**Glendale Water and Power**

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# Experimental Design for Hexavalent Chromium Removal using Reduction with Ferrous Sulfate, Coagulation, and Filtration (RCF) Process:

## A Demonstration-Scale Study

June 2008

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# 1. Introduction

The City of Glendale's groundwater supply in the San Fernando Valley has been contaminated with a wide variety of chemicals, including hexavalent chromium [Cr(VI)], trichloroethylene (TCE), perchloroethylene (PCE), 1,2,3-trichloropropane (TCP), and others, mainly as a result of improper disposal of industrial waste products. Extraction and treatment of volatile organic compounds (VOCs) is underway in the San Fernando Valley using air stripping and granular activated carbon (GAC), and the treated water is served to customers. Although Cr(VI) was also found in the groundwater supplies, levels were below the total Cr maximum contaminant level (MCL) of 50 μg/L in California. No Cr(VI) treatment was included with the VOC facilities at the time they were constructed.

Until June 2007, the health effects of Cr(VI) in drinking water were uncertain; Cr(VI) was a proven carcinogen by inhalation but little evidence existed to demonstrate the impact of Cr(VI) ingestion. However, a recent study conducted by the National Toxicology Program (NTP) showed that Cr(VI) is a carcinogen by ingestion in animal studies (NTP 2007). Even prior to this study, the Legislature of California mandated that the California Department of Public Health (DPH) establish a Cr(VI) MCL. First, the Office of Environmental Health Hazard Assessment (OEHHA) must set a public health goal (PHG), which will likely be based on the new NTP findings. In Glendale, public concern about Cr(VI) in the groundwater supply led the city to embark on a multi-phase study to identify and install Cr(VI) treatment in anticipation of a Cr(VI) MCL lower than the current total Cr MCL in California.

In the year 2000, the City of Glendale, along with the Cities of Los Angeles, Burbank, and San Fernando, initiated a testing program to develop a full-scale Cr(VI) treatment system capable of removing Cr(VI) to low parts-per-billion levels. The **Phase I Bench-scale study** was conducted to improve the understanding of fundamental chromium chemistry and to screen promising technologies for their ability to remove Cr(VI) to very low levels. The Phase I study is complete and the final report was published by AwwaRF (Brandhuber et al. 2004).

The **Phase II Pilot-scale study** was initiated in the summer of 2003 to further test the promising Cr(VI) removal technologies at pilot scale (i.e., several gallons-per-minute flows) using Glendale groundwater. A final report on the Phase II pilot-scale study was completed in 2005 (MEC 2005). Selected results were also published in peer-reviewed scientific journals (Qin et al. 2005, McGuire et al. 2006).

The **Phase III Demonstration-scale study** will finalize the treatment evaluation, residuals assessment, and cost estimate development by implementing one or more Cr(VI) removal technologies. The initial part of the Phase III effort was designated as the

Phase III Bridge Project, which included additional studies to finalize testing of weak-base anion (WBA) exchange resins for Cr(VI) treatment, refinement of treatment technology cost estimates based on Phase III Bridge Project results, and assembly of an expert panel to recommend one or more treatment processes for demonstration-scale testing. The Phase III Bridge Project was completed in early 2007 and the project report was published by AWWA (McGuire et al. 2007).

The Phase III Demonstration-scale study will start with testing WBA resin for Cr(VI) removal from a 425 gallons per minute (gpm) groundwater well. The WBA resin evaluation is funded in part by the US Environmental Protection Agency (USEPA) State and Tribal Assistance Grant (STAG) and California Proposition 50. The Experimental Plan and Quality Assurance Project Plan (QAPP) for WBA resin evaluation are currently under review by different stakeholders including USEPA Region 9, California DPH, City of Glendale, and Glendale Respondent's Group (GRG). Construction of the WBA demonstration-scale system is expected to begin in 2008.

Reduction with ferrous sulfate, coagulation, and filtration (RCF) was recommended for demonstration-scale testing by the expert panel convened as part of the Phase III Bridge Project. The recommendation was based on process effectiveness, a thorough understanding of the RCF technology, and ease of permitting. Consequently, the City of Glendale intends to design and build a demonstration-scale RCF treatment facility to treat part or all of the water from two high-chromium wells from the North Operable Unit (i.e., GN-2 and GN-3), depending on additional funding availability.

The purpose of this project is to demonstrate the effectiveness of the RCF process in removing Cr(VI) to low part-per-billion levels. The system will be operated for one year under the Proposition 50 grant and other available grants. Treated water will be put to beneficial use by serving Glendale's consumers. Treatment cost information developed in the Phase II Pilot-scale and Phase III Bridge studies will be updated as a result of this effort. This information is intended to be of use to other utilities requiring Cr(VI) treatment and to the state of California in setting a Cr(VI) MCL.

This document provides the experimental design for the RCF technology evaluation at demonstration scale. Chapter 2 briefly describes the RCF process. Chapter 3 depicts the overall study objectives. Data collection and sampling protocols for water quality and process-related parameters are described in Chapters 4 and 5, respectively. Operations evaluation and optimization of the RCF system are presented in Chapter 6.

# 2. RCF Process Description

## 2.1. Conceptual Design

In the RCF process, Cr(VI) is first reduced to Cr(III) with the addition of excess ferrous iron ($Fe^{2+}$), which is oxidized to ferric iron ($Fe^{3+}$) by the electron transfer during the reduction of Cr(VI) and by dissolved oxygen present in the water. Ferrous iron doses found to be acceptable in Phase II testing ranged from 1.5 to 2.5 mg/L for reducing 100 μg/L of Cr(VI) to less than 5 μg/L. Cr(III) either precipitates, forms a co-precipitate with the ferric iron, or adsorbs onto the ferric floc. The ferric iron/Cr(III) particles form larger floc during the aeration and coagulation (with the use of a polymer) stages. Particles are then removed by filtration.

RCF is a mature treatment process for removing of high concentrations of Cr(VI) from industrial wastewaters. RCF minus the reduction step (i.e., just coagulation/filtration) is an accepted technology for arsenic removal in drinking water treatment. Unfortunately, only limited studies have been conducted to examine the possibility of achieving low chromium treatment goals using the RCF process for drinking water. Recent studies investigating the reduction of Cr(VI) with ferrous sulfate in bench-scale experiments yielded mixed results (Brandhuber et al. 2004, Lee and Hering 2003). The process was effective for the removal of Cr from drinking water in one study (Lee and Hering 2003) but not in the other (Brandhuber et al. 2004). Both studies demonstrated that ferrous sulfate effectively reduces Cr(VI) but that subsequent Cr(III) removal by filtration is not effective under all conditions. In Phase II testing, a pilot-scale RCF unit (approx. 2-gpm capacity) successfully removed total chromium to below detectable levels for 23 to 46 hours (Qin et al. 2005).

Based on the Phase II pilot results, a demonstration-scale RCF system was conceptually designed with a treatment capacity of 500 gpm (i.e., one of the likely configurations to treat one well). Figure 2-1 illustrates the proposed flow schematic for a 500-gpm RCF system.

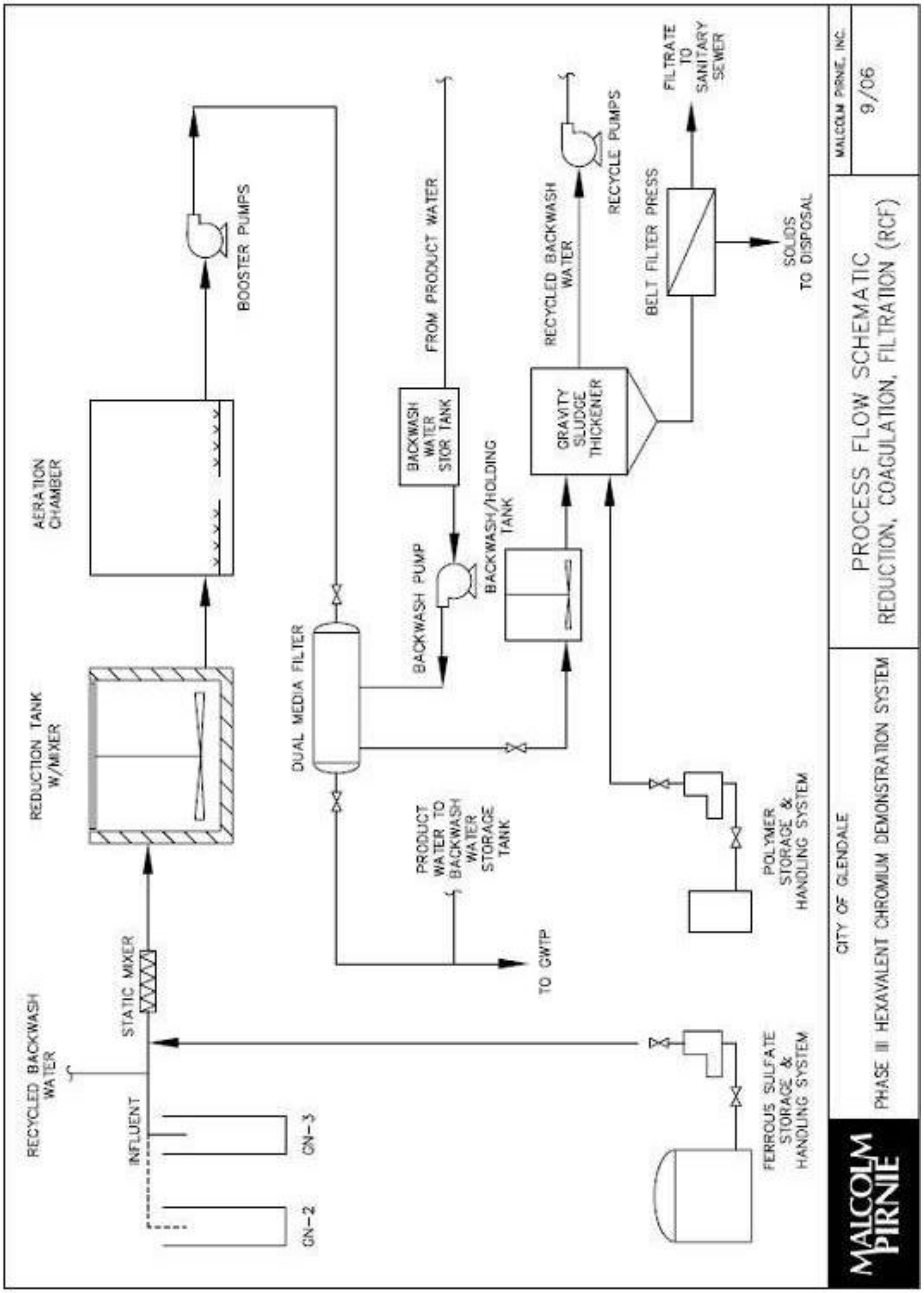


**Figure 2-1: Schematic of the conceptually designed RCF demonstration-scale system (500 gpm)**

## 2.2. Additional RCF Pilot Testing to Optimize Design

According to a recent cost estimate by Malcolm Pirnie, the total capital cost for the conceptually designed 500-gpm RCF system was $3.05 million and the annual operations and maintenance (O&M) cost was estimated at $164,000. Due to limited funding availability, the treatment capacity of the demonstration-scale system may have to be reduced to 100 gpm. Further optimization of the RCF system was also necessary to reduce the overall capital cost. As part of the optimization effort, an additional RCF pilot system with 2-gpm capacity was tested during February and March of 2008 to identify the most effective and least costly design.

The additional pilot testing results revealed that an RCF process with 45 minutes of reduction time followed by filtration was successful in consistently reducing Cr(VI) and removing total Cr to concentrations below 1 μg/L (i.e., the method reporting level for total Cr) without the need for an aeration step. In addition, the pilot testing demonstrated that the RCF system could be operated for extended hours (more than 24 hours) with little pressure drop across the filters, further reducing the frequency of backwashing and the quantity of wash water produced. Figure 2-2 shows a simplified schematic of the pilot-scale treatment process. Refer to the “Report on Additional RCF Pilot Testing to Optimize Design” for more details.

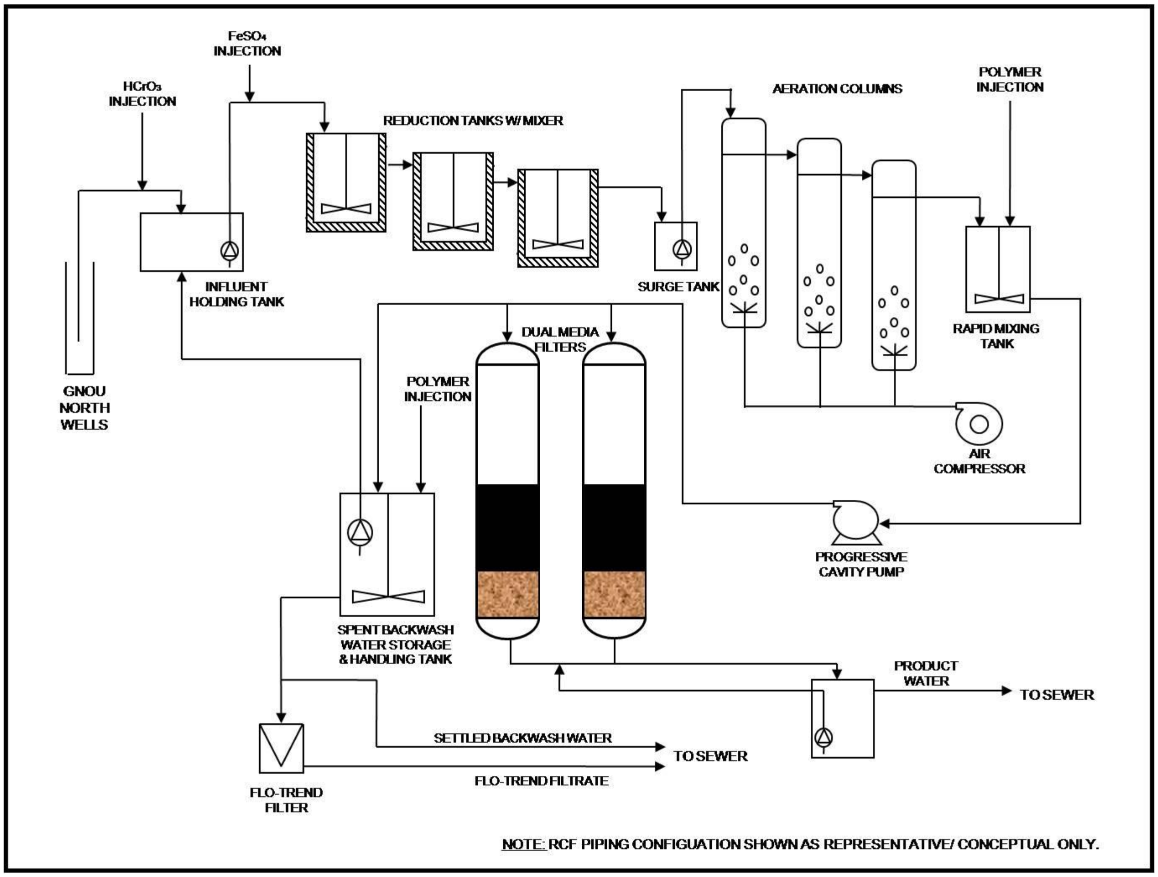


**Figure 2-2: Simplified schematic of the system tested during the additional RCF pilot study (2 gpm)**

## 2.3. Optimized Demonstration-Scale RCF System (100 GPM)

Figure 2-3 provides the process flow schematic of a 100-gpm demonstration-scale RCF system, which incorporates the design concepts of the 500-gpm system and modifications based on additional pilot study findings.

Raw water from GN-2 and/or GN-3 will flow to the RCF demonstration site at a rate of 100 gpm. Ferrous sulfate will be injected into the water at a dose of 1.25 mg/L as Fe. The Fe dosage is based on the influent Cr(VI) concentration of 50 µg/L, and the 25:1 ratio of Fe to Cr(VI) shown to be effective in both Phase II and the additional RCF pilot study[1].

After going through a static mixer, the Fe-spiked influent water will flow to three identical reduction tanks piped in series. Each reduction tank will be equipped with a mechanical mixer and have a volume of 1,500 gallons. The three reduction tanks in series provide a total detention time of 45 minutes for the 100 gpm water flow. The purpose of using three tanks in series is to increase mixing efficiency by minimizing short circuiting and back flow problems. The three reduction tanks will also be designed with the ability to bypass one or two tanks so that any maintenance or malfunction issues with the tank and/or mechanical mixer will not cause a shut-down of the whole RCF system.

One of the most important findings from the additional pilot study was that no pH adjustment or additional aeration (beyond that provided by the dissolved oxygen in the water) was necessary. Therefore, Malcolm Pirnie recommended the exclusion of those two components in the demonstration-scale RCF system design for cost saving purposes. However, physical space and hydraulic capacity for pH adjustment and aeration will be included in the design process in case the two components are needed at a later time.

After going through the reduction tanks, the water will flow to a 500-gallon rapid mixing tank, into which polymer is injected for enhanced Fe and Cr floc formation. The mixing tank will provide an additional 5 minutes for floc formation. Different anionic polymers, Magnafloc Ciba E38, E40, and Nalco 9901, were tested during the additional RCF pilot study. Under optimized condition, 0.1 mg/L of Magnafloc Ciba E38 polymer was determined to be an effective dose for floc formation in the RCF process.

After mixing tank, water containing Fe and Cr floc will be pumped by progressive cavity pump to two pressurized dual media filters in down-flow mode. One lesson learned from the additional pilot study is that the use of progressive cavity pump is necessary for enhanced filtration performance by minimizing the break-up of Fe and Cr floc that has already been formed. In fact, any pumping of process water in which floc formation has occurred should employ a progressive cavity pump. The dual media filters will consist of approximately 24 inches of anthracite and 12 inches of sand, with a supportive underdrain. The design hydraulic loading rate for both filters is about 3 gallons per

[1] Fe dosage will be adjusted during the demonstration-scale study to account for the actual influent water Cr(VI) concentration.

[2] Phase II RCF pilot testing showed that the settled backwash solids failed the California WET test and

minute per square foot (gpm/sf). Conceptually, two 4.5-foot diameter vertical pressure vessels will be needed for the 100 gpm system.

The majority of filtered water will blend with water from other GOU wells and undergo further VOC treatment at the Glendale Water Treatment Plant. A small portion of filtered water will be diverted to a product water storage tank for backwash purpose or product water from the GWTP will be used for backwash.

During backwash, stored product water will be pumped through the filters in an up-flow mode at a loading rate of 21 gpm/sf or higher for 5 to 10 minutes. Concurrent air scouring is also desirable during backwash. Spent backwash water will overflow to a separate storage tank, where polymer is injected and mixed so that the solids in the backwash water will settle efficiently. During the additional RCF pilot study, backwash water was effectively settled using 1.0 mg/L Magnafloc Ciba E38 anionic polymer. It should be noted that the same polymer was also effective for promoting floc formation in the rapid mixing tank. Therefore, it is possible to design a common polymer storage system for use in both the rapid mixing tank and spent backwash water storage tank at the demonstration-scale facility. Supernatant from the backwash storage tank contained approximately 30 µg/L total Cr and 1 mg/L Fe as determined during the addition pilot study. The supernatant water quality was considered acceptable to be recycled to the head of the RCF system at a rate of 4 – 5 % of the influent flow (i.e., 4 – 5 gpm).

Settled backwash solids will be sent to a passive filtration system using a technology akin to the Flo-Trend system. The filtrate is expected to have a water quality similar to the backwash supernatant and can be recycled to the spent backwash water storage tank while dewatered solids captured on the filter will be shipped for disposal at a hazardous waste landfill[2].

[2] Phase II RCF pilot testing showed that the settled backwash solids failed the California WET test and were characterized as hazardous waste in California.

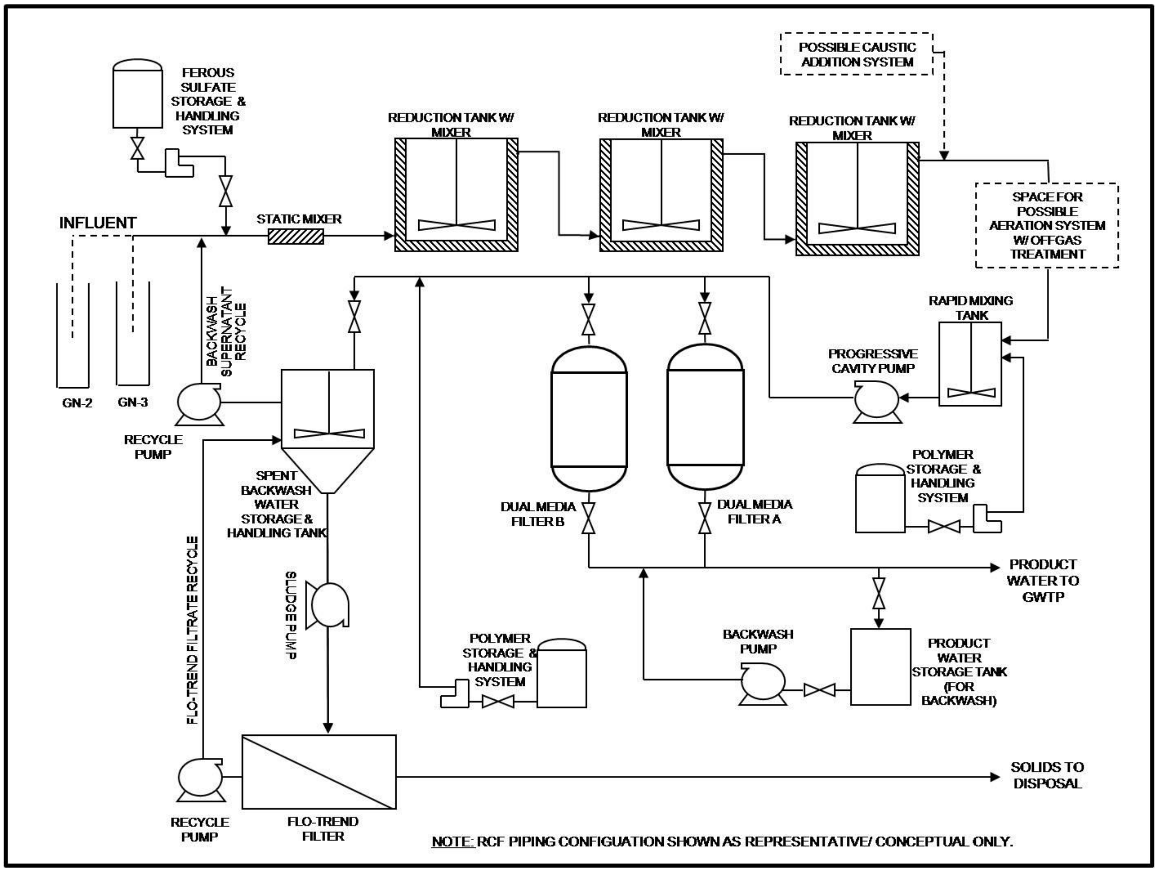


**Figure 2-3: Schematic of the proposed demonstration-scale RCF plant (100 gpm)**

## 2.4. Location of the RCF System

The demonstration-scale RCF system is proposed to be located adjacent to the Glendale Water Treatment Plant (GWTP) to treat water from GN-2 and/or GN-3. The wells GN-2 and GN-3 each have a capacity of 567 gpm. Cr(VI) concentration in these two wells ranges from 40 to 60 µg/L and is expected reach as high as 170 µg/L according to a CH2MHILL report. High Cr(VI) levels in the well water make them good candidates for the demonstration study.

Well GN-2 is located on the site of the Dream Works Animation Studios and Well GN-3 is located on the new Disney Animation Studios site now under development. For both locations, no property is available at the well sites for the demonstration-scale RCF system.

A dedicated pipeline will be constructed from the well site(s) to the proposed demonstration facility next to the GWTP. The site of this potential RCF demonstration facility is owned by the City of Glendale and is part of the City's Corporate Yard for the water and power field personnel. The City has "fee" title to this property that has been designated as the location for a demonstration facility. Figure 2-4 shows the location of proposed demonstration-scale RCF system.

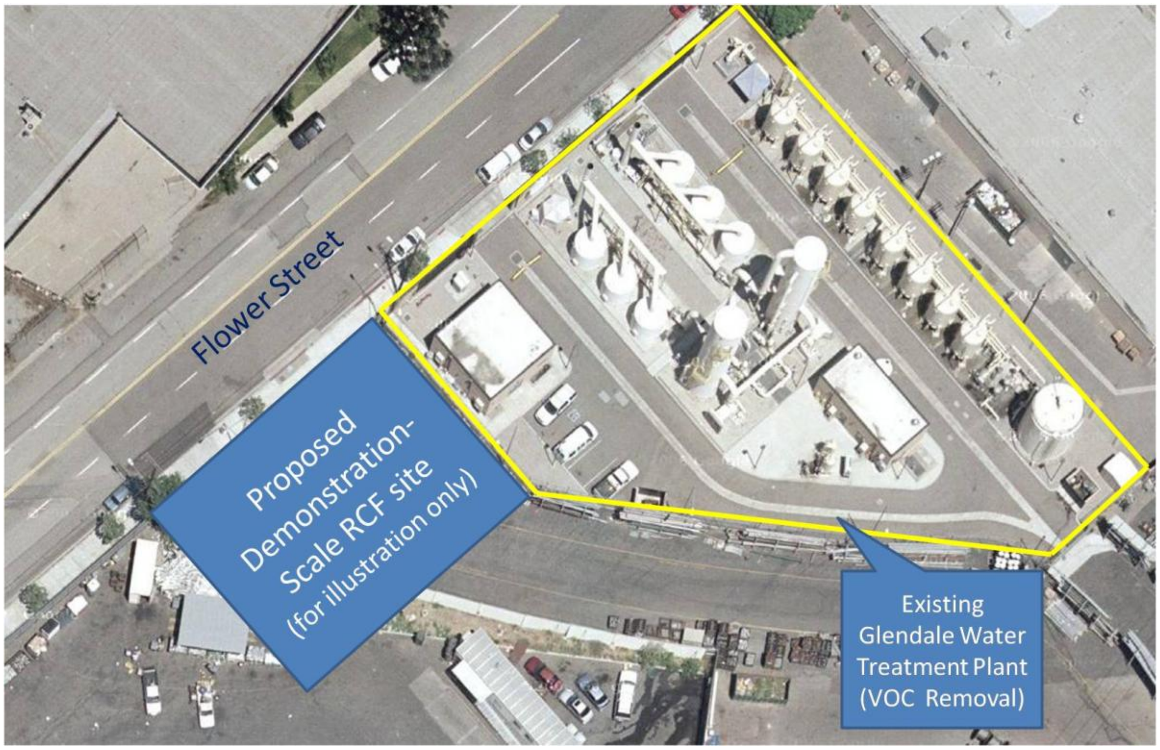


**Figure 2-4: Map showing the location of proposed RCF system (100 gpm)**

# 3. Study Objectives

The primary goal of the study is to demonstrate that a 100-gpm RCF system can reduce Cr(VI) concentration in the GN-2 and/or GN-3 wells, and Cr(VI) and total Cr concentrations from the RCF system effluent remain below 1 µg/L over extended periods of time. It should be noted that total Cr and/or Cr(VI) concentration in the RCF effluent might exceed 1 µg/L due to possible system upsets. However, as a Cr(VI) –specific MCL does not currently exist and the 100-gpm RCF effluent will be blended with approximately 4,900 gpm GOU well water for subsequent VOC removal, total Cr concentrations in the GWTP effluent are not expected to exceed the 50 µg/L California MCL.

In addition, the objectives of the Phase III Demonstration-scale RCF study include:

- Minimizing operational costs of the RCF system through treatment process optimization
- Optimizing residuals handling and disposal strategies
- Drafting a comprehensive operations and maintenance (O&M) manual for the system
- Updating unit cost information developed in the Phase II Pilot-scale study with actual treatment cost, and
- Publicly disseminating project plans and findings to a wide audience, including water agencies also concerned with Cr(VI) in water supplies, California DPH, USEPA, and consumers

# 4. Sampling Plan for Water Quality Parameters

During the demonstration-scale RCF study, we will focus on measuring key water quality and process related parameters (including residuals) to fully evaluate the treatment process. This chapter describes the sampling plan for water quality parameters in the study. The plan provides details on sampling location, sampling parameters, sampling frequency, and analytical approaches. Chapter 5 describes the sampling plan for process-related parameters (including residuals), and Chapter 6 provides the RCF start-up plan and outline for ongoing optimization. The sampling plans for water quality and process related parameters do not include a quality assurance/ quality control (QA/QC) section. A comprehensive Quality Assurance Project Plan (QAPP), which focuses on QA/QC issues, has been prepared separately to fulfill USEPA requirements and is provided as Appendix A to this document.

## 4.1. Sampling Locations

Sampling ports will be installed as part of the RCF system and water quality samples will be collected from these ports during the demonstration-scale study. Figure 4-1 shows a schematic of the RCF system with sampling ports highlighted in red. A brief description of each sampling port is listed in Table 4-1.

**Table 4-1. Water quality sampling location identification**

| Sampling Port Identification | Description |
|---|---|
| SP-001 | GN-2 and/or GN-3 Well/Plant Influent |
| SP-100 | Influent after Ferrous Sulfate Addition |
| SP-101 | Reduction Tank #1 Effluent |
| SP-102 | Reduction Tank #2 Effluent |
| SP-103 | Reduction Tank #3 Effluent |
| SP-201 | Dual Media Filter A Influent |
| SP-202 | Dual Media Filter B Influent |
| SP-301 | Dual Media Filter A Effluent |
| SP-302 | Dual Media Filter B Effluent |
| SP-303 | Combined Filter Effluent |
| SP-401 | Backwash Supernatant |
| SP-501 | Settled Backwash Solids |
| SP-502 | Flo-Trend Filtrate |

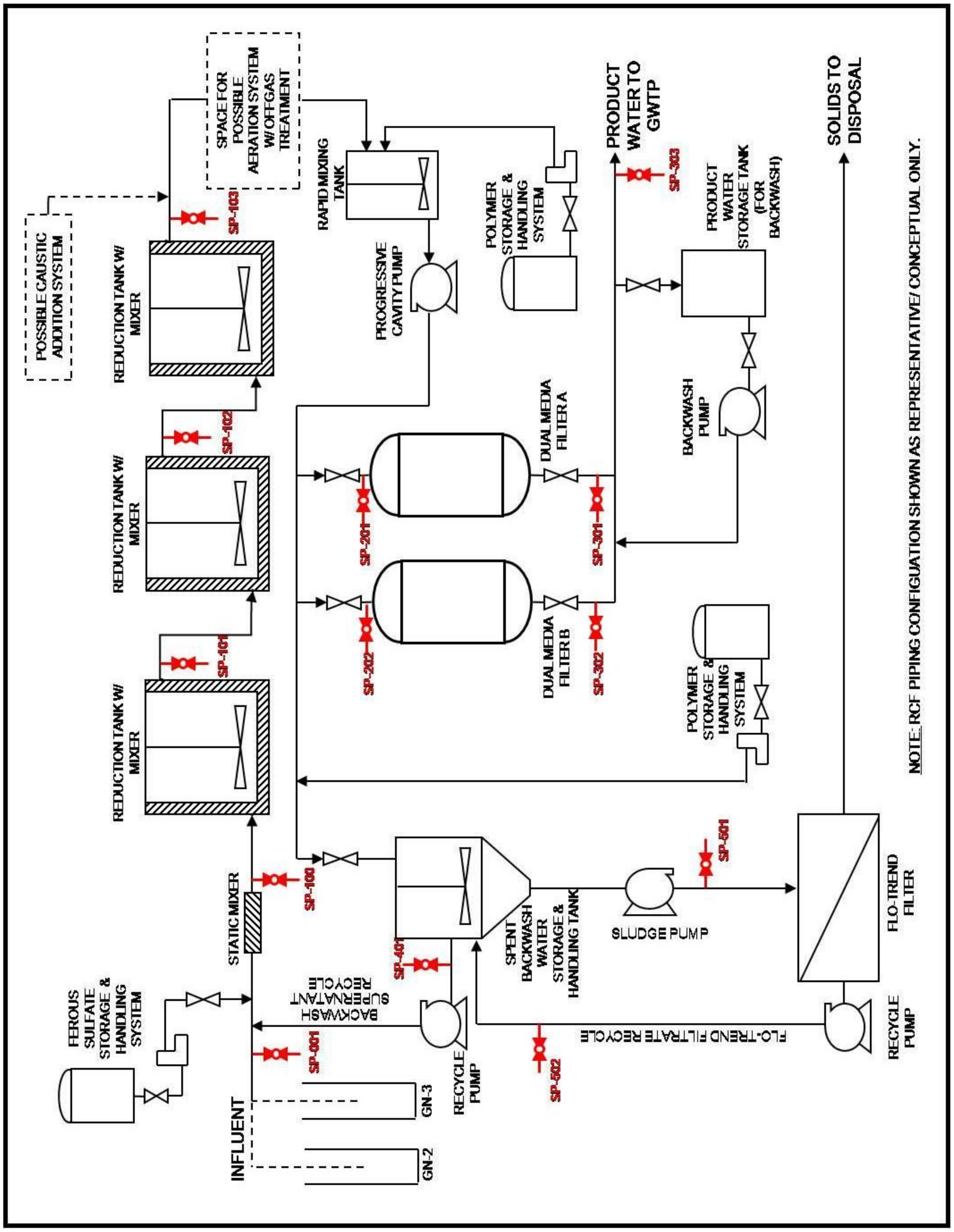


**Figure 4-1: Demonstration-scale RCF schematic with sampling ports highlighted in red**

## 4.2. Water Quality Parameters

Critical water quality parameters of the demonstration-scale RCF study include Cr(VI), total Cr, total Fe, turbidity, dissolved oxygen (DO), and pH. Cr(VI) and total Cr concentrations in process influent and effluent samples are measured to determine whether the treatment goal of less than 1 μg/L Cr(VI) and total Cr is achieved and to determine Cr removal efficiencies. Total Fe, turbidity, and DO from selected sampling ports are important because they are good indicators of the RCF system performance and can be easily measured using onsite instruments. The additional RCF pilot study demonstrated that total Cr concentration in the filter effluent greater than 5 μg/L was coupled with high filter effluent turbidity (i.e., greater than 1 NTU) and high total Fe concentration (i.e., greater than 0.19 mg/L). A high DO concentration in the influent (above ~5 mg/L) would ensure that enough dissolved oxygen is available to oxidize excess ferrous sulfate in the treatment process. pH from selected sampling ports is another important parameter which needs to be monitored routinely.

Other chemical and physical parameters, including ferrous iron ($Fe^{2+}$), pH, temperature, and total suspended solids (TSS) will be routinely measured to monitor any drastic water quality changes within the RCF process and investigate the possible causes for water quality changes. Table 4-2 summarizes the proposed water quality parameters to be monitored in the demonstration-scale RCF study. Water quality parameters from each sampling port are identified as critical (C), non-critical (N/C), or not necessary (-).

**Table 4-2. Water quality parameters to be monitored in the RCF demonstration-scale Study [parameters identified as Critical (C), non-Critical (N/C), and not necessary (-)]**

| Sampling Port | Cr(VI) | Total Cr | Total Fe | $Fe^{2+}$ | Turbidity | pH | Temp | DO | TSS |
|---|---|---|---|---|---|---|---|---|---|
| SP-001 | C | C | N/C | N/C | N/C | C | N/C | C | |
| SP-100 | - | - | C | C | - | - | - | - | - |
| SP-101 | - | - | N/C | N/C | - | C | N/C | - | - |
| SP-102 | - | - | N/C | N/C | - | C | N/C | - | - |
| SP-103 | C | - | C | C | - | C | N/C | C | - |
| SP-201 | - | - | - | - | - | C | N/C | C | - |
| SP-202 | - | - | - | - | - | C | N/C | C | - |
| SP-301 | C | C | C | C | C | N/C | N/C | N/C | - |
| SP-302 | C | C | C | C | C | N/C | N/C | N/C | - |
| SP-303 | C | C | C | C | C | C | C | C | - |
| SP-401 | C | C | C | C | C | N/C | N/C | - | - |
| SP-501 | - | - | - | - | - | - | - | - | N/C |
| SP-502 | C | C | N/C | N/C | C | N/C | N/C | - | - |

## 4.3. Sampling Frequency

The planned sampling frequency for water quality parameters, shown in Table 4-3, is based on treatment process design and the expected duration of testing (approximately one year for the demonstration-scale study). Water quality samples will be collected at sufficient frequency to provide enough information to achieve the project's stated objectives.

Generally, measuring of the critical water quality parameters at each sampling port will occur on a weekly basis, except for parameters that will be monitored continuously. The weekly sampling frequency will generate 52 sets of Cr(VI) and total Cr data from various locations of the RCF system over one-year period, which will enable us to have a comprehensive evaluation of the system performance. Dual media effluent turbidity is a good indicator of total Cr removal performance and will be monitored continuously during the one-year study. Other non-critical parameters will be monitored on a monthly basis, unless noted otherwise in Table 4-3. It should be noted that the sampling frequency listed in Table 4-3 will be adopted once the RCF system has reached a steady-state condition. During system start-up and other operation optimization periods, the sampling frequency may vary. Chapter 6 provides more information on sampling frequency during system start-up and operation optimization periods.

**Table 4-3. Sampling frequency for water quality parameters**

| Sampling Port | Laboratory Analysis | | | Field Analysis | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cr(VI) | Total Cr | TSS | Cr(VI) | Total Fe | $Fe^{2+}$ | Turbidity | pH/ Temp[3] | DO |
| SP-001 | 1/W[1] | 1/W | | 1/W | 1/M[2] | 1/M | 1/M | Continuous | Continuous |
| SP-100 | - | - | - | - | 1/W | 1/W | - | - | - |
| SP-101 | - | - | - | - | 1/M | 1/M | - | 1/W | - |
| SP-102 | - | - | - | - | 1/M | 1/M | - | 1/W | - |
| SP-103 | 1/W | - | - | - | 1/W | 1/W | - | 1/W | 1/W |
| SP-201 | - | - | - | - | - | - | - | 1/W | 1/W |
| SP-202 | - | - | - | - | - | - | - | 1/W | 1/W |
| SP-301 | 1/W | 1/W | - | 1/W | 1/W | 1/W | Continuous | 1/M | 1/M |
| SP-302 | 1/W | 1/W | - | 1/W | 1/W | 1/W | Continuous | 1/M | 1/M |
| SP-303 | 1/W | 1/W | - | 1/W | 1/W | 1/W | Continuous | 1/W | 1/W |
| SP-401 | 1/W | 1/W | - | 1/W | 1/W | 1/W | 1/W | 1/M | - |
| SP-501 | - | - | 1/M | - | - | - | - | - | - |
| SP-502 | 1/W | 1/W | - | 1/W | 1/M | 1/M | 1/W | 1/M | - |

1. 1/W = Once per week
2. 1/M = Once per month
3. pH and temperature will be monitored at the same frequency because the pH meter selected for the RCF study has temperature compensation function to ensure more accurate measurement.

## 4.4. Analytical Approach

Analytical methods for the water quality parameters will conform to USEPA guidelines and recommended test methods, including those in Standard Method for the Examination of Water and Wastewater (SM, APHA 1999). This section briefly describes the analytical approach used in the demonstration-scale study. Refer to the QAPP document in Appendix A for more detailed information (e.g., sample handling and transportation methods, and QA/QC measures).

During the demonstration-scale study, chemical and physical analytes will be measured either in a laboratory or in the field. ELAP – certified Montgomery Watson Harza Laboratories (MWH Labs) will be the contract lab for analysis of selected water quality parameters (see Table 4-4). Laboratory analysis of total Cr will be performed by ICP-MS (EPA Method 200.8). Cr(VI) will be analyzed using EPA Method 300.0. TSS will be measured gravimetrically using EPA Method 160.2. The Method Reporting Level (MRL) at MWH Labs for Cr(VI), total Cr, and TSS are 0.1 µg/L, 1.0 µg/L, and 4 mg/L, respectively. Samples found to be less than these values are reported as "<MRL."

Standard-tested Hach and other equipment will be used for field monitoring. Table 4-4 also lists the analytical approaches for water quality parameters measured using online or field instruments.

**Table 4-4. Analytical methods, locations of analyses, and detection limits**

| Sample Analysis | Analytical Method | Analysis Location | Method Detection Level (MDL) | Method Reporting Level (MRL) |
|---|---|---|---|---|
| Cr(VI) – Lab | EPA 218.6 (IC) | MWH Labs | 0.015 μg/L | 0.1 μg/L |
| Total Cr | EPA 200.8 (ICP-MS) | MWH Labs | 0.192 μg/L | 1.0 μg/L |
| TSS | EPA 160.2 (Gravimetric) | MWH Labs | 4 mg/L | 4 mg/L |
| Cr(VI) – Field | Hach Method 8023 (Diphenylcarbohydrazide) | Field | 10 μg/L | 10 μg/L |
| Total Iron | Hach Method 8008 (FerroVer) | Field | 0.02 mg/L | 0.02 mg/L |
| Ferrous Iron | Hach Method 8146 (1,10-Phenanthroline) | Field | 0.02 mg/L | 0.02 mg/L |
| pH | SM 4500H+ B (Electrometric) | Field | N/A | N/A |
| pH (Continuous)[1] | SM 4500H+ B (Electrometric) | Online | N/A | N/A |
| Temperature | SM 2550 (Thermometric) | Field | N/A | N/A |
| Turbidity[2] | SM 2130 B (Nephelometric) | Field | 0.02 NTU | 0.02 NTU |
| Turbidity (Continuous)[3] | SM 2130 B (Nephelometric) | Online | 0.02 NTU | 0.02 NTU |
| DO | Hach Method 8166 (HRDO) | Field | 0.3 mg/L | 0.3 mg/L |
| DO (Continuous)[4] | Hach Method 10360 (Luminescence measurement)[5] | Online | 0.1 mg/L | 0.1 mg/L |

1. Based on Hach LGI DPC1R2A pH sensor
2. Based on Hach 2100P Turbidimeter
3. Based on Hach 1720E Low Range Turbidimeter
4. Based on Hach LDO Dissolved Oxygen probe
5. EPA approved method

# 5. Sampling Plan for Process-Related Parameters

In addition to chemical and physical water quality parameters, process-related parameters will be routinely monitored to evaluate the operations of the RCF system. Process parameters for the demonstration study include water flow rate, chemical feed rate, and pressure buildup through the filter columns. Treatment residuals are also categorized as process-related parameters in the study.

Figure 5-1 shows a schematic of the RCF system with monitoring locations for process-related parameters highlighted in red. Table 5-1 identifies the process parameters that will be monitored at each location and associated monitoring frequencies. It should be noted that the demonstration-scale RCF system will be designed to operate automatically with minimal operators' supervision. As a result, some of the process-related parameters will be monitored and recorded continuously and the data will be transmitted to the GWTP via the Supervisory Control and Data Acquisition (SCADA) system. However, system operators are still required to follow the monitoring plan as specified in Table 5-1 to ensure the completeness of the operational data.

Process-related parameters will be measured with appropriate instruments. For example, a flow meter will be used for flow rate and total volume measurement, a pressure transducer for pressure reading, calibration column and stop watch for chemical injection rate determination, and sight-glass or level indicators for liquid level reading. All instruments used for the RCF study will be specified during the preliminary design phase.

The treatment residual – dewatered sludge captured on the passive filtration system – will be assessed at Test America Labs to confirm disposal options using the Toxicity Characteristic Leaching Procedure (TCLP, EPA Method 1311 as mandated by 40 CFR 261) and the California Waste Extraction Test (CWET). The Phase II pilot-scale testing indicated that the sludge would be classified as hazardous waste in the State of California because total Cr concentration in the leachate exceeded the regulatory limit during CWET.

The quantity of dewatered sludge captured on the passive filtration system will also be determined during the study. Tare weight of the passive filter will be determined or provided by the vendor before any sludge loading. The gross weight of the filter with dewatered sludge will also be determined each time an off-site disposal occurs. The net weight of dewatered sludge can thus be calculated by subtracting the tare weight from the gross weight and the daily sludge production rate can be calculated by dividing the net weight by the filter operation duration. In addition, the dewatered sludge will be sent to Test America Labs for moisture content determination. As a result, the solids content in the dewatered sludge can be easily calculated (i.e., 100 - % of moisture content).

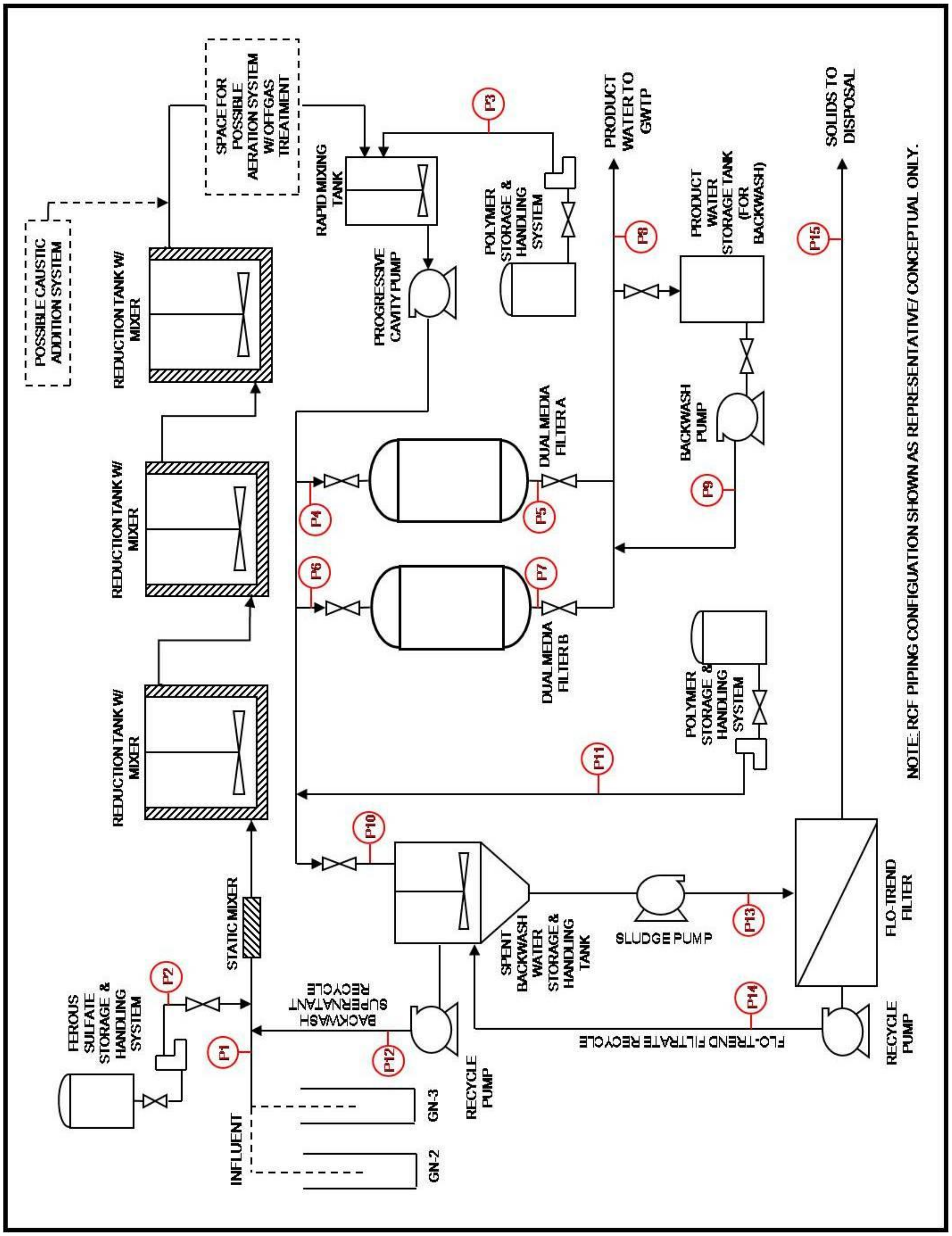


**Figure 5-1: RCF schematic with monitoring locations for process-related parameters highlighted**

**Table 5-1. Monitoring locations and frequencies for process-related parameters**

| Monitoring Location | Process-related parameters | Frequency |
|---|---|---|
| P1 | Influent water flow rate and total volume | Once Daily |
| P2 | Ferrous sulfate injection rate and liquid level | Once Daily |
| P3 | Polymer injection rate and liquid level | Once Daily |
| P4 | Dual Media Filter A influent flow rate and inlet pressure | Once Daily |
| P5 | Dual Media Filter A outlet pressure | Once Daily |
| P6 | Dual Media Filter B influent flow rate and inlet pressure | Once Daily |
| P7 | Dual Media Filter B outlet pressure | Once Daily |
| P8 | Combined filter effluent flow rate and total volume | Once Daily |
| P9 | Backwash water flow rate and total volume | Once every backwash cycle |
| P10 | Spent backwash water total volume | Once every backwash cycle |
| P11 | Polymer injection rate and liquid level | Once every backwash cycle |
| P12 | Backwash supernatant recycle flow rate and total volume | Once every backwash cycle |
| P13 | Settled backwash solids total volume | Once every backwash cycle |
| P14 | Flo-Trend filtrate recycle total volume | Once every backwash cycle |
| P15 | Dewatered sludge total quantity, moisture content, and TCLP and WET test on dewatered sludge | Once every off-site disposal |

# 6. Operations Evaluation and Optimization

## 6.1. Start-up Period

The first week of the demonstration-scale RCF study will be dedicated to system start-up. Engineers and operators will be onsite during the start-up period to perform critical tasks, including initial filling of the treatment chemicals, calibrating the system flow rate and chemical injection rate, testing all monitoring instruments, and verifying the communication and control systems on the RCF plant. Water quality and process-related parameters sampling more frequently than specified in Tables 4-3 and 5-2 will be necessary to evaluate the system performance during the start-up period.

Some start-up conditions for the RCF system are suggested:

- 25:1 Fe to Cr(VI) ratio
- 45-minute reduction time
- 5-minute rapid mixing time (with polymer)
- 0.1 ppm polymer dosing (Ciba Magnafloc E38) into influent water
- 3 gpm/sf hydraulic loading rate for the dual media filters
- Daily backwash cycle
- 1 ppm polymer dosing (Ciba Mangafloc E38) into the spent backwash water

Other start-up conditions will be determined by field engineers and operators.

During the start-up period, RCF effluent samples will be collected at least twice daily (the beginning and the end of each daily run) and sent to the laboratory for Cr(VI) and total Cr measurements. A 24-hr turnaround time is desired for those analyses so that engineers and operators can use the data to adjust the operating conditions in a timely fashion.

Once the demonstration-scale RCF system can operate uninterrupted for at least 72 hours and effluent Cr(VI) and total Cr concentrations remain below 1 µg/L, engineers and operators can terminate the start-up period and switch to normal operation and sampling schedules at their discretion.

## 6.2. Normal Operation

During normal operation, water quality and process-related parameters should be maintained as close as possible to values required to ensure safe and efficient operation of the RCF system. The following is a list of suggested operating parameters for the RCF system. The final operating parameters will be specified in the drinking water permit issued by California Department of Public Health.

- RCF system influent not to exceed 105 gpm (100 gpm from well water plus 5 gpm recycle flow)
- Fe to Cr dosing ratio not to exceed 25:1
- Evenly distributed flow to each dual media filter
- Headloss of the filters not to exceed 100 inches of water
- Turbidity of combined filter effluent not to exceed 0.30 NTU
- Weekly Cr(VI) and total Cr concentrations in combined filter effluent not to exceed 1 μg/L

In addition, engineers and operators will perform water quality and process-related sampling as specified in Sections 4 and 5.

## 6.3. Operations Optimization

After the RCF plant has demonstrated a stable Cr(VI) removal performance for at least 3 months, engineers, with the approval of the CDPH, may consider performing a series of tests to further optimize the RCF system. The operating conditions to be optimized will include:

- Lowering Fe:Cr dosing ratio from 25:1 to 15:1 (or as low as possible)
- Changing polymer type and dosage for optimum dual media filtration
- Changing polymer type and dosage for optimum backwash water settling, and
- Other conditions that will result in a lower O&M cost without impairing Cr(VI) removal performance

## 6.4. Cost Evaluation

Cost components (including capital costs and O&M costs) of the RCF plant will be tracked carefully during the demonstration-scale study and compiled at the end of study to provide detailed and accurate cost information. Such information will be valuable to other water utilities requiring Cr(VI) treatment and to the California DPH, who will be charged with setting an MCL for Cr(VI).

### 6.4.1. Capital Costs

The capital cost for the demonstration-scale RCF system will be tracked using various tools. Copies of all contracts and invoices will be obtained from the construction contractors.

### 6.4.2. O&M Costs

#### 6.4.2.1. Staffing Requirements

Operations staff for the demonstration-scale RCF plant will record the time spent on routine O&M duties on a daily basis. In case of an emergency related to the RCF system (e.g., chemical feed problem), the operators will also record the time spent on resuming system operation.

#### 6.4.2.2. Chemical Expenses

The type and total volume of each chemical (i.e., ferrous sulfate and polymers) used in the study will be tracked carefully. The operations staff will record the level in the chemical feed system once per day. In addition, paper records from each chemical delivery will be collected and managed.

#### 6.4.2.3. Other Related Expenses

All other related expenses incurred during the demonstration-scale study will also be recorded. Those expenses include, but not limited to, energy costs, water sample analytical costs, waste disposal costs, and periodic system inspection and repair costs.

# 7. References


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# 8. Appendix

Appendix A: The Treatment of Hexavalent Chromium (Cr(VI)) in the City of Glendale, California Ground Water Supply: Phase III Demonstration-Scale Reduction with Ferrous Sulfate, Coagulation, Filtration Treatment Technology Evaluation Quality Assurance Project Plan