSF) Standard 60. All membrane pilot units will conform to ANSI/NSF Standard 61.

Table 2-1 lists the capacity of each of the primary treatment components. Approximately 20 to 30 gpm of water from the break tank will be piped to each membrane system. To ensure sufficient flow for the MF pilot systems, approximately 60 gpm flow from aeration tank will be diverted to the break tank. The break tank is set up to allow overflow to be discharged to one sump pump in the RCF containment area. The 60 gpm flow rate may be adjusted based on the MF operations. The break tank capacity is 500 gallons.

**Table 2-1: Operating Parameters of Major Pilot System Process Components**

| Process Component | Typical Operating Parameters |
|---|---|
| Break Tank | 500 gallons |
| Pall Pressure MF Membranes | ≤ 40 gpm (typically 20 – 30 gpm) |
| GE/Zenon Submerged UF Membranes | 10 - 30 gpm |

## 2.2. Pre-treatment

Reduction and aeration steps will be accomplished at the existing RCF facility. Ferrous sulfate is injected through a static mixer, upstream of reduction tanks. Three reduction tanks with 4,500 gallons of capacity (i.e. 1,500 gallon per tank) are connected in series. Each reduction tank is designed to provide hydraulic retention time of 15 min at 100 gpm flow. Water from the reduction tanks will flow into the aeration tank, where air is introduced at approximately 54 standard cubic feet per minute (SCFM). A stream of approximately 60 gpm of aerated water will be diverted to the break tank. The membranes will receive coagulated water (containing ferric but no polymer) from the break tank.

## 2.3. Membrane Filtration

Two proprietary membrane filtration systems will be tested in parallel, including one MF system (Pall) and one UF system (GE/Zenon). Both pilot scale systems will employ modules identical to those used in the respective suppliers' full-scale water treatment equipment. Target fluxes, recoveries, and operating schemes for each system will be established by the respective suppliers in conjunction with the Malcolm Pirnie and CDM, taking into account the site-specific treatment processes upstream and anticipated feed water quality. The selection of operational parameters will also consider differences in the Cr(VI) concentrations. Note that each of the pilot units will be equipped with turbidimeters on both the feed (conventional) and filtrate (laser). Grab samples will be collected for turbidity analysis for quality assurance and control (QA/QC) as defined in the sampling plan provided in Section 4.

Standard procedures associated with the operation of the membrane filtration systems are discussed in the following subsections.

### 2.3.1. Integrity Testing

Periodic direct integrity testing will be conducted on each membrane filtration system to detect the presence of any integrity breaches and confirm the log removal value (LRV) achieved. The direct integrity tests will be performed according with the USEPA *Membrane Filtration Guidance Manual*. Accordingly, pressure decay tests will be applied with sufficient pressure to identify a 3 micron (μm) breach. The appropriate test parameters will be determined in consultation with the membrane system suppliers. Pressure decay tests will be conducted once every other week, as well as after any cleaning operation (see Section 2.3.3). Each membrane system will be also be subject to continuous indirect integrity monitoring as discussed in the *Membrane Filtration Guidance Manual*, using Hach FilterTrak laser turbidimeters and/or particle counters capable of measuring discrete particles in the size range of 2 to 15 μm.

### 2.3.2. Log Removal Values

LRV data will be collected during pilot testing. The LRVs can be calculated by two approaches: 1) using particle count data; and 2) by converting the results of direct integrity testing using the methods described in the *Membrane Filtration Guidance Manual*. Both methods have shortcomings at pilot scale. Particle count data LRVs are lower when the feed water quality is better (i.e., at a lower coagulant dose), a contradiction that would indicate worse membrane performance when the risk of particle passage through the membranes in the event of an integrity breach is lower. In the case of the *Membrane Filtration Guidance Manual* methodology, a number of system-specific variables, such as the pressurized volume upstream of the membrane barrier in a pressure decay integrity test, may not accurately translate from pilot- to full-scale systems. For the purposes of calculating LRV during the pilot, LRVs for each integrity test will be calculated using the *Membrane Filtration Guidance Manual* methodology even though this LRV method was developed primarily for tracking pathogen removal.

### 2.3.3. Cleaning Procedures

In general, two types of processes are used to clean MF/UF membranes and control fouling: maintenance cleans and recovery cleans. A maintenance clean is a process that occurs with a frequency ranging from approximately daily to weekly and is designed to control fouling on a more routine basis, thereby extending the time between more extensive recovery cleans. The maintenance cleans require a membrane unit (i.e., a rack or skid) to be off-line for a significant amount of time (e.g. half an hour), and typically involves the addition of an acid, base, and/or disinfectant (e.g., chlorine) to the backwash water. A recirculation step prior to rinsing may also be included. Although the nomenclature varies between the different membrane system suppliers [e.g., enhanced flux maintenance (EFM) or chemically enhanced backwash (CEB)], “maintenance clean” is used in this pilot testing plan for its inherent description of the purpose of the operation. The membrane system suppliers will select and optimize their respective maintenance cleaning practices during Stage 1 of the pilot testing (as described in Section 3). Note that no industry standards exist that are specifically related to maintenance cleaning; however, our experience indicates that a minimum of 24-hour interval between maintenance cleans is desirable.

A recovery clean, commonly known as a clean-in-place operation, or CIP or "recovery clean," requires that a membrane unit be off-line for a longer period of time than a maintenance clean. A CIP is a more rigorous cleaning process designed to reverse accumulated fouling since the last CIP event. During operations, the accumulation of foulants that are not removed by backwashing and maintenance cleaning may eventually increase the TMP to the product-specific threshold point specified by the system supplier, at which time a CIP is necessary. A typical CIP event consists of the recirculation of chlorine, acid, and/or caustic in successive steps for several hours. Soak cycles may also be used in conjunction with the applied chemicals. During the pilot testing, the MF/UF membranes associated with each proprietary system will be cleaned according to the procedures recommended by the respective supplier at the end of each stage of testing, taking into account the feed water quality and suspected causes of fouling (i.e., particulate, biological, organic, inorganic, etc.).

Standard industry practice is to design and operate membrane filtration systems such that a CIP is required no more frequently than once per 30 days of operation. This practice is also a critical benchmark for Stage 3 testing as described in Section 3. If a membrane pilot system fouls to a point at which a CIP is required prior to the end of the 30-day Stage 3 testing, a CIP procedure and direct integrity test will be conducted. In this case, Malcolm Pirnie will consult with the membrane manufacturer to decide how to proceed in order to complete the 30-day operational benchmark. Each membrane manufacturer will have two opportunities to complete the 30-day Stage 3 testing. The out-of-production time for the CIP procedure will be recorded and taken into account in the evaluation of the potential average daily net production.

The maintenance clean and CIP protocols used during pilot testing will be identical to those employed at a full-scale facility if implemented. Pilot testing will also useful in establishing estimates of chemical usage, system recovery, and productivity (i.e., accounting for the down time associated with maintenance cleans, CIPs, and direct integrity testing) for a full-scale MF/UF facility.

### 2.3.4. Fouling Assessment

A "clean water flux test," as described in Section 6.3.3 of the *Membrane Filtration Guidance Manual* will be used to assess the effectiveness of each recovery clean (i.e., CIP; see Section 2.3.3) conducted during the pilot test. A plot of the TMP as a function of flux (or filtrate flow) will be developed before based on operating conditions before the cleaning process and after each subsequent chemical cleaning step.

For example, if the chemical cleaning includes circulating acid and base in succession, three curves relating TMP and flux (typically a linear relationship) will be generated and plotted on the same graph. The differences in the slopes of these lines indicate the relative effectiveness of each step in the CIP process, thereby providing an indication of the type of fouling observed. During the pilot testing program, the relative effectiveness of each CIP as a whole will also be compared using these data. A progressive decline in slope would indicate either the accumulation of irreversible fouling or the use a cleaning regime insufficient for the water quality conditions.

### 2.3.5. Temperature Correction

Temperature correction of data (as appropriate) will be conducted in accordance with the equations and methodology described in the *Membrane Filtration Guidance Manual*. Membrane fluxes will be corrected to 20 degrees Celsius ($^{o}$C) for the purpose of evaluating fouling via the clean water flux tests (as described in Section 2.3.4). In addition, for the purpose of evaluating the success of the 30-day test in Stage 3, TMP data will be corrected to the coldest anticipated water temperature in order to evaluate membrane performance under similar water quality conditions during a simultaneous occurrence of the limiting temperature (i.e., those that require the highest baseline TMP as a result of high viscosity water).

# 3. Pilot Test Program

This section presents details of the proposed pilot test program.

## 3.1. Overview of Test Program

The City of Glendale MF/UF pilot test program is designed to evaluate performance of MF and UF membrane systems for low-ppb-level Cr(VI) removal in RCF process. MF/UF membranes serve as direct filtration following reduction by ferrous sulfate and aeration processes. Two raw water sources with different Cr(VI) concentrations (i.e. ~80 ppb and 6 to 12 ppb) will be tested to evaluate membrane performance to represent relatively high and low Cr(VI) levels observed by utilities. The low influent Cr(VI) concentration is expected to fluctuate between 6 and 12 ppb due to operational constraints at the Glendale Water Treatment Plant.

The MF/UF pilot testing will be conducted in a series of stages as summarized in Table 3-1. Following the pilot set-up, the low Cr(VI) water will first be tested through Stages 1a to 4a. Two Fe:Cr(VI) ratios will be evaluated (25:1 and 50:1) for the lower Cr(VI) concentration. Then, the high Cr(VI) water will be tested through Stages 1b to 4b. Two Fe:Cr(VI) ratios will be evaluated (25:1 and 50:1) for the higher Cr(VI) concentration. After each Stage 3 testing (3a and 3b), the membranes will be chemically cleaned using the manufacturer recommended CIP protocols. Descriptions of the various stages of testing are provided in respective subsections under Section 3.3: Membrane Filtration Testing. A separate section discusses the pretreatment bench-scale testing preceding Stage 1 (Section 3.2).

**Table 3-1. Pilot Testing Program Summary**

| **Testing Stage** | **Objective** | **Test Plan Reference** | **Estimated Duration** |
|---|---|---|---|
| Pre-testing | Evaluate previous bench-scale jar testing results to select two Fe:Cr(VI) ratios for each of the high and low influent Cr(VI) concentrations. | Section 3.2 | Complete |
| Pilot Set-up | Pilot setup, equipment testing, leak test, etc. | - | 2 weeks |
| 1a | Establish optimum Fe:Cr(VI) ratio for the low (6~12 ppb) influent Cr(VI) concentration. | Section 3.3.1 | Up to 4 days, Plus 3 days for lab analysis |
| 2a | Establish site-specific membrane filtration operating parameters for the low influent Cr(VI) concentration. | Section 3.3.2 | 14 days |
| 3a | Conduct 30-day demonstration tests of both membrane filtration units under their respective optimum set of simulated, full-scale water treatment plant design conditions for low influent Cr(VI) concentration as established by the Stage 2a testing. | Section 3.3.3 | 30 days |
| 4a | After conducting a CIP, continue the pilot testing under Stage 3a conditions and quantify any decline in performance. | Section 3.3.3 | 7days |
| 1b | Establish optimum Fe:Cr(VI) ratio for high (~80 ppb) influent Cr(VI) concentration. | Section 3.3.1 | Up to 4 days, Plus 3 days for lab analysis |
| 2b | Establish site-specific membrane filtration operating parameters for high influent Cr(VI) concentration. | Section 3.3.2 | 14 days |
| 3b | Conduct 30-day demonstration tests of both membrane filtration units under their respective optimum set of simulated, full-scale water treatment plant design conditions for high influent Cr(VI) concentration as established by the Stage 2b testing. | Section 3.3.3 | 30 days |
| 4b | After conducting a CIP, continue the pilot testing under Stage 3b conditions and quantify any decline in performance. | Section 3.3.4 | 7 days |
| - | Time for conducting CIPs after each Stage of Testing (approximately 8 to 12 hours after Stages 2,3, and 4, for a total estimate of 5 days of time) | - | 5 days |
| - | Decommissioning Pilot Units | - | 2 days |
| **TOTAL** | | | **4.5 months** |

## 3.2. Pre-Testing

Table 3-2 provides the jar testing results of five different water qualities (Glendale GN-3, Utilities I, II, and III, Glendale North Transmission Main) tested with various Fe:Cr(VI) mass ratios and filtered through 0.45 and 0.1 µm filter paper. For the Glendale water sample containing 78 ppb of Cr(VI), a Fe:Cr(VI) ratio of 25:1 effectively removed Cr(VI) to below the detection limit of 0.025 ppb and total Cr to 0.74 ppb.

For Utility II with 110 ppb of Cr(VI), three Fe:Cr(VI) ratios were tested, including 25:1, 35:1 and 50:1. The Fe:Cr(VI) ratio of 50:1 achieved the best removal of Cr(VI) to below 0.02 ppb and total Cr to 0.12 ppb. Thus, the jar testing results suggest that for water with relatively high Cr(VI) concentrations (e.g. ~80 ppb), a Fe:Cr(VI) mass ratio higher than 25:1 (e.g. 50:1) can improve Cr(VI) removal, although 25:1 can be efficient to achieve total Cr below 1 ppb.

For the Utilities I and III with relatively low Cr(VI) concentrations (13 and 9.6 ppb, respectively), a Fe:Cr(VI) mass ratio higher than 25:1 (i.e. 50:1 or 75:1) along with pH reduction to 7.50 was necessary to effectively remove Cr(VI) and total Cr.

A sample from the Glendale North Transmission Main was also tested, which is expected to be the source for the low influent Cr(VI) concentration water (approximately 13 ppb) during part of the MF/UF testing. Three Fe:Cr(VI) ratios were tested to identify the optimum Fe:Cr(VI) ratio for low Cr(VI) chromium concentrations. The results show that a 50:1 Fe:Cr(VI) ratio removed Cr(VI) and total chromium to less than 0.5 ppb. A 75:1 Fe:Cr(VI) ratio removed Cr(VI) and total chromium to lower levels - 0.03 ppb and non-detect, respectively.

The same sample from the North Transmission Main was spiked with a Cr(VI) standard to 80 ppb to exclude the effects of other water quality parameters on Fe:Cr(VI) ratio selection for effective chromium removal. The results showed 25:1 as well as 50:1 was efficient for the high Cr(VI) concentration. Combined with the results of the un-spiked North Transmission Main sample, the results verify that a higher Fe:Cr(VI) ratio is needed for a lower Cr(VI) concentration, which was in agreement with the Utilities I, II and III results.

Additionally, membranes are expected to react/foul differently based on the coagulant dose, which is determined by both Fe:Cr(VI) ratio and the influent Cr(VI) concentration. Therefore, the MF/UF pilot testing is designed to evaluate two water sources with high and low Cr(VI) concentrations, with the intention of providing information for utilities with different levels of Cr(VI) contamination. Based on the jar testing results, two Fe:Cr(VI) ratios for each Cr(VI) influent concentration will be evaluated at the pilot scale, including 25:1 and 50:1 ratios for the higher Cr(VI) concentration and 50:1 and 75:1 ratios for the lower Cr(VI) concentration.

## Table 3-2. Jar Testing Results

**Glendale GN-3, Cr(VI) = 78 ppb, pH = 7.52**

| **Fe:Cr(VI) mass ratio** | **Fe:Cr(VI) = 25:1 pH = 7.52** | |
|---|---|---|
| **Filter Size** | **0.45 um** | **0.1 um** |
| Cr(VI) in filtrate (ppb) | ND | 0.013 |
| Total Cr in filtrate (ppb) | 0.73 | 0.74 |
| Total Fe in filtrate (ppm) | 0.03 | 0.03 |

**Utility I, Cr(VI) = 13 ppb, pH = 7.87**

| **Fe:Cr(VI) mass ratio** | **Fe:Cr(VI) = 25:1 pH = 7.87** | | **Fe:Cr(VI) = 50:1 pH = 7.87** | | **Fe:Cr(VI) = 50:1 pH = 7.35** | | **Fe:Cr(VI) = 75:1 pH = 7.35** | |
|---|---|---|---|---|---|---|---|---|
| **Filter Size** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** |
| Cr(VI) in filtrate (ppb) | 6.8 | 6.6 | 3 | 2.9 | 0.04 | 0.044 | <0.02 | <0.02 |
| Total Cr in filtrate (ppb) | 6.2 | 6.3 | 2.8 | 2.9 | 0.18 | 0.17 | 0.098 | 0.11 |
| Total Fe in filtrate (ppm) | 0 | 0 | 0.10 | 0.15 | 0.03 | 0.03 | 0.05 | 0.02 |

**Utility II, Cr(VI) =110 ppb, pH = 7.70**

| **Fe:Cr(VI) mass ratio** | **Fe:Cr(VI) = 25:1 pH = 7.70** | | **Fe:Cr(VI) = 50:1 pH = 7.70** | | **Fe:Cr(VI) = 35:1 pH = 7.70** | |
|---|---|---|---|---|---|---|
| **Filter Size** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** |
| Cr(VI) in filtrate (ppb) | 0.51 | 0.52 | <0.02 | <0.02 | 0.27 | 0.27 |
| Total Cr in filtrate (ppb) | 0.69 | 0.63 | 0.11 | 0.12 | 0.28 | 0.24 |
| Total Fe in filtrate (ppm) | 0.09 | 0.07 | 0.03 | 0.02 | 0.06 | 0.013 |

**Utility III, Cr(VI) = 9.6 ppb, pH = 7.97**

| **Fe:Cr(VI) mass ratio** | **Fe:Cr(VI) = 25:1 pH = 7.97** | | **Fe:Cr(VI) = 50:1 pH = 7.97** | | **Fe:Cr(VI) = 50:1 pH = 7.50** | | **Fe:Cr(VI) = 75:1 pH = 7.97** | |
|---|---|---|---|---|---|---|---|---|
| **Filter Size** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** |
| Cr(VI) in filtrate (ppb) | 4.5 | 4.4 | 1.6 | 1.6 | 0.086 | 0.094 | 0.62 | 0.60 |
| Total Cr in filtrate (ppb) | 4.9 | 5 | 2.1 | 2.2 | 1.3 | 0.72 | 0.7 | 1.10 |
| Total Fe in filtrate (ppm) | 0.04 | 0.05 | 0.05 | 0.02 | 0.04 | 0.03 | 0.02 | 0.03 |

**Glendale North Transmission Main, Cr(VI) = 13 ppb**

| Fe:Cr(VI) mass ratio | Fe:Cr(VI) = 25:1<br>pH = 7.43 | | Fe:Cr(VI) = 50:1<br>pH = 7.43 | | Fe:Cr(VI) = 75:1<br>pH = 7.43 | |
|---|---|---|---|---|---|---|
| **Filter Size** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** |
| Cr(VI) in filtrate (ppb) | 2.6 | 2.8 | 0.45 | 0.47 | 0.030 | 0.037 |
| Total Cr in filtrate (ppb) | 2.9 | 2.5 | 0.50 | 0.50 | <0.09 | <0.09 |
| Total Fe in filtrate (ppm) | 0.09 | 0.03 | 0.04 | 0.01 | 0.03 | 0.02 |

**Glendale North Transmission Main, Spiked Cr(VI) to 80 ppb**

| Fe:Cr(VI) mass ratio | Fe:Cr(VI) = 25:1<br>pH = 7.43 | | Fe:Cr(VI) = 50:1<br>pH = 7.43 | |
|---|---|---|---|---|
| **Filter Size** | **0.45 µm** | **0.1 µm** | **0.45 µm** | **0.1 µm** |
| Cr(VI) in filtrate (ppb) | <0.009 | <0.009 | <0.009 | <0.009 |
| Total Cr in filtrate (ppb) | <0.09 | <0.09 | <0.09 | <0.09 |
| Total Fe in filtrate (ppm) | 0.02 | 0.02 | 0.01 | 0.01 |

## 3.3. Membrane Filtration Testing

The testing program for both membrane filtration systems is similar in terms of the various stages and their respective objectives, as discussed in the following subsections. Any differences between the two systems are noted in context, as applicable.

### 3.3.1. Stage 1 Testing

The objective of Stage 1 testing is to establish optimal Fe:Cr(VI) ratio for both low and high influent Cr(VI) concentrations. The low Cr(VI) concentration water will be tested first. Two Fe:Cr(VI) ratios for each Cr(VI) influent concentration will be evaluated at pilot level, including 25:1 and 50:1 ratios for the lower Cr(VI) concentration and the higher Cr(VI) concentration. For the lower Cr(VI) concentration, a higher Fe:Cr(VI) ratio (i.e. 75:1) was considered; however, it will not be tested due to potential ferrous residual in the MF feed (since ferrous was observed at even a 25:1 ratio), which can cause membrane fouling. Each Fe:Cr(VI) ratio will be tested for 1-2 days, with a total of 4 days for each Cr(VI) concentration. The test fluxes for each unit during Stage 1 testing will be established in consultation with the respective membrane manufacturer. The Project Team will ensure fluxes selected in Stage 1 testing are comparable to the fluxes tested in other pilot studies and/or full-scale plant treating similar water quality. Best performing Fe:Cr(VI) ratios identified in Stage 1 for low and high Cr(VI) concentrations will be applied in Stage 2 testing.

### 3.3.2. Stage 2 Testing

The objective of Stage 2 testing is to establish site-specific operating parameters for both membrane filtration systems. In the RCF process, Cr(VI) is reduced to Cr(III) and adheres to ferric hydroxide flocs/colloids. Membranes in the RCF process will act as the physical barrier to Cr(III) bearing ferric hydroxide flocs/colloids, hence removing chromium by size exclusion mechanism. The Pall and GE/Zenon pilot units will be tested at multiple fluxes (at least two) for short periods (3-5 days per flux) for each influent Cr concentration, followed by a recovery clean. Membrane flux matters most for capital and O&M costs and not so much for Cr(VI) removal efficiency. At different flux levels, the membrane fouling rate is different, thus require different chemical cleanings to maintain production for 30-days without requiring a CIP. The test fluxes for each unit will be selected in consultation with the respective membrane manufacturers, with the purpose of establishing operating conditions that are comparable to the other plants treating similar water quality and will allow at least 30-day intervals between CIP events.

Operational data such as flux, TMP, flow, and temperature will be collected continuously (or as frequently as possible with each system's automated data management system). Other operational and water quality data will be collected as described in Section 4.1. Stage 2 testing and optimization will be conducted for a maximum of 14 days for each influent Cr(VI) concentration. Prior to the commencement of Stage 1 testing, an initial clean water flux test (as described in Section 2.3.4) will be conducted to serve as the reference point for evaluating the accumulation of any irreversible fouling that may occur. As stated in Section 2.3.4, this method of evaluation is normally described as a "clean water flux test." This test requires that the membrane unit be placed into filtration mode in between each steps in chemical cleaning process in order to observe the effect of the flux (or filtrate flow) on TMP. Three trend lines of TMP versus flux are recorded prior to cleaning, after caustic/chlorine cleaning, and acid cleaning step. Each trend line is generated by recording TMP at 5 fluxes – 20%, 40%, 60%, 80% and 100% of design flux. In an ideal cleaning, the final plot generated (i.e. 2nd step in CIP) of TMP versus flux (or filtrate flow) would be similar to that after the previous cleaning events such that the plots generated after each cleaning would overlap. Another clean water flux test will be conducted at the end of Stage 2, following the CIP. If the flux recovery is not acceptable, an alternate cleaning strategy will be used for Stages 3 and 4.

### 3.3.3. Stage 3 Testing

In Stage 3 testing, the membrane filtration systems will be evaluated at their optimum conditions determined from the data collected in Stages 1 and 2 for low and high influent Cr(VI) concentrations, as selected by each respective manufacturer. The purpose of Stage 3 testing is to simulate full-scale water treatment plant operation and evaluate the ability of each membrane filtration system to operate continuously for a minimum of 30 days without fouling to the point at which a CIP is required. The appropriate metric (typically TMP) and threshold value that triggers a recovery clean will be established in accordance with each manufacturer's standard system specification. This metric will be corrected for temperature as discussed in Section 2.3.5, as appropriate.

During Stage 3 testing, maintenance cleans will be performed at the pre-determined frequency established in Stage 2. Direct integrity tests will be conducted after each maintenance clean. Data for membrane flux, TMP, flow, and temperature will be collected continuously (or as frequently as possible with each system's automated data management system). Other operational and water quality data will be collected as described in Section 4.1.

After operating continuously at the designated flux for 30 days, the membranes will be cleaned using the CIP protocols established in Stages 1 and 2. Subsequently, a clean water flux test will be conducted to assess the extent of fouling.

### 3.3.4. Stage 4 Testing

Stage 4 testing replicates Stage 3 testing over a period of at least 7 days in order to confirm the membrane performance demonstrated in Stage 3 and assess the flux recovery achieved by the CIP event after the 30-day test.

# 4. Sampling and Monitoring Plan

This section presents details of the sampling and monitoring plan.

## 4.1. Sampling Plan

The pilot test sampling plan is designed to address the test objectives specified in Section 1. Tables 4-1 through 4-4**Error! Reference source not found.** summarize the water quality sampling schedule for Stages 1 through 4, respectively. Parameters will be analyzed using EPA or State approved methods. Total organic carbon, total chromium, hexavalent chromium, alkalinity, hardness, total suspended solids (TSS), disinfection by products (TTHM and HAA5) and citric acid will be analyzed by certified laboratory (MWH Labs). Turbidity, pH, total iron, ferrous iron and free chlorine will be monitored in the field using portable instruments, including a Hach DR 2800 spectrophotometer, a pH meter, and a turbidimeter.

Online turbidity meters and particle counters will be used to continuously monitor turbidity and numbers of particles in both membrane feed and permeate for the MF/UF pilot units. The Pall MF pilot unit will have Hach turbidity meters and Met One Particle Counters on both MF feed and permeate. The GE/Zenon UF pilot unit will have a Hach 1720E turbidimeter on the UF feed, FilterTrack Model 660 turbidimeter on the permeate, and ChemTrac PC 2400D particle counters on both UF feed and permeate. As the online particle counters on the two MF skids are from different manufacturers, the particle removal results may not be directly comparable due to different standards and performance variations. Thus, an additional portable particle counter, Met One Particle Counter, will also be used to directly compare particle removal by the two MF units. Specifically, the Met One Particle Counter will be used to measure particles in MF permeate from one skid for 30 minutes (one run cycle) and then from the other skid for another 30 minutes during normal MF operations in Stage 3a and 3b. A total of six tests (i.e. three in Stage 3a and three in Stage 3b) will be conducted. The results will be used to evaluate particle removal, which is expected to be related to chromium removal.

In Stages 1, 2 and 4, daily sampling is needed to capture water quality data for analysis of MF effectiveness for Cr(VI) removal, considering multiple operational parameters will be tested during relatively short periods of time. For example, during Stage 1, two Fe:Cr(VI) ratios will be tested for each influent Cr(VI) concentration, with only 1 to 2 days for each ratio. Two samples per day at MF effluents will provide four data points at each Fe:Cr(VI) ratio. During Stage 2, at least two fluxes will be tested, with only 3 to 5 days per flux. Daily samples at MF effluents will provide 3 to 5 data points for each flux. During Stage 3, the optimum operational conditions will be tested for 30 days and three sampling events per week will yield approximately 12 data points. During Stage 4, daily sampling for one week will provide 7 data points for assessment of flux recovery achieved by the CIP event after the 30-day test.

**Table 4-1: Water Quality Sampling Schedule for MF/UF Pilot Study Stages 1a and 1b**

| Sample Point | Laboratory Analysis | | | | | | Field Analysis | | | | Online Monitoring | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cr(VI)** | **Total Cr** | **TOC** | **Alkalinity** | **Hard-ness** | **TSS** | **Turbidity** | **Total Iron** | **Ferrous Iron** | **pH** | **Temp./ pH** | **Turbidity** | **Flow Rate** |
| SP-001 (Raw water) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | - | C | - | C |
| SP-601 (MF Skid 1 influent) | 2/D | 2/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-602 (MF Skid 1 effluent) | 2/D | 2/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-604 (MF Skid 2 effluent) | 2/D | 2/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-605 (MF Skid 1 backwash waste) | 1/D | 1/D | Once | Once | Once | Twice | 1/D | 1/D | 1/D | 1/D | - | - | C |
| SP-606 (MP Skid 2 backwash waste) | 1/D | 1/D | Once | Once | Once | Twice | 1/D | 1/D | 1/D | 1/D | - | - | C |

**Notes:**

QA/QC samples will be collected for at least 10% of lab samples and at least 10% for field analysis samples.
1/D = once per day
2/D = twice per day
Once = one sample for Stage 1a and one sample for Stage 1b
TSS = Total Suspended Solids. One sampling event for each of the Fe:Cr ratios to be tested for low and high influent Cr(VI) concentrations.
C = Continuous monitoring by online meters

## Table 4-2: Water Quality Sampling Schedule for MF/UF Pilot Study Stages 2a and 2b

| **Sample Point** | **Laboratory Analysis** | | | | | | **Field Analysis** | | | | **Online Monitoring** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cr(VI)** | **Total Cr** | **TOC** | **Alkalinity** | **Hardness** | **TSS** | **Turbidity** | **Total Iron** | **Ferrous Iron** | **pH** | **Temp. /pH** | **Turbidity** | **Flow Rate** |
| SP-001<br>(Raw water) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | - | C | - | C |
| SP-601<br>(MF Skid 1 influent) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-602<br>(MF Skid 1 effluent) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-604<br>(MF Skid 2 effluent) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-605<br>(MF Skid 1 backwash waste) | 1/D | 1/D | Once | Once | Once | Twice | 1/D | 1/D | 1/D | 1/D | - | - | C |
| SP-606<br>(MP Skid 2 backwash waste) | 1/D | 1/D | Once | Once | Once | Twice | 1/D | 1/D | 1/D | 1/D | - | - | C |

**Notes:**
QA/QC samples will be collected for at least 10% of lab samples and at least 10% for field analysis samples.
1/D = once per day
Once = one sample for Stage 2a and one sample for Stage 2b
TSS = Total Suspended Solids. One sampling event for each of the fluxes to be tested.
C = Continuous monitoring by online meters

## Table 4-3: Water Quality Sampling Schedule for MF/UF Pilot Study Stages 3a and 3b

| Sample Point | Laboratory Analysis | | | | | | | | Field Analysis | | | | | Online Monitoring | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Cr(VI) | Total Cr | TOC | Alkalinity | Hard-ness | TSS | DBP | Citric Acid | Turbidity | Total Iron | Ferrous Iron | pH | Free $Cl_2$ | Temp. /pH | Tur-bidity | Flow Rate |
| SP-001 (Raw water) | 3/W | 3/W | 1/M | 1/M | 1/M | - | - | - | 1/M | 1/M | 1/M | - | - | C | - | C |
| SP-601 (MF Skid 1 influent) | 3/W | 3/W | 1/M | 1/M | 1/M | - | - | - | 1/D | 1/W | 1/W | 1/D | - | C | C | C |
| SP-602 (MF Skid 1 effluent) | 3/W | 3/W | 1/M | 1/M | 1/M | - | - | - | 1/D | 1/W | 1/W | 1/D | - | C | C | C |
| SP-604 (MF Skid 2 effluent) | 3/W | 3/W | 1/M | 1/M | 1/M | - | - | - | 1/D | 1/W | 1/W | 1/D | - | C | C | C |
| SP-605 (MF Skid 1 backwash waste) | 3/W | 3/W | 1/M | 1/M | 1/M | 1/W | - | - | 3/W | 1/W | 1/M | 3/W | - | - | - | C |
| SP-606 (MP Skid 2 backwash waste) | 3/W | 3/W | 1/M | 1/M | 1/M | 1/W | - | - | 3/W | 1/W | 1/M | 3/W | - | - | - | C |
| SP-605 (MF Skid 1 maintenance clean waste) | Once | Once | Once | Once | Once | Once | Once | Once | - | Once | - | Once | Once | - | - | - |
| SP-606 (MF Skid 2 maintenance clean waste) | Once | Once | Once | Once | Once | Once | Once | Once | - | Once | - | Once | Once | - | - | - |

**Notes:**
QA/QC samples will be collected for at least 10% of lab samples and at least 10% for field analysis samples.
1/M = once per month
1/W = once per week
3/W = three times per week
1/D = once per day
DBP = Disinfection byproducts, including total trihalomethanes (TTHM) and haloacetic acids (HAA5).
TSS = Total Suspended Solids
C = Continuous monitoring by online meters

## Table 4-4: Water Quality Sampling Schedule for MF/UF Pilot Study Stages 4a and 4b

| **Sample Point** | **Laboratory Analysis** | | | | | | **Field Analysis** | | | | **Online Monitoring** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Cr(VI)** | **Total Cr** | **TOC** | **Alkalinity** | **Hardness** | **TSS** | **Turbidity** | **Total Iron** | **Ferrous Iron** | **pH** | **Temp. /pH** | **Turbidity** | **Flow Rate** |
| SP-001 (Raw water) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | - | C | - | C |
| SP-601 (MF Skid 1 influent) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-602 (MF Skid 1 effluent) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-604 (MF Skid 2 effluent) | 1/D | 1/D | Once | Once | Once | - | 1/D | 1/D | 1/D | 1/D | C | C | C |
| SP-605 (MF Skid 1 backwash waste) | 3/W | 3/W | Once | Once | Once | Once | 3/W | 3/W | 3/W | 3/W | - | - | C |
| SP-606 (MP Skid 2 backwash waste) | 3/W | 3/W | Once | Once | Once | Once | 3/W | 3/W | 3/W | 3/W | - | - | C |

**Notes:**
QA/QC - Field-collected duplicate samples will be collected for at least 10% of all samples.
1/D = once per day
Once = one sample for Stage 4a and one sample for Stage 4b
3/W = three times per week
TSS = Total Suspended Solids
C = Continuous monitoring by online meters

Operational parameters will also be closely monitored during pilot testing. A summary of the operating parameters that will be monitored for each MF/UF unit are shown in Table 4-5. All operating parameters will be monitored as frequently as permitted by the respective units' automated data collection systems. In addition, the field operator of the MF/UF pilot units (i.e., CDM) will record major operations parameters and set points on a daily basis for both membrane units, which will help to identify operational problems on a timely basis.

During all the stages of the pilot study, the pretreatment units will be monitored according to the demonstration-scale RCF Operational and Maintenance Manual, except for the sampling locations listed in Tables 4-1 through 4-4. Raw and filtered water turbidities will be monitored using online conventional (NTU) and laser (mNTU) turbidimeters, respectively, which are capable of collecting data on a continuous basis. These instruments will be calibrated according to the manufacturer's specifications prior to the beginning of the pilot study.

**Table 4-5: Operating Data Monitoring for MF/UF Membranes**

| Operating Parameter | Units | Frequency |
|---|---|---|
| Membrane Inlet Pressure | Psi | Every 5 minutes |
| Membrane Outlet Pressure | Psi | Every 5 minutes |
| Filtrate Pressure | Psi | Minimum of every 4 hours |
| Feed Flow Rate | Gpd | Minimum of every 4 hours |
| Filtrate Flux | Gfd | Minimum of every 4 hours |
| Backwash Flow | Gpm | Minimum of every 4 hours |
| Backwash Frequency | #/week | TBD |
| Backwash Duration | Sec | TBD |

TBD – to be determined

Data for TMPs, duration, and chemical usage will be collected for maintenance cleans and CIPs. Additionally, clean water fluxes, TMP recoveries and flux recoveries will be recorded for each CIP.

## 4.2. Post-Mortem Membrane Autopsies

Post-mortem autopsies will also be conducted by the vendor on the polymeric membrane fibers to determine the degree of fouling (and a report on findings provided). The potential analyses include but are not limited to external and internal visual examination, chemical identification of surface foulants using acid digestion, fourier transform infrared spectroscopy (FTIR), energy dispersive X-ray spectrometry (EDX) and scanning electron microscope (SEM), and loss on ignition tests.

## 4.3. Quality Assurance/Quality Control (QA/QC)

Cr(VI) and total Cr will be analyzed using ion chromatography (EPA Method 218.6) and ICP-MS method (EPA Method 200.8), respectively, by an ELAP-certified laboratory. For Cr(VI), the method detection limit (MDL) is 0.020 ppb and the method reporting limit (MRL) is 0.050 ppb. Cr(VI) will be analyzed within 5 days of sample collection and buffered using ammonium sulfate. For total Cr, the MDL is 0.088 ppb and the MRL is 1.0 ppb. Samples falling within the range of the MDL and the MRL will be flagged as “J values”.

Laboratory analyses, including Cr(VI) and total Cr measurements, will be subjected to numerous procedures to assess quality assurance objectives. The ion chromatograph for Cr(VI) measurements will be calibrated as needed (approximately every few days) when the opening QC run fails and instrument maintenance does not rectify the problem, or the retention time shifts by more than 10%. Acceptance criteria include a correlation coefficient for the linear calibration curve of greater than 0.999. An external laboratory control sample (LCS) with a concentration of 2 ppb will be analyzed for every batch of 20 samples or less. The acceptance percent recovery range for the LCS sample is within 90-110%. A 20 ppb instrument performance check (IPC) sample will be run after the initial calibration and subsequently after every 10 samples, with an acceptable percent recovery range of 95 to 105%. A laboratory reagent blank (LRB) will also be measured after every 10 samples and should be below the MRL of 0.05 ppb each time.

The ICP-MS for total Cr will also be calibrated each analysis day. Acceptance criteria include a correlation coefficient for the linear calibration curve of greater than or equal to 0.995. An initial calibration verification standard (ICV) will be analyzed immediately after the calibration curve with an acceptance percent recovery range of 95 to 105%. A continuing calibration verification standard (CCV) will be run subsequently after every 10 samples, with an acceptable percent recovery range of 90 to 110%. A continuing calibration blank (CCB) will also be measured after every 10 samples and should be below one-half of the MRL of 1.0 ppb each time.

Accuracy in Cr(VI) and total Cr analyses will be evaluated by determining percent recoveries in laboratory-spiked samples. A matrix spike (MS) will be performed on 10% of samples (or at least one sample per run), chosen at random. MS recoveries should be between 90 and 110% of the expected value for Cr(VI) and between 70 to 130% for total Cr. National Institute of Standards and Technology (NIST) traceable Cr(VI) solutions and ICS total Cr standard solutions will be used for matrix spikes. Accuracy will also be tested for Cr(VI) throughout the runs and after every 10 samples by analyzing a mid-range IPC sample and a laboratory reagent blank (LRB). The acceptance criteria for the

IPC sample are between 95 and 105%. The LRB should be below one-half the MRL. If concentrations are outside of these ranges, corrective actions will be performed.

Precision (random error) will be investigated by performing repeat analyses on the same analytical instruments. For every batch of twenty samples, a LCS and a MS will be run. The acceptable ranges for these sample results are between 90 to 110% for Method 218.6 and 85 to 115% for Method 200.8. Laboratory replicates and matrix spike duplicates (MSD) will be analyzed for every batch of twenty samples with an acceptance criterion of less than 20% relative percent difference (RPD). MS/MSD acceptance range is 70 to 130% for total Cr.

As the critical parameters in evaluating the success of the project, Cr(VI) and total Cr concentration data will also be subjected to paired sample analyses (i.e., Cr(VI) and total Cr samples collected at the same time). Paired samples will be used to assess the chromium speciation and ensure full reduction in the RCF process.

For field-measured water quality parameters including iron, turbidity and pH, accuracy and precision acceptance criteria will be based on manufacturer specifications, which will be tested using standards prepared in the water matrices. In general, acceptance criteria for these analytes will be less than 20% for field-collected duplicate samples. For the field methods, precision will be analyzed every 20 samples from repeat analyses on known-concentration accuracy check standards, with an acceptance criteria of 80 to 120%.

QA/QC sampling will include field-collected duplicate samples and field blanks. Field-collected duplicate samples will serve to ensure acquisition of representative samples, consistency of sampling, and precision of the analytical methods. Field-collected duplicate samples will be collected for at least 10% of all samples. These duplicates will not be identified as QA samples when sent to the laboratory. Field blanks will be prepared by filling metal-free distilled water in sample bottles provided by the laboratory. These samples will be sent to test any possible contamination during sample handling, transport and storage. At least one field blank sample will be prepared for each shipment. Blanks submitted to the laboratory for analysis will not be identified as QA samples. Sufficient sample volume will be collected for the required analysis. Samples will not be composited to amplify sample volume or average samples over time. Split samples will be used to verify analytical precision.

All field and process equipment will be calibrated. Field equipment calibration will be performed in accordance with manufacturer specifications for each instrument. Certified standard solutions will be used to test the functionality and accuracy of each instrument within the range of measurements and a frequency specified by the manufacturer, or at least once per month. In addition to online meters, portable meters for turbidity and pH will also be used to verify the online meter measurements. In case of instrument malfunction, a back-up instrument will be obtained and calibrated for interim use while the malfunctioning instrument is under repair. Process equipment, such as pumps and flow meters, will be calibrated before the MF/UF pilot units are brought online, and at the conclusion of the test, to avoid disturbing the membrane operation during the test period unless unexpected results warrant recalibration.

# 5. Schedule, Data Processing, and Reporting

This section presents details of the proposed schedule, approach for data processing, and report development.

## 5.1. Pilot Test Timeline

Figure 5-1 provides a summary of the schedule for pilot testing, depicting the Stages of testing and approximate dates based on an anticipated start date of around the fourth week in February 2012.

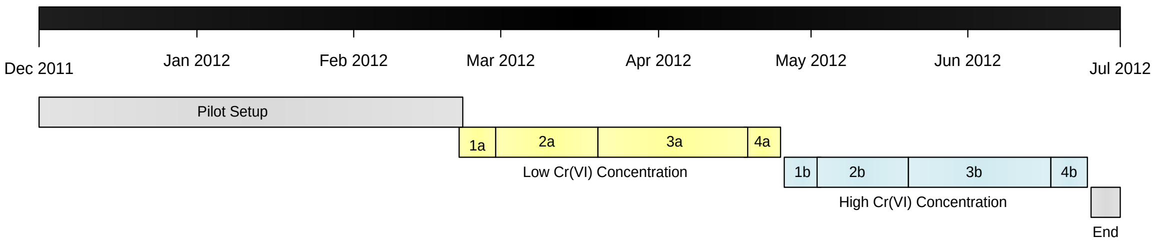

**Figure 5-1: Pilot Test Schedule**

## 5.2. Operational Logs

Operational logs will be maintained during piloting to track the progress of the testing. The operational logs will include any data collected during daily pilot monitoring and any changes in operating parameters, as well as a note of significant events and any shutdowns.

## 5.3. Data Processing

Data collected from the field and laboratory monitoring will be processed and reviewed on a weekly basis. Conference call meetings with the Project Advisory Committee will be held during each stage of testing to review the data for QA/QC. The data will be summarized in tables and graphs and presented in the final report.

## 5.4. Pilot Report

The information collected during the pilot study will be documented by Malcolm Pirnie in a summary report submitted to the Water Research Foundation and the Project Advisory Committee for review. Comments will be incorporated into the draft and a final WaterRF report prepared.