Report

AQUA METROLOGY SYSTEMS

SafeGuard™ H2O Demonstration Report

Isleton Water System, California

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April 2022

This report summarizes results from the demonstration study of Aqua Metrology Systems' SafeGuard™ H2O intelligent arsenic treatment system and details the technology's ability to mitigate total arsenic contamination in drinking water at California American Water's Isleton Water System.

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Table of Contents

Section 1

Executive Summary

Overview

In drinking water supplies, arsenic (As) poses a threat to human health because it is a known carcinogen. In 2001, the U.S. Environmental Protection Agency (EPA) lowered the federal maximum contaminant level (MCL) for arsenic in drinking water from 50 parts-per-billion (ppb) to 10 ppb, where it remains today. In 2018, the World Health Organization stated that "Every effort should be made to keep arsenic concentrations as low as reasonably possible and below the guideline value of 10 ppb when resources are available." Currently, the EPA is reviewing its MCL recommendations for arsenic. This has led utilities across the U.S. to evaluate the efficacy of their existing arsenic removal treatment systems.

In Isleton, California, California American Water has been using a range of drinking water treatment technologies to remove naturally occurring arsenic, iron and manganese, and chlorination for disinfection to maintain water quality in the distribution network of the Isleton Water System. Since 2008, the Isleton Water System has been using a coagulation/filtration treatment scheme that, under optimized conditions, can reduce an influent arsenic level of 20 ppb to an effluent level between 5-8 ppb. While effective at arsenic removal, the existing coagulation/filtration process is reliant on the use of bulk chemicals that are toxic and hazardous in nature. These chemicals require special transportation, storage, handling and use to ensure safety. In addition, a large storage area is required to house the bulk chemicals onsite at the facility.

Aqua Metrology Systems (AMS), based in Sunnyvale, California, developed an innovative arsenic treatment approach that eliminates the pitfalls of conventional systems. The SafeGuard™ H2O technology aids in the delivery of an affordable and reliable remediation process through a fully automated and space saving system design.

SafeGuard™ H2O generates a ferrous ion reagent in-situ via an electrolytic process to address arsenic contamination effectively and economically. The electrolytic ferrous ion generation process does not require special complex infrastructure or safety protocols as compared to bulk chemicals. The SafeGuard™ H2O system also features an online analyzer for real-time monitoring of arsenic and iron contaminant levels to help control and optimize the treatment process.

A full-scale SafeGuard™ H2O demonstration unit with a treatment capacity of 3 gallons-per-minute (gpm) was installed at the Isleton Water System Well #3A (Isleton Well #3A) for an evaluation in September 2021 and February 2022. The objective was to demonstrate the ability of the

electrogenerated ferrous reagent produced on demand by the SafeGuard™ H2O system to remove arsenic from unchlorinated well water reliably and effectively. The demonstration system was configured to replicate Isleton's current coagulation/filtration treatment process; with the only difference being the reagent dosing method where the electrolytic ferrous reagent generator replaced the liquid ferric reagent dosing system.

The characteristics of the source water for Isleton Well #3A are challenging. The groundwater contains relatively elevated levels of dissolved silica at 33 ppm. Silica, sulfates, phosphates, fluorides and many other substances can pose significant interferences for conventional treatment approaches; yet they have minor to no effect on arsenic removal with the SafeGuard™ H2O system.

The demonstration of the SafeGuard™ H2O system at Isleton Well#3A confirmed the performance of the in-situ ferrous ion reagent generation technology to treat arsenic to under 10 ppb in unchlorinated well water; achieving a removal efficiency matching the existing coagulation/filtration system that uses liquid ferric chloride.

Results

The SafeGuard™ H2O technology evaluation at Isleton Well #3A (September 2021 and February 2022) demonstrated the high capability of the technology to effectively remove dissolved arsenic species and provide an effluent arsenic concentration of approximately 6 ppb. The removal efficiency of the SafeGuard™ H2O technology closely matches the effluent arsenic concentration range (5-8 ppb) achieved by the existing full-scale coagulation/filtration treatment process.

SafeGuard™ H2O showed a fast and reliable response to treatment process parameters which allowed for real-time automated online treatment system fine tuning and adjustments. In addition, the system's versatile automated treatment design, in combination with frequent online arsenic monitoring via the online and onboard MetalGuard™ trace metal analyzer also manufactured by AMS, enabled the operation of an unattended and low maintenance arsenic treatment system under field conditions.

The greensand filter media implemented in the SafeGuard™ H2O treatment process, also demonstrated a high capacity to remove both total arsenic and iron residuals to safe levels. A high media filter recovery after backwash ensured stable filter performance.

The SafeGuard™ H2O system reduced arsenic to safe levels and its corresponding greensand filter system was effective at removing arsenic and iron.

Section 2

Demonstration Technology

Site Background

Several technologies have been identified by U.S. EPA as a best available technology (BAT) for arsenic removal, including coagulation/filtration.

The traditional coagulation/filtration process consists of the addition of ferric chloride to contaminated water, followed by a filtration step to remove particles. Ferric chloride is hydrolized when it comes into contact with water to form colloidal particles of ferric hydroxide which carry a net positive charge on their surface. Arsenate [As(V)] is an anion negatively charged and tends to be adsorbed onto the positively charged ferric hydroxide surface. At a pH of around 7.3 or below ferric hydroxide formation is optimal, and the arsenic removal process is most effective.

Removal of ferric hydroxide particulates from the treated water is achieved by filtration through greensand media. Greensand is a granular material composed of the mineral glaucite, which has been coated with manganese oxide. It is a natural zeolite (microporous mineral), and has strong ion exchange properties, which can remove fine iron particulates along with adsorbed arsenic species.

In the Isleton Water System, the removal of dissolved arsenic species from the well water is achieved by a coagulation/filtration process (see Figure 1). The treatment approach is based on pre-oxidation of arsenite [As(III)] into As(V) with a chlorine dose up to 6 parts-per-million (ppm) and the addition of a ferric chloride reagent (approximately 15 ppm) as a coagulation precursor. In addition, aluminum chlorohydrate hydroxide (ACH) is added to enhance the coagulation process and greensand pressure filters are used to remove the colloidal particulates. The greensand filtration module requires periodic backwash to maintain its performance and stability.

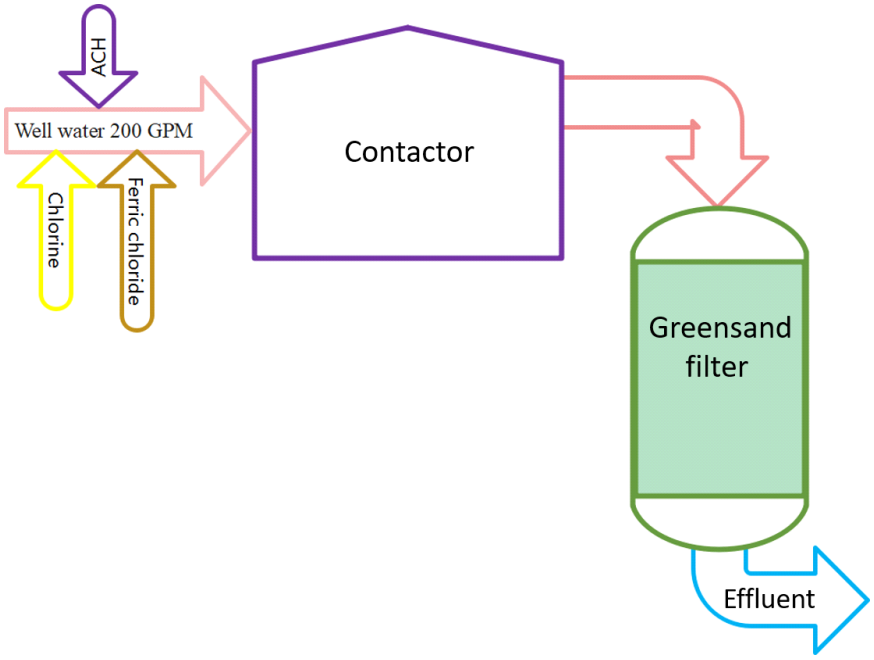

Figure 1 – Isleton Well #3A Arsenic Removal System Process Schematic (Coagulation/Filtration Technology)

SafeGuard™ H2O Intelligent Arsenic Treatment System

AMS' SafeGuard™ H2O technology is a novel remediation system that generates a ferrous ion reagent on demand using non-toxic, certified reagent precursor material (low carbon steel). As a result, there is no shelf life of the reagent and operational costs are drastically reduced because shipping and handling of a hazardous ferric solution are eliminated.

SafeGuard™ H2O also features automatic dosing and incorporates AMS' proprietary, continuous, real-time monitoring of contaminant levels at the influent and effluent to ensure optimal treatment and compliance with regulatory and operational targets 24/7/365. Data generated from the onboard arsenic monitoring system, AMS' online MetalGuard™ trace metal analyzer, helps drive a highly accurate remediation process by ensuring reliable reagent dosing control through manipulation of site-specific process parameters.

Unlike some traditional treatment systems, which cannot operate unattended, the fully autonomous SafeGuard™ H2O system can be controlled, monitored and optimized remotely. The need of personnel on site for supervision is minimal, further reducing operating costs. Depending on treatment size needs and site requirements, a system can be designed to operate unattended for up to several weeks.

The ferrous reagent generator within the SafeGuard™ H2O system has a modular and flexible design that can be scaled to any size. The system features low capital and operating costs making it an economical and reliable arsenic remediation system.

Electrolytic Ferrous Reagent Generation

With SafeGuard™ H2O, AMS has developed a unique approach to produce a controlled amount of ferrous ions in-situ. This is accomplished through the process of electrolysis, wherein a current is passed through electrolytic cell (electrolyzer) containing an iron anode and cathode of a certified quality. Ferrous ions are generated on demand as a result of the anodic dissolution of iron metal.

The quantification of electrogenerated ferrous ions that are produced can be understood through the well-studied laws of electrolysis, originally proposed by Michael Faraday in 1834. Faraday's laws of electrolysis established the relationship between the charge passed through the electrolytic cell and the mass of anodic dissolution that occurs: (See Equation 2)

$$m = \left(\frac{Q}{F}\right)\left(\frac{M}{z}\right) \qquad (2)$$

Where m is the mass of anodic dissolution, Q is the total electric charge passed through the metal, F= 96.485 C° mol^{-1}, known as Faraday's constant, M is the molar mass of the substance, and z is the electrons transferred per ion.

An important characteristic of electrolytic ferrous ion generation on demand is the precision of its control. A high efficiency of ferrous ion generation ensures accurate reagent dose in a broad concentration range. Generation of a ferrous ion reagent can be easily adjusted in real time, based on changing treatment process conditions. Moreover, the ferrous ion generator can be terminated immediately simply by switching the power off, and restored as soon as power is switched on, making it highly suitable for stop-and-run operation modes associated with wells that do not run continuously.

The unique ferrous ion generator is integrated with an online trace metal monitoring capability. As with any water treatment system, high frequency continuous monitoring of contaminants at critical treatment process steps supports process automation, optimization, reliability, and can give remote visibility of system performance for the utility and their customers.

Advantages of Electrolytic Ferrous Reagent Generation

Three of the most significant benefits of the SafeGuard™ H2O in-situ electrogenerated ferrous reagent treatment approach over traditional bulk reagents include:

1. Electrogenerated ferrous ions are produced from a certified iron metal precursor therefore the reagent does not contain impurities (inorganic and organic) which may be present in bulk ferric chloride chemical solutions and interfere with the treatment process.

2. Electrogenerated ferrous ions are non-toxic in nature. While ferric solutions are highly acidic, toxic and corrosive, a ferrous ion reagent is produced in-situ using highly inert iron metal. As opposed to dangerous and corrosive ferric chloride concentrates, the electrolytic ferrous ion generation process does not require special complex infrastructure or safety protocols.

3. The electrolytic approach to ferrous ion generation offers a more economical alternative to conventional ferric solutions. In fact, this method uses inexpensive and readily available resources – mild steel metal and electricity. Another highly important advantage of electrolytic approach to generation of ferrous ions on demand is scalability of the electrogeneration system.

SafeGuard™ H2O Demonstration System Setup and Operation

A full-scale, trailer mounted 3 gpm SafeGuard™ H2O arsenic treatment system was provided by AMS to California American Water for demonstration at Isleton Well #3A (Figure 2). The SafeGuard™ H2O demonstration system was configured to replicate the current coagulation/filtration treatment process at Isleton Well #3A (Figure 1); the only difference was in the reagent dosing method that uses an electrolytic ferrous reagent generator to replace the liquid ferric reagent dosing system.

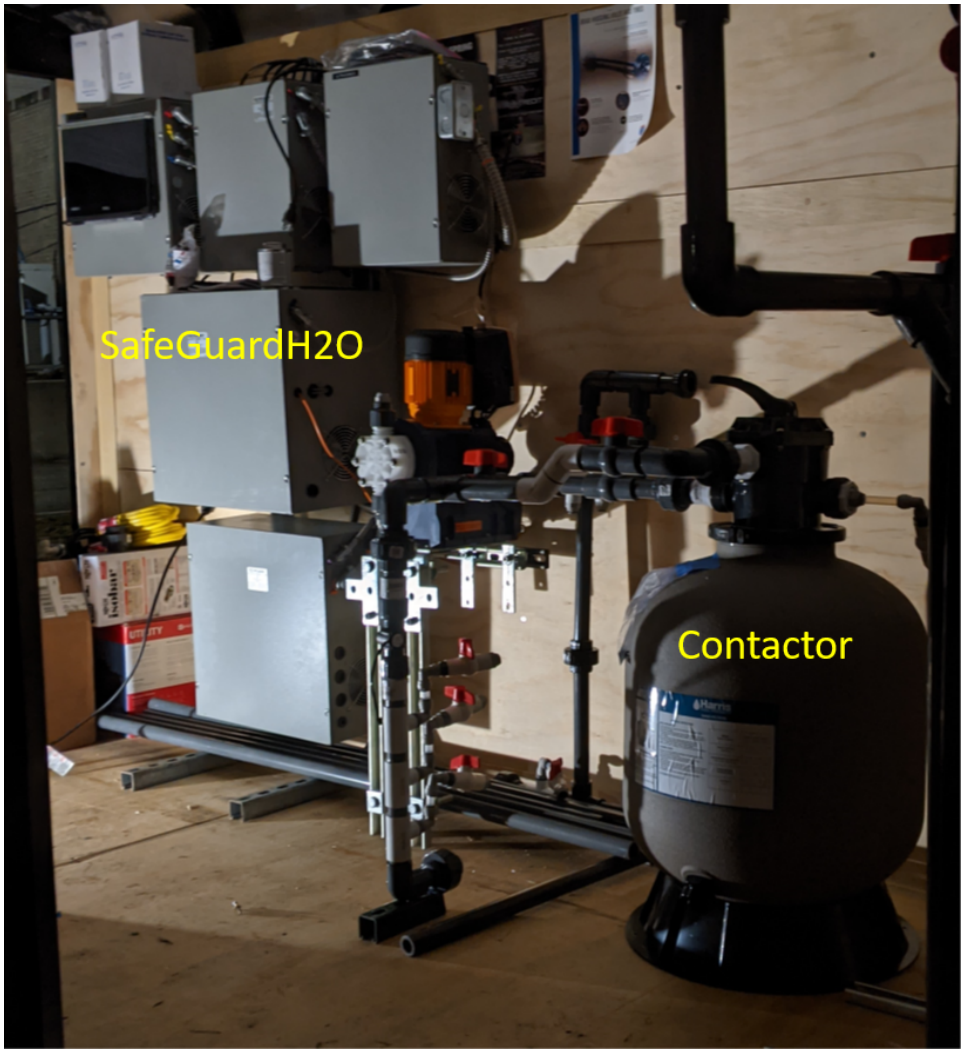

Figure 2 - SafeGuard™ H2O Trailer Mounted Arsenic Removal Demonstration System Installed at Isleton Well #3A

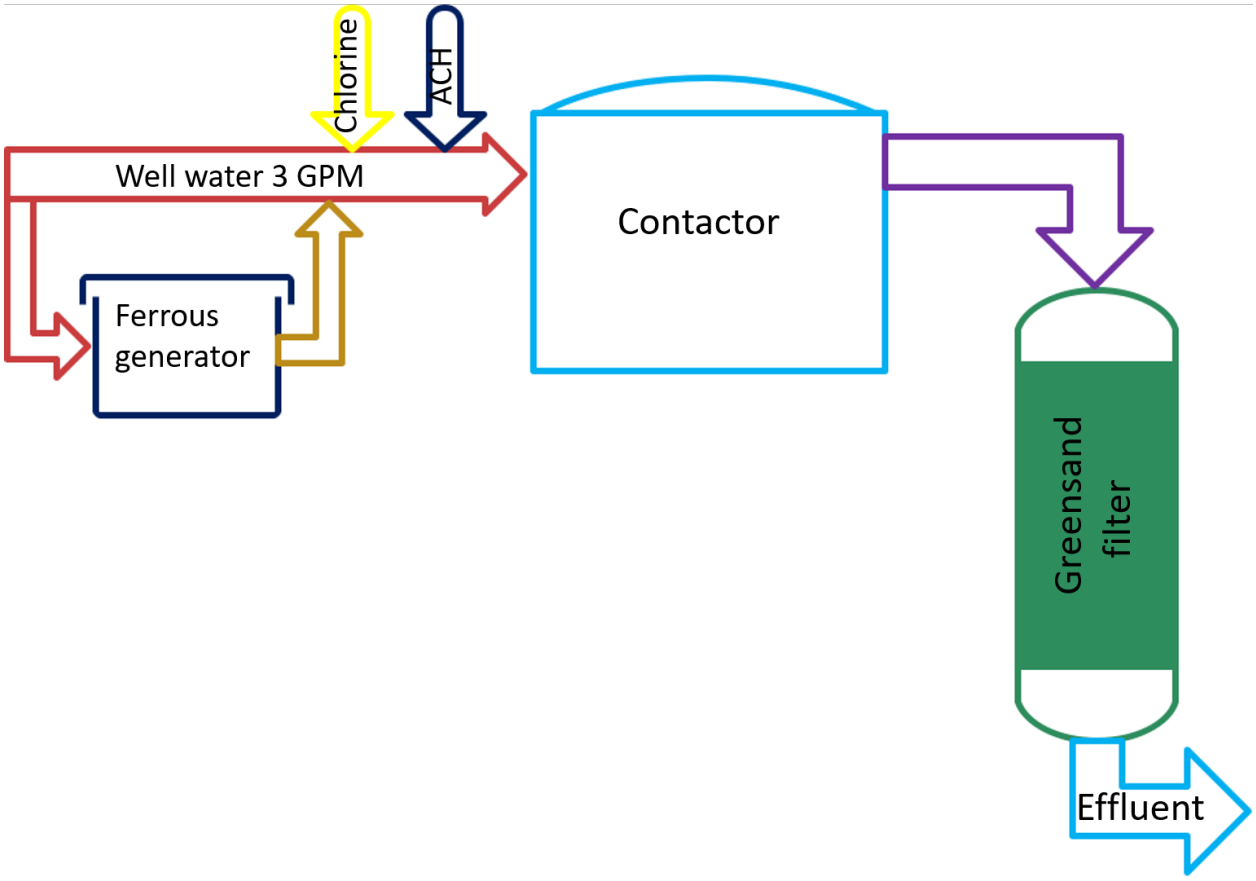

Figure 3 - SafeGuard™ H2O Arsenic Removal System Process Schematic (In-Situ Ferrous Reagent Generation Technology)

Within the SafeGuard™ H2O demonstration system, the unchlorinated well water flow (3 gpm) was treated with a ferrous reagent concentrate produced within a side stream of the well water (0.04 gpm) by the electrolytic generator. The electrogenerated reagent concentration was pre-set and controlled to provide a desirable reagent dose after blending the reagent stream and raw water stream.

The blended water stream passed through a contactor vessel with a 15-minute nominal contact time, in which reduction by ferric hydroxide colloidal particle formation was accomplished and these particles absorbed dissolved arsenic species and were coagulated by the addition of an ACH reagent.

A greensand filter with an effective granule size 0.3-1 millimeters (mm), a uniformity coefficient approximately 1.6 and a volume of 2 cubic feet (two individual 10 inch diameter by 60 inch height filters in series) was used to remove both ferric hydroxide particulates along with absorbed arsenic from the treated water.

An online MetalGuard™ arsenic analyzer (not shown in Figure 3), continuously and autonomously monitored total arsenic effluent levels and reported measurement data to the Cloud for remote monitoring in real time. In addition, the key parameters of the electrolytic reagent generation process (reagent dose, etc.) were controlled by the proprietary software of the SafeGuard™ H2O technology (Figure 4).

Figure 4 - Proprietary Software, SafeGuard™ H2O Control Panel

Online, Real-Time Total Arsenic Monitoring

Total arsenic residuals in the treated water were monitored by AMS' online MetalGuard™ arsenic analyzer in a continuous manner during the entire demonstration period. The treated water aliquot was drawn from the sample fast loop sampling chamber and analyzed by the monitor with a frequency of two tests per hour. The highly sensitive probe of the MetalGuard™ analyzer allowed accurate and reliable arsenic readings down to 1 ppb level.

Section 3

Demonstration Results

Treatment Objective

The main objective was to demonstrate the ability of the SafeGuard™ H2O treatment system to reduce influent arsenic levels of 20 ppb to a level reliably below the MCL of 10 ppb.

Other objectives included:

- To demonstrate a high generation efficiency of ferrous reagent and the high stability of the electrogeneration process in order to achieve high accuracy of the reagent dosing;
- To demonstrate the low inertia of SafeGuard™ H2O arsenic treatment system and its fast recovery after shut-down;
- To demonstrate the possibility of integrating the SafeGuard™ H2O arsenic treatment system within the existing coagulation/filtration treatment process;
- To demonstrate SafeGuard™ H2O ferrous reagent generation module integration capability within the existing coagulation/filtration treatment process to replace the use of a bulk ferric chloride reagent.

Grab Sampling and Laboratory Analysis

Manual greensand filter effluent grab samples were collected periodically by AMS personnel and analyzed for total arsenic, total iron, and aluminum by a certified laboratory (Pace Analytical, formerly BC Labs). Determination of total arsenic was performed using EPA method 200.8 with MDLs of 1 ppb. Both total iron and aluminum determinations were performed using EPA method 200.7 with MDLs of 50 ppb.

Results

Determination of Ferrous Reagent Generation Efficiency

Generally, an efficiency of any electrolytic process (%) is determined as the ratio of the actual mass of a substance liberated from an electrode by the passage of charge to the theoretical mass calculated according to Faraday's second law (see Equation 3).

$$E_{Gen} = \frac{\Delta M_{Act}}{\Delta M_{Th}} 100 \qquad (3)$$

Ferrous reagent generation efficiency E_{Gen} has been evaluated by determining the iron anode mass loss by weighing the generation electrode before and after the demonstration. The charge which passed the system during the trial was 7.84 Ah which corresponds to a theoretical mass loss of 8.189 g. Actual mass loss has been determined gravimetrically and consisted of 8.162 g. The generation efficiency calculated according to Equation 3 is 99.7%.

The high ferrous reagent generation efficiency ensures an accurate and reliable reagent dose, allowing accurate tracking of the iron anodes remaining capacity and avoiding iron anode passivation and fouling.

Assessing Optimal Full Scale Process Parameters

In order to evaluate the potential of retrofitting the existing coagulation/filtration system that uses a ferric chloride-based approach for arsenic removal with the SafeGuard™ H2O ferrous reagent generation module it was critically important to operate the demonstration system under conditions identical to those in the existing full-scale treatment process. These key treatment process parameters included water pH, coagulant dose, both chlorine and polymer doses and filter hydraulic loading rate (HLR).

Key treatment process parameters provided by the operations staff at the Isleton Water System are summarized in Table 1.

Table 1 – Key Arsenic Removal Parameters in Existing Coagulation/Filtration Process

pH	$FeCl_3$, ppm	Free Chlorine, ppm	ACH, ppm	HLR
8.10 - 8.50	13 - 14 (4.5 - 4.8 as iron)	2 - 3	0.5 - 1.0	~ 1.4

Behavior of the full-scale coagulation/filtration arsenic treatment system under steady treatment process conditions is detailed in Figure 5. This diagram details the fraction of the online effluent arsenic results obtained from February 18 to March 2, 2022.

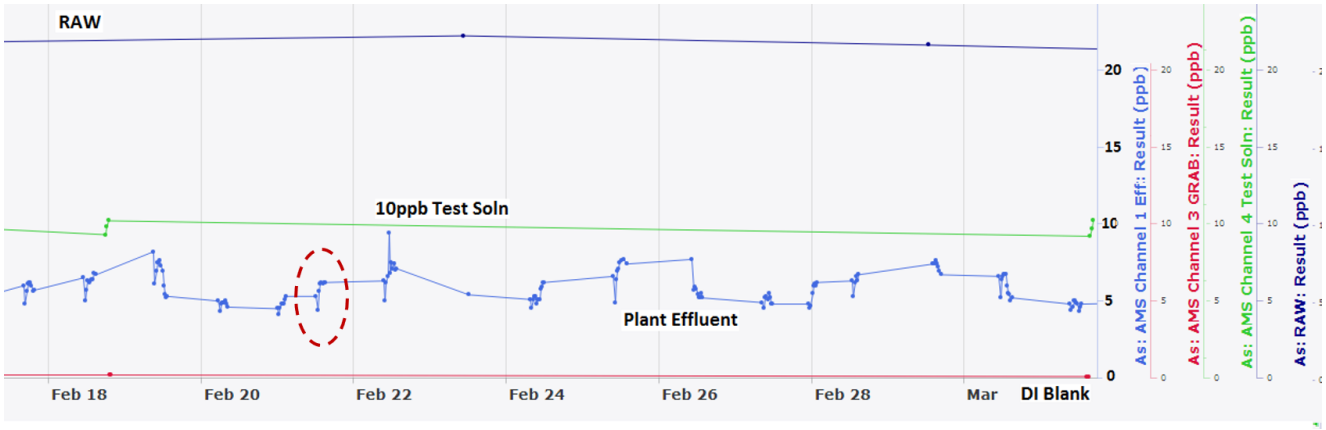

Figure 5 - Coagulation/Filtration Technology Treatment System Performance Under Steady Process Conditions

With coagulation/filtration the effluent arsenic level remained reliably below 10 ppb, averaging 5-8 ppb. Periodic increase in the effluent arsenic levels is due to media filter saturation by the treatment process by-products (colloidal ferric hydroxide). The media filter backwash resulted in reduction of residual arsenic in the treatment system effluent.

SafeGuard™ H2O System Performance

The SafeGuard™ H2O arsenic treatment system was optimized to match the operation range of the key treatment process parameters summarized in Table 1. Typical values of the parameters achieved during demonstration of the SafeGuard™ H2O technology is summarized in Table 2. The water parameters maintained in SafeGuard H2O™ demonstration were in good correlation with those in the full-scale coagulation/filtration treatment process.

Table 2 – Key Arsenic Removal Parameters in SafeGuard™ H2O Demonstration System

pH	$FeCl_3$, ppm	Free Chlorine, ppm	ACH, ppm	HLR
8.10- 8.50	4.1-4.2	0.5-1.0	0.7 – 0.8	1.5

The effect of key process parameters on the performance of the SafeGuard™ H2O treatment system is detailed in Figure 6. As detailed, around 12 pm on February 19 online arsenic results from the MetalGuard™ online arsenic analyzer indicated high arsenic levels in the treatment system influent without any treatment applied (raw flush). After turning on the ferrous reagent generation along with the addition of chlorine into the raw water, there was a significant arsenic reduction in the effluent to 10-11 ppb and it remained steady for number of consecutive tests.

Then, the SafeGuard™ H2O system was turned off and it remained idle for 40 hours. The system was restarted again on February 21 around 9 am while a ferrous reagent dose was applied and coupled with both chlorine and ACH additions at levels indicated in Table 1. Dosing of the optimal levels of ferrous, chlorine and ACH resulted in arsenic residual levels in the effluent at 6-8 ppb; the effluent remained stable for the next eight consecutive measurements (Figure 5).

Online SafeGuard™ H2O system effluent monitoring results obtained between 9 am and 1 pm on February 21 (Figure 5) are in very close correlation with those made by online readings obtained in full-scale arsenic treatment system (Figure 5- Red Circle). Good agreement between online effluent arsenic results obtained by both the full-scale coagulation/filtration system and the SafeGuard™ H2O demonstration system indicates the high efficiency of the electrogenerated reagent produced by the in-situ reagent generation technology. Also, accuracy of the online effluent arsenic data produced by the onboard MetalGuard™ arsenic analyzer that continuously monitors the performance of the SafeGuard™ H2O system has been confirmed by testing two manual effluent grab samples at an external laboratory (Figure 6).

The SafeGuard™ H2O treatment system demonstrated reliable performance under stop/run and its fast stabilization after a long idle time is highly important in "stop-run" operation mode.

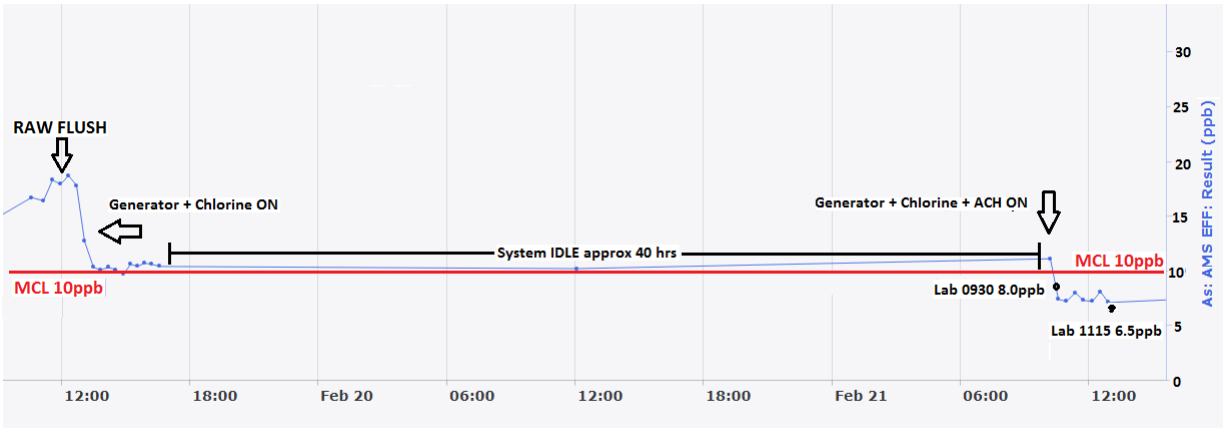

Figure 6 - SafeGuard™ H2O Treatment System Performance Under Stop/Run Mode

SafeGuard™ H2O Integration

As it has been demonstrated the SafeGuard™ H2O ferrous reagent generation module is a very compact low power in-situ reagent generation technology and dosing method which can be easily deployed and integrated with the existing coagulation/filtration arsenic removal treatment process that uses a ferric chloride bulk reagent. In fact, the low SafeGuard™ H2O electrolytic generator footprint allows a reduction in the bulk reagent storage area as well as the elimination of bulk reagent transportation and logistical costs.

Conclusions

- The SafeGuard™ H2O arsenic removal system installed at the Isleton Water System (Isleton Well #3A) demonstrated an ability to reduce an influent arsenic level of 20 ppb down to an effluent between 5-8 ppb under steady-state treatment process conditions;
- Performance of the SafeGuard™ H2O arsenic treatment system under optimal conditions was similar to that of the full-scale coagulation/filtration ferric chloride-based removal process;
- The SafeGuard™ H2O ferrous reagent generation module was demonstrated to produce the treatment reagent in a highly accurate and reliable manner;
- The SafeGuard™ H2O treatment system demonstrated low inertia and an ability to recover fast after a long idle time period;
- The compact and versatile SafeGuard™ H2O electrolytic reagent configuration allows for easy integration within the existing coagulation/filtration arsenic removal process.

Acknowledgements

AMS is extremely grateful to California American Water for the opportunity to conduct this demonstration project of the SafeGuard™ H2O treatment technology at its Isleton Water System. We are thankful for the advice, time and support of the Sacramento District Team.