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Energy Research and Development Division

FINAL PROJECT REPORT

Low Energy Adsorption Technology to Remove Contaminants from Source Water

Demonstration and Evaluation of a Single-use Low Energy Adsorption Process for Arsenic Removal from Groundwater

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PREPARED BY:

Primary Author:
Jinjian Wu and Joon H. Min

Montrose Environmental Group
1 Park Plaza, Suite 1000, Irvine, Ca 92614
949-988-3500
www.montrose-env.com

Contract Number: EPC-16-006

PREPARED FOR:
California Energy Commission

Kevin Mori
Project Manager

Virginia Lew
Manager
Energy Efficiency Research Office

Jonah Steinbuck, Ph.D.
Deputy Director
ENERGY RESEARCH AND DEVELOPMENT DIVISION

Drew Bohan
Executive Director

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PREFACE

The California Energy Commission's Energy Research and Development Division supports energy research and development programs to spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

In 2012, the Electric Program Investment Charge (EPIC) was established by the California Public Utilities Commission to fund public investments in research to create and advance new energy solutions, foster regional innovation and bring ideas from the lab to the marketplace. The California Energy Commission and the state's three largest investor-owned utilities—Pacific Gas and Electric Company, San Diego Gas & Electric Company and Southern California Edison Company—were selected to administer the EPIC funds and advance novel technologies, tools, and strategies that provide benefits to their electric ratepayers.

The Energy Commission is committed to ensuring public participation in its research and development programs that promote greater reliability, lower costs, and increase safety for the California electric ratepayer and include:

- Providing societal benefits.
- Reducing greenhouse gas emission in the electricity sector at the lowest possible cost.
- Supporting California's loading order to meet energy needs first with energy efficiency and demand response, next with renewable energy (distributed generation and utility scale), and finally with clean, conventional electricity supply.
- Supporting low-emission vehicles and transportation.
- Providing economic development.
- Using ratepayer funds efficiently.

"Low Energy Adsorption Technology to Remove Contaminants from Source Water" is the final report for the "Low Energy, Zero Liquid Discharge Adsorption Technology to Remove Contaminants and Recover Source Water" project (EPC-16-006) conducted by ES Engineering LLC. The information from this project contributes to the Energy Research and Development Division's EPIC Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's research website (www.energy.ca.gov/research/) or contact the Energy Commission at 916-327-1551.

ABSTRACT

California faces severe water resource challenges while simultaneously enforcing some of the most stringent and comprehensive water regulations in the United States and around the world. Some 7,600 wells statewide are contaminated, limiting valuable water resources during drought conditions. Contamination treatment and control are often costly and energy consuming. To ensure the health of communities and continued provision of safe drinking water and to prevent well closure, water utilities, municipalities, and engineers must adopt a more energy- and water-efficient strategy to remove contamination, which will, in turn, help to optimize California's energy structure and reach the state's energy goals.

The project demonstrated and evaluated a single-use, low-energy adsorption process to remove arsenic, a naturally occurring contaminant, from water. Removal of trace level contaminants such as arsenic is usually cost and energy intensive. The treatment process evaluated used an adsorption media that can effectively take up arsenic, operates under low pressure (low energy), and can be handled and disposed of once saturated. A pilot system installed at the host site operated for approximately 24 months. Water quality parameters and energy data were recorded. The data showed that the system treated on average 1.2 million gallons of water per month during the project. The system treated the source water (with arsenic concentration up to 88 micrograms per liter) to below the regulatory discharge limit (10 micrograms per liter) despite other contaminations in the water. Energy data showed that the system had an energy consumption of about 1.09 kilowatt-hours per 1,000 gallons treated. Compared with data from other treatment processes such as coagulation filtration and reverse osmosis processes, the system could achieve an energy savings between approximately 22 percent and 83 percent.

Keywords: *Arsenic Treatment, Groundwater Treatment, Adsorption Process, Single-use, Low Energy,*

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Introduction

More than 7,600 wells statewide have been contaminated, limiting the use of these valuable resources during drought conditions. Most contaminants are naturally occurring from the soil and rock underground, which makes treatment and control difficult due to the widespread nature of the contamination. Treatment and control are often costly and energy consuming, shouldered in part by ratepayers. To ensure the health of communities and continued provision of safe drinking water and to prevent well closure, high cost, energy-intensive treatment processes have to be implemented when there are multiple contaminants or the flowrate/concentration of the contaminant is high. By exploring new and more efficient technologies that have the potential to address the emerging contaminant issues of California's water resources, this project can help engineering companies, water utilities, and municipalities expand their treatment options and adapt to a more energy- and water-efficient strategy, and in turn, help to optimize California's energy structure.

Water treatment and removal of emerging micro-pollutants are and will increasingly be a significant energy consumption segment of California's energy infrastructure. Emerging contaminants usually occur in trace level concentrations (nanograms per liter to microgram per liter levels) while posing significant adverse health effects to the general population at these low levels. Removing these contaminants effectively and efficiently at these low concentrations is challenging. Traditional treatment processes either consume a significant amount of energy to remove the contaminants or have a relatively low recovery rate while generating a large amount of waste stream that subsequently must be disposed of, requiring significant energy.

The water treatment industry is a conservative market that requires extensive validation of a new technology before it is adopted. Through the opportunity of the EPIC program, this project intends to use this support to accelerate the evaluation and adaptation of a water treatment alternative that could effectively remove trace level contaminants from groundwater and other water sources with low energy and water consumption compared with other options.

Project Purpose

The project was conceived to develop a more energy and water-efficient solution to California's water challenges and benefit the water consumers, water utilities, as well as ratepayers. It demonstrated and evaluated a single-use, low-energy adsorption process to remove contaminants from source water and examined and compared system performance data and energy consumption data with conventional treatment processes. and around the world. A report analyzing recorded data was intended to provide an overall evaluation of the treatment efficacy and the energy efficiency of the treatment process and serve as a reference to potential future water treatment solution providers as well as water utility decision makers.

Project Approach

The project was carried out by researchers and engineers at ES Engineering, LLC, now named Montrose Water and Sustainability Services, a subsidiary of Montrose Environmental, Inc., in collaboration with the City of Cerritos, which hosted the project. The project evaluated a single-use, low-energy water treatment technology via a 24-month pilot of testing and monitoring of groundwater with multiple contaminants. The project team designed the pilot treatment system with feedback from internal and external advisory members and technical staff from the host city. The team then fabricated, constructed, installed, and operated the pilot system on site. A state-certified energy manager recorded and evaluated the influent and effluent water quality, energy consumption, and other performance parameters to assess the system's contaminant removal efficacy, energy savings, and operational reliability.

Significant water quality challenges emerged at the host site, including the discovery that the water source, initially considered a groundwater source, had several connected pipes that introduced unplanned solids and oil and grease into the source water. Furthermore, some water quality parameters, including arsenic, manganese, and phosphate, were found to be significantly higher during project operation than the initially determined design levels.

The project team worked closely with the host site and implemented several measures to effectively mitigate the challenges, installing additional storm drain filters and basket strainers, modifying pre-filter configurations of the system, and changing the operation and maintenance schedule of the system to adapt to the water quality changes.

Project Results

The project team successfully completed the operation, monitoring, and evaluation of the performance of the treatment system in removing trace level contaminants from the source water at the host site. System operating parameters (such as water flow, pressure), water quality parameters (for example contaminant concentrations, potential hydrogen and chlorine levels), and energy consumption data were collected to evaluate the performance of the system.

The results showed that the treatment system was able to effectively remove the main contaminant, namely arsenic, from an average source level of approximately 60 micrograms per liter to less than 10 micrograms per liter. The treatment system operated for 24 months and treated on average 1.2 million gallons of water a month. The treatment media had an adsorption capacity for arsenic at approximately 60 grams per cubic foot of media, with a change-out life cycle period of 3 months to 4.5 months depending on the concentration of competing water quality, including phosphate and arsenic speciation as well as manganese level. However, these averages were based on changes made as a function of the water quality challenges mentioned previously; actual predictions for the removal capacity and life cycle of the media are expected to be longer under a more typical source water condition. In fact, based on collected data and calculations from the reports prepared by the certified energy manager, projections are that the single-use adsorption system will have a 22 percent lower energy consumption per volume of water treated compared with a conventional arsenic treatment process (coagulation filtration) and an 88 percent lower energy consumption compared with the more energy-intensive reverse osmosis treatment process

Technology/Knowledge Transfer/Market Adoption (Advancing the Research to Market)

The project team engaged with stakeholders and regulators, as well as the general public to spread the knowledge regarding the low-energy treatment process tested for this project. The team worked closely with Cerritos' water service manager, city engineer, and director of public works during the project. While receiving their feedback regarding the design, operation, and monitoring of the treatment system, the team also communicated the knowledge of the technology with the city through frequent meetings, technical discussions, and presentations. Regulators from the Los Angeles Regional Water Quality Control Board conducted site visits, and the project team hosted a technical meeting with presentations to discuss the technology. The Los Angeles team provided valuable feedback to improve the design for future adaptations and operation for regional and state-level regulatory compliance.

At a local level, a small-scale demonstration model of the water treatment system was displayed at the public library located at the Cerritos Civic Center near the project area. The model display was intended to promote the knowledge of groundwater water resources, naturally occurring contamination, and cost-effective treatment technology to the general public and students to increase their awareness of water issues and technical solutions. Since the library is located across the Cerritos High School and visited by many students interested in science, technology, engineering, and math, the display helped disseminate the project information to interested groups. Due to the shutdowns during the COVID breakout, planned knowledge transfer workshops and other activities and some wrap-up plans were limited.

The near-term targeted intention for the technology is the treatment of contaminated groundwater sources. The source waters are usually point sources and groundwater wells, with a relatively more defined flow capacity and comparatively fewer challenging water qualities than those faced in this project. The main water quality issues to be addressed are the trace level contaminants, including arsenic, chromium, selenium, and others, that have been effectively removed by the adsorption media and the treatment sysPem. public utility and regulators were closely engaged to help promote the near-term market adaptation of the technology.

For the mid to long term, the technology also has potential in groundwater and surface remediation for other oxyanion contaminants, but particularly selenium. Due to the high efficacy and low energy requirement of the treatment media, potential passive adsorption treatment devices can be designed for these applications, which are usually area sources (surface water or groundwater seepage) with more challenging water qualities. Initial engagement and discussions have been carried out with potential stakeholders, including the Orange County area and the Salton Sea area, which are known to face significant selenium challenges in their groundwater and surface water sources. However, the adaptation in those cases requires additional design, evaluation, and testing efforts specifically tailored to the water source conditions.

Benefits to California

The proposed project will provide important benefits to California ratepayers by reducing the energy demand associated with the treatment of groundwater and runoff water contaminated by emerging contaminants. The typical treatment system for such contaminants relies on a chemical-based system, which requires a number of steps involving chemical addition using injection pumps, promoting reactions with chemicals using a mechanical mixer, separating precipitated insoluble flocs formed from the process using filtration with regular backwashing relying on backwash pump, dewatering solids from the backwash process using a mechanical press, which all require additional energy to meet the treated water quality. Other treatment systems, such as reverse osmosis membranes require even more energy due to the high-pressure pumping required and management or treatment of waste concentrate.

The demonstration project using adsorption media eliminates a number of these steps resulting in a reduced need for new electricity production infrastructure for such systems and avoiding cost increases for ratepayers for treating contaminated water sources to comply with regulations.

There are several thousand sites in California where groundwater sources have been shut down due to these types of groundwater contamination, and many of these sites are located in IOU service territory. Therefore, the cumulative energy savings that could be realized through implementation and optimization of such a process with near-zero liquid discharge instead of a highly energy-intensive conventional treatment system for treating these water resources could result in significant energy savings.

As a reference, a coagulation filtration system rated at 250 gpm (30 HP) would require approximately $37,000 per year (at 14 cents per kWh) to operate the system, while the single-use adsorption media system is estimated to require $22,000 of electricity per year based on a 14 cents per kWh rate. For California with more than several thousand wells needing such groundwater treatment and potential system needs (average flow of more than 250 gpm), this would equal savings of $15,000 per site or $75 million per year using the adsorption-based water treatment system instead of chemical-based system.

The proposed type of system could provide a 30 percent reduction in electricity costs over the chemical-based treatment system. The adsorption process is also advantageous by reducing chemical usage and eliminating sludge generation. A comparable system would generate 50 kg/day of sludge or 40,000 lbs. of sludge per year, which requires additional energy to dewater the sludge prior to disposal.

In addition, numerous chemical deliveries for a conventional coagulation system could be avoided using adsorption treatment, reducing about 9,000 grams of CO_2 per gallon of gasoline, resulting in 4.4 metric tons of CO_2 reduction without the estimated chemical delivery. Greenhouse gas (GHG) emissions are generated in the electricity sector by fuel source. These gases include carbon dioxide, methane, nitrous oxide, and sulfur hexafluoride. The changes have negative effects on the environment such as drought, water shortage, desertification, and sea level rise. The energy-saving provided by the demonstrated system reduces GHG and helps to mitigate global warming contribution. With a typical media adsorption system, an estimated 78,720 kWh or equivalent 54.3 metric tons of CO_2 can be reduced.

In addition to the energy savings described, this project will provide benefits to investor-owned utility (IOU) ratepayers by providing safe, local water resources from a simple, low-energy adsorption system. Also, low-energy water treatment could avoid the need for new electricity generation infrastructure, reducing air pollution for residents in IOU territory.

CHAPTER 1:
Introduction

1.1 Water Resource Contamination in California

The shortage and contamination of water resources have been a persistent issue in California. According to the California State Water Resources Control Board's Groundwater Ambient Monitoring and Assessment Program (GeoTracker GAMA), more than 7,600 wells statewide have arsenic levels exceeding the current regulatory limit of 10 micrograms per liter (µg/L). Most of these contaminations are naturally occurring from the soil and rock underground, which makes treatment and control more difficult. To ensure the health and provision of safe drinking water to the community, costly and energy-intensive treatment processes generally must be implemented, or the well site has to be shut down due to contamination.

Water treatment is and will increasingly be a significant energy-consuming segment of California's energy infrastructure, especially for the treatment and removal of emerging micro-pollutants in drinking water sources. Emerging contaminants usually occur in trace level concentrations (nanograms per liter [ng/L] to micrograms per liter [µg/L]) and pose adverse human health effects even at these low levels. Removing these contaminants effectively and efficiently at low concentrations is challenging. Traditional treatment processes either require significant energy to remove these contaminants or have a relatively low recovery, generating a large amount of waste stream in the process that must subsequently be disposed of using what is also an energy-intensive process.

1.2 Energy Consumptions in Water Treatment

To support California's goal to reduce energy consumption related to providing critical infrastructure, such as the water treatment sector, the current project proposed to evaluate a low-energy adsorption process to remove trace contaminants in groundwater. The treatment uses an adsorbent-based process that can selectively remove arsenic and other contaminants from the water. Once its treatment capacity is exhausted, the adsorbent media can be replaced without having to handle and dispose of the sludge and solid waste generated by a chemical-based coagulation filtration system at significant additional cost and consumption of energy.

Currently, several treatment technologies are available to handle metal contaminants such as arsenic found in many groundwater sources. However, drawbacks exist in these alternatives, mainly in terms of their high energy requirement for operation, lower water recoveries, and waste management challenges. Table 1 presents the main energy-consuming components in the treatment process and the typical recovery of the currently available technologies in treating arsenic. Coagulation removes arsenic via precipitation; however, the arsenic is phase transferred from the influent to solid and water-laden sludge stream that is difficult to handle. The ion exchange process is also available to remove arsenic by exchanging the ion from the resin with arsenic. Typical ion exchange systems require a significant amount of brine to re-activate the resins saturated with contaminants on a daily basis. The brine used for such onsite regeneration is both expensive to use and difficult to dispose of. When other contaminants are also present in the feed water, the available option for arsenic treatment is the reverse osmosis membrane process. Reverse osmosis purifies water by separating most of the soluble contaminants, thus removing them, including arsenic, from the water that permeates the membrane. This process generates a relatively large volume of concentrated water that has to be handled (typically 15 percent-25 percent of the feed water). Although it is an effective process for purifying water with multiple contaminants concurrently, the membrane process is energy-intensive and also generates a large volume of waste stream that must either be further treated with additional energy input or discharged.

Table 1: Energy and Process Water Requirement of Different Treatment Technologies

	Energy Requirements		Water Requirements	
Technology	Filtration	Backwash / media replacement	Backwash/ reject rate	Start-up wash water
Coagulation Filtration	- Influent pumping - Chemical injection/pumping - Chemical mixing	- Daily backwash pumping - Daily surface wash pumping - Daily air scouring during backwash - Backwash handling pumping - Daily sludge handling pumping - Daily backwash discharge pumping	- 5 to ~10% - Daily backwash to remove solids retained by filter media	- Start-up rinse water to wash out fine media due to attrition
Media Adsorption (single use)	- Influent pumping - Chemical injection for some application	- No daily backwashing - Some granular media requires fluffing (mini backwashing) - Spent media disposal handling pumping	0%	- Start-up rinse water to wash out fine media due to attrition for some media
Conventional Ion Exchange (regenerable)	- Influent pumping - Chemical injection for some application	- Daily high-salinity brine pumping to regenerate the resin - Daily waste brine transfer pumping for transportation of brine for disposal - Salt delivery pneumatic pumping to a storage tank on a regular basis	- ~ 5 % - Daily regeneration with high salt water and rinse cycle	- Start-up rinse water to wash out fine media due to attrition
Membrane (RO)	- High pressure influent pumping - Inter-stage pumping	- Reject stream pumping - Evaporation to dispose of concentrate for inland site	- 15 to ~25 % - Continuous reject stream due to RO recovery	- Membrane conditioning water - Regular membrane

Technology	Energy Requirements		Water Requirements	
	Filtration	Backwash / media replacement	Backwash/ reject rate	Start-up wash water
				cleaning water

Source: Adapted from Jensen et al, 2012.

Comparatively, the proposed treatment process effectively addresses the two shortcomings of traditional treatment processes. First, it is a low-energy process, using only a feed pump as the main driver. Second, handling waste from the process is much easier as the process does not generate daily waste or sludge streams.

1.3 Project Objectives

The water treatment market is a conservative market that must have extensive validation of a new technology before that technology is adopted. This project evaluated the performance of the proposed adsorption process to validate its effectiveness and efficiency, facilitate its application, and support California's overall energy goal. The project evaluated:

- The performance of the treatment system to remove arsenic from the source water.
- The capacity of the adsorption media to remove arsenic from the source water.
- The energy consumption of the treatment system to remove arsenic from the source water.
- The ability of the treatment system to withstand different challenging operating conditions.

CHAPTER 2: Project Approach

The project demonstrated a low-energy water treatment system using an adsorption process to remove arsenic from a groundwater source. A pilot demonstration system was installed at the host site in the City of Cerritos to treat the source water, which was primarily groundwater but with local runoff water as well. The treatment system was operated for approximately 24 months, and performance parameters, such as flow rates, energy consumption, and selected water quality parameters were measured. The arsenic removal performance, energy usage, and challenge testing of the proposed single-use adsorption system for emerging water contaminants treatment were conducted and evaluated.

2.1 The Host Site and Water Quality

2.1.1 Host Site

The host site for the demonstration was chosen at a groundwater source in Cerritos, California. The groundwater source is a dewatering cistern at the Cerritos Civic Center underground parking structure third (bottom) floor underground located at 18125 Bloomfield Avenue.

During the design phase of the underground parking structure, engineers anticipated that groundwater intrusion was likely due to the high perched water table levels in the area according to data provided by the host site. As a result, the city installed a dewatering system as part of the original parking structure design to prevent the seepage of groundwater from damaging the integrity of the building structure. Perforated tubes were placed in the aquifer around the parking structure to drain the groundwater and lower the groundwater table. The drained groundwater is channeled into the dewatering cistern and pumped out and discharged into a storm drain that flows into the Coyote Creek discharge point (M-001, latitude 33° 15′ 03″, longitude 118° 03′ 18″) under a discharge permit from the Los Angeles Regional Water Quality Control Board (Los Angeles Water Board). The groundwater flow to the cistern fluctuates seasonally. The city indicated an average flow rate of 50 gallons per minute (GPM) as the base flow condition.

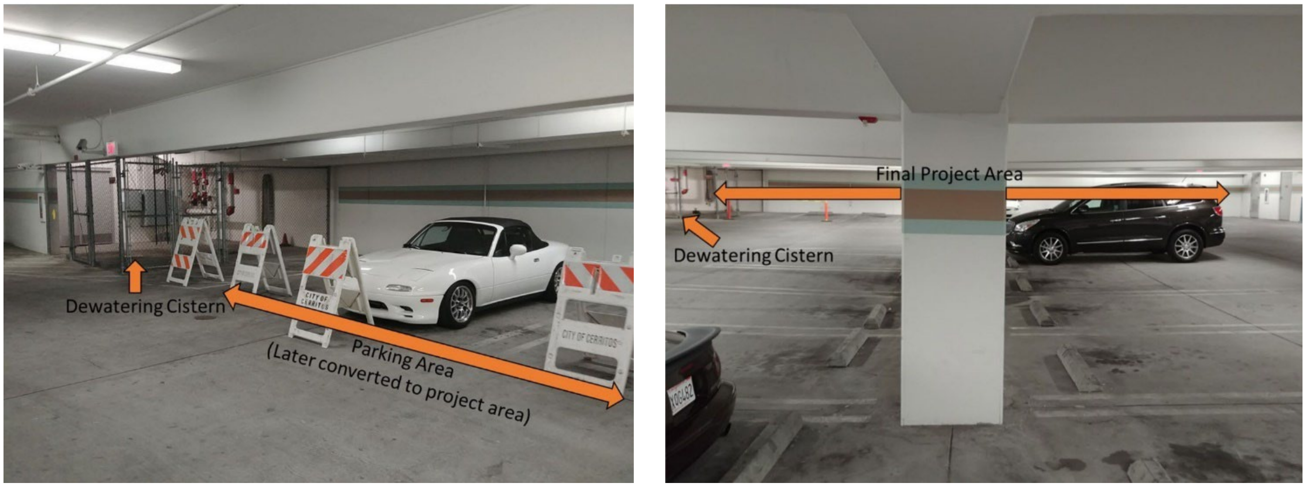
The dewatering cistern that collects the seepage groundwater is approximately 20 feet deep from the floor of the lowest level of the parking structure to the bottom of the cistern. The cistern is circular with an inner diameter of 72 inches and a precast concrete wall thickness of 7 inches. At the top of the cistern, a set of rectangular aluminum duplex hatch covers (with a dimension of 36″ × 44″ for each cover) provides access to the sump. The city installed two submersible pumps (one duty, one standby) at the bottom to pump the water out of the cistern to the discharge pipe. The submersible pumps operate on an ultrasonic level sensor, which triggers and turns on the pump when the groundwater level in the cistern reaches a certain high point and turns off the pump when the water level falls back below a certain low point. Figure 1 shows the dewatering cistern at the project site.

Figure 1: Dewatering Cistern at the Project Site

Source: ___

The dewatering cistern is located on the second subterranean level (third floor underground) of the city's Civic Center parking structure, at the northeastern corner of the parking floor. Outside the dewatering cistern area are the parking area and vehicle driveways. After discussion and negotiation with the city, an area approximately 80 feet by 15 feet along the eastern wall of the bottom floor of parking structure outside of the dewatering cistern was allotted as the project area for installation of the treatment system and related auxiliary systems. Additional space was needed to operate the facility and provide additional storage of equipment. Figure 2 presents the project area at the parking structure.

Figure 2: Project Area at the Parking Structure



Source: ___

The Civic Center area where the parking structure is located is in a community center with facilities and public institutions such as the Cerritos Sheriff Station, Cerritos City Hall, and the Cerritos Library, some of which served as platforms for the project's public outreach and stakeholder engagement activities.

2.1.2 Water Quality

In the first quarter of 2012, the Los Angeles Water Board indicated that the quality of the groundwater discharged from the dewatering cistern did not meet allowable standards and would require treatment. As a part of the permit compliance, Cerritos conducted monthly sampling and quarterly reporting of the groundwater quality. [Deleted Table] summarizes the groundwater quality parameters from March to June of 2015, and was provided by the city as the water quality basis for the source water to be treated. Also included in [Deleted Table] are the discharge limits as indicated in the Los Angeles Water Board permit. There are also additional discharge limits for copper, lead, and zinc based on the San Gabriel River and impaired tributaries (Coyote Creek) metal total maximum daily load (TMDL) effluent limitations, as summarized in [Deleted Table].

Based on the water quality data, it can be seen that arsenic is the main parameter of concern for this particular groundwater source. The four source water arsenic concentrations provided have an average of 48.75 µg/L approximately five times that of the daily maximum discharge limit. As such, treatment is required for the city to discharge the water to Coyote Creek to meet the discharge limit.

2.2 Arsenic Treatment System

The treatment process consists of five primary and auxiliary treatment systems, namely 1) the Prefilter System; 2) the Arsenic Adsorption System; 3) Chemical Dosing System; 4) Water Quality and Energy Monitoring System, and; 5) Effluent Holding and Pump System. The main functions and major components of each of the systems are summarized.

2.2.1 The Prefilter System

The prefilter system was designed to remove the large particulate matters from the source water to reduce clogging of the media in the arsenic adsorption vessels. In the initial design, the Prefilter System consisted of a single 105-GPM rated SS304 cartridge filter housing that loads 5 of the 50 micron, 30″ × 2-1/2″ polyester cartridge filters. Later during the operation of the system, the system encountered some water quality challenges including particulate matters, oil & grease, iron and manganese precipitation particles that were not fully treated by the single 50-micron filter and were severely impacting the process downstream. (Details can be found in Section 2.3 Project Challenges). Subsequently, an additional 100-GPM rated SS304 bag filter housing that loads one #2 bag filter (50 micron) was installed upstream of the existing cartridge filter. Additionally, the cartridge filters used were changed from the initial 50-micron polyester filters to 5-micron cotton wound filters. The purposes of the adjustments were to 1) improve the removal of particulate matters and (to a lesser degree) oil and grease to less the fouling and clogging of the downstream process; and, 2) prolong the lifecycle of the filters and reduce the filter changeout frequencies.

The piping connection of the two filter housings was designed such that by adjusting the valves in the pipeline, the operator has the option to 1) operate the two filter housings in series, with the option to use either housing as the lead (first) stage and the other housing as the lag (second) stage; and 2) operate the two vessels in parallel. The purposes of the design were to 1) allow at least one filter housing to be online during filter change-outs to minimize downtime of the system, and; 2) prepare for the cases of high solid loadings of the source water during precipitation weather or irrigation events (as will be explained in more detail in Section 2.3) that introduce high solids to the sump where the feed water is pumped from.

Table 2 summarizes the valving configurations for the corresponding flow modes, as well as for isolating and bringing certain filter housing offline for maintenance and filter change out. Figure 3 presents the piping connection configuration of the bag and cartridge filter housings, as well as the different lead/lag/parallel flow modes. Figure 4 presents the pictures of the bag and cartridge filter housing installed at the project site.

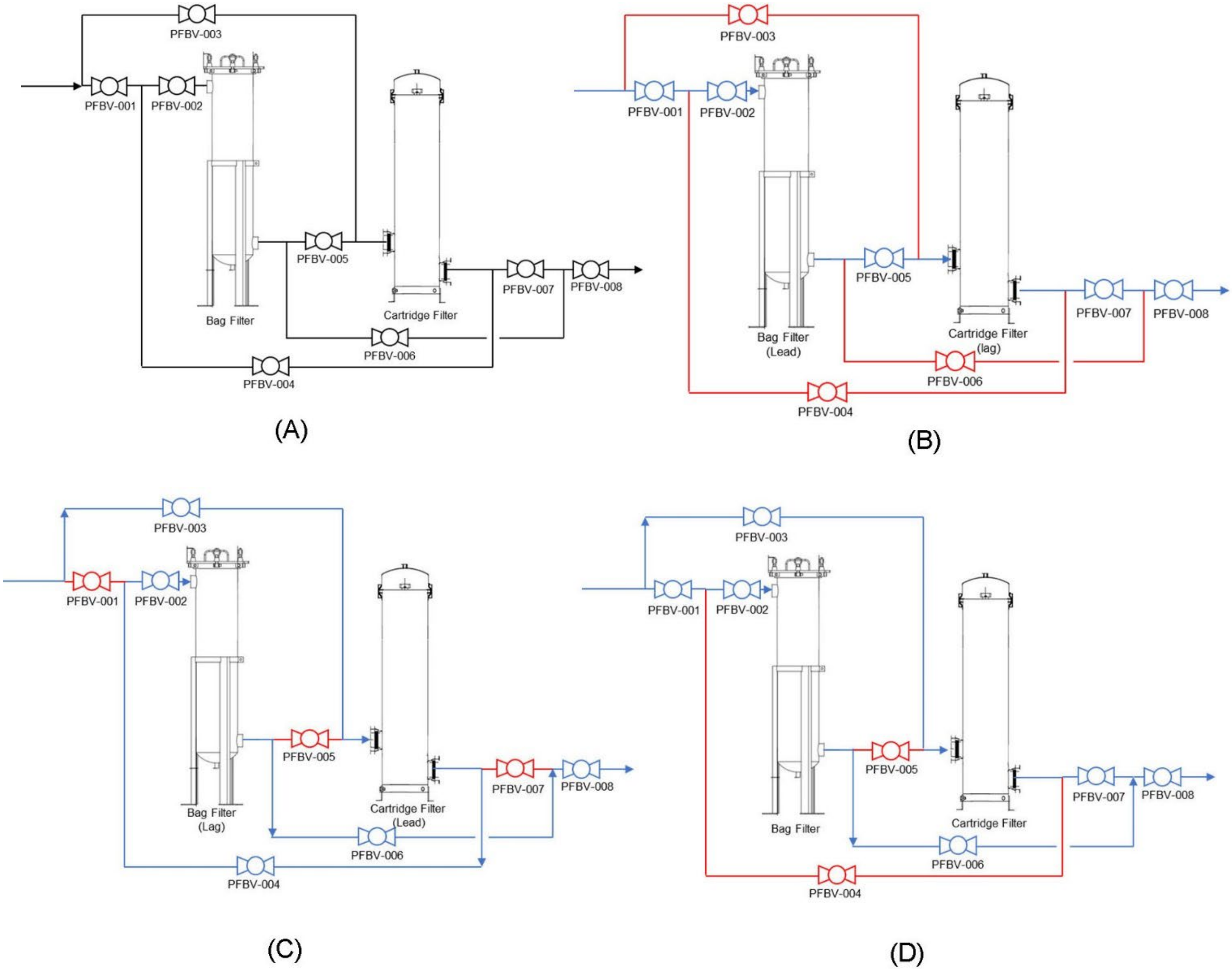
Table 2: Valving Configurations and Flow Modes of the Prefilter System

	Operation			Maintenance (Filter change-outs)	
Valve number	Lead(Bf) – Lag(Cf)	Lead(Cf) – Lag(Bf)	Parallel	Bf-off; Cf-on	Bf-on; Cf-off
PFBV-001	O	C	O	O	O
PFBV-002	O	O	O	C	O
PFBV-003	C	O	O	O	C
PFBV-004	C	O	C	C	C
PFBV-005	O	C	C	C	C
PFBV-006	C	O	O	C	O
PFBV-007	O	C	O	O	C
PFBV-008	O	O	O	O	O

Abbreviations: Bf - Bag Filter; Cf - Cartridge Filter; O – valve open; C – valve close

Source: ___

Figure 3: Configuration of the System



(A) Piping Configuration of the Prefilter System and (B) Lead (bag filter) – Lag (cartridge filter); (C) Lead (cartridge filter) – lag (bag filter); (D) parallel Operation Modes of the Prefilter System (Blue lines: flow paths; Red lines: no flow)

Source: ___

Figure 4: The Dual Prefilters at the Project Site

Source: ___

2.2.2 The Arsenic Adsorption System

2.2.1 Arsenic Adsorption Vessels

A dual-skid, eight-vessel treatment system was designed to remove arsenic from the source water at the project site. Each skid contains four treatment vessels. The four treatment vessels are designed to operate with two vessels in parallel, in lead-lag mode (i.e., two parallel vessels in series). The two skids are designed for 100 percent redundancy and to allow special configuration testing for the project and are not normally designed in such configuration. The piping and valving connections for the vessels and the skids are configured in such a way that allows different flow modes through the treatment system, as presented in detail in Table 3. Figure 5 presents the piping configuration of the Arsenic Adsorption System. An example flow mode is also presented to illustrate the flow path of bypassing Skid 1 and operating Skid 2 in Lead(F-B1/B2)-Lag(F-B2/B4) mode.

Table 3: Valving Configurations and Flow Modes of the Arsenic Adsorption Vessels

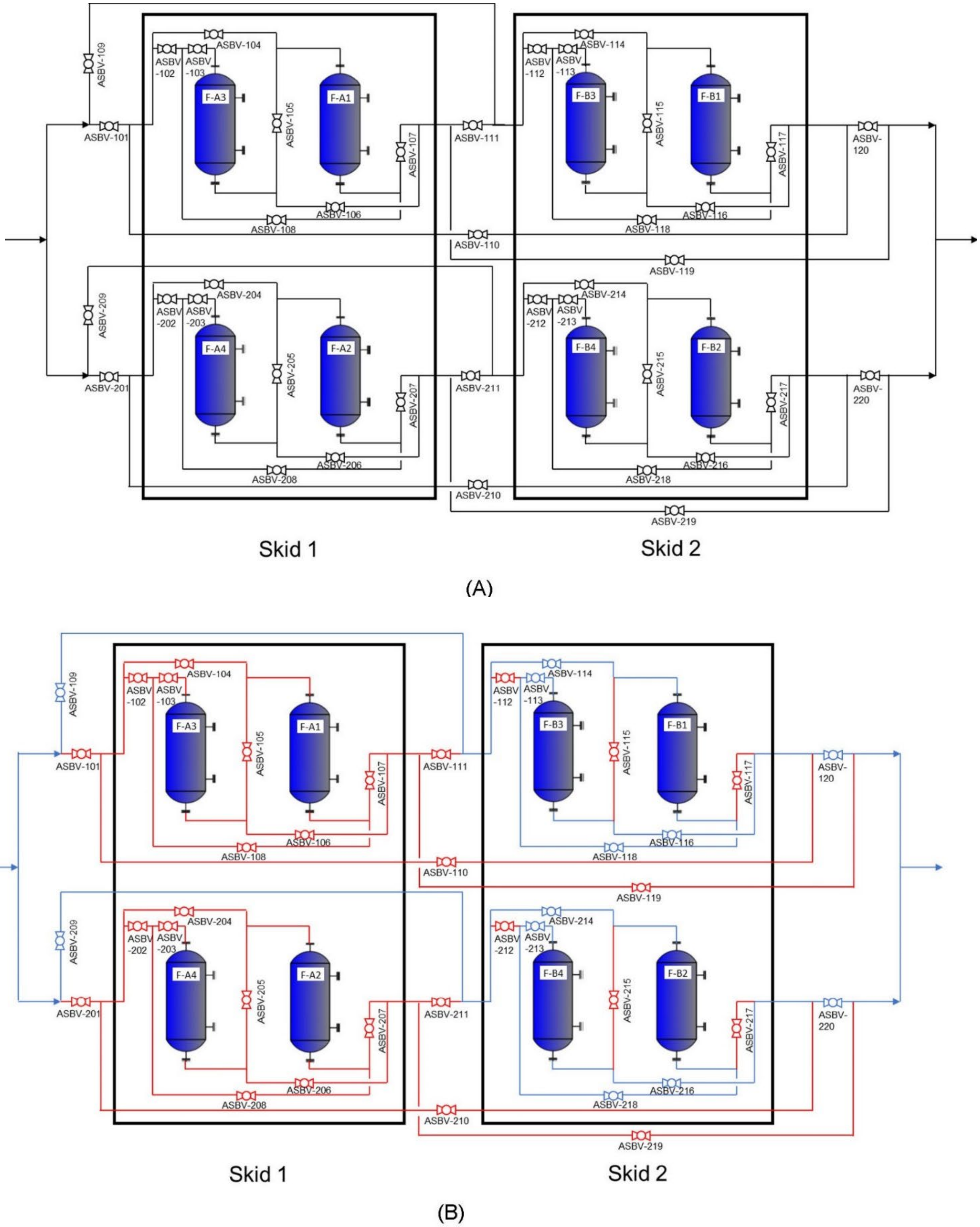
Position	Valve Number	Skid 1 bypass		Skid 2 bypass	
		Lead(F-3)-Lag(F-4)	Lead(F-4)-Lag(F-3)	Lead(F-1)-Lag(F-2)	Lead(F-2)-Lag(F-1)
Inter-connection	ASBV-01	C		O	

Position	Valve Number	Skid 1 bypass		Skid 2 bypass	
		Lead(F-3)-Lag(F-4)	Lead(F-4)-Lag(F-3)	Lead(F-1)-Lag(F-2)	Lead(F-2)-Lag(F-1)
Skid 1	ASBV-02	C		O	C
	ASBV-03			O	O
	ASBV-04			C	O
	ASBV-05			O	C
	ASBV-06			C	O
	ASBV-07			O	C
	ASBV-08			C	O
Inter-connection	ASBV-09	O		C	
	ASBV-10	C		C	
	ASBV-11	C		C	
Skid 2	ASBV-12	O	C	C	
	ASBV-13	O	O		
	ASBV-14	C	O		
	ASBV-15	O	C		
	ASBV-16	C	O		
	ASBV-17	O	C		
	ASBV-18	C	O		
Inter-connection	ASBV-19	C		O	
	ASBV-20	O		C	

Valving positions are shown for one pair of the vessels only (F-A or F-B). The valving positions can be mirrored for the other pair of vessels. The system is capable of more flow variations, including lead-intermediate-lag and short-term single (pair of) vessel operation during vessel maintenance. Detailed valving configurations for all flow options are not listed in detail here.

Source: ___

Figure 5: Piping Configuration of the Arsenic Adsorption System



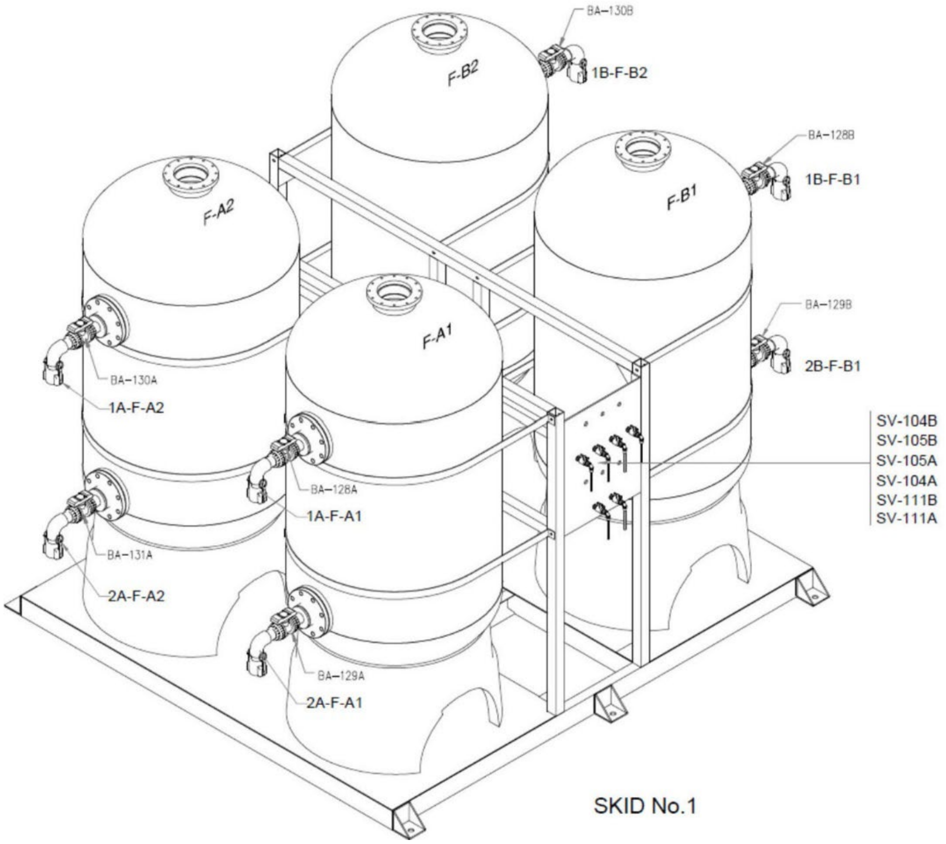
(A) Piping Configuration of the Arsenic Adsorption System and (B) an Example Flow Mode of Bypassing Skid 1 and Operating Skid 2 in Lead(F-B1/B2)-Lag(F-B2/B4) mode. (Blue lines: flow paths; Red lines: no flow)

Source: ___

Each arsenic adsorption vessel is 32″ in diameter × 72″ in height. The cylindrical height of the vessel is 46″. The media loading capacity of each vessel is approximately 22 cubic feet or 165 gallons. This translates to an empty bed contact time (EBCT) of approximately 6.6 min for a pair of parallel vessels receiving an incoming flow of 50 GPM.

The main body of the vessel is made of fiberglass, with a maximum pressure rating of 150 psi. Flow enters the top of the vessel and exits from the bottom of the vessel. Both the top inlet and bottom outlet connection is a 6″ × 6″ flange for a 1-1/2″ piping connection. Inside of the vessel, the top flow distributor is a 3″ 316SS slotted nozzle, and the bottom distributor is a 316SS 3″ hub with six slotted filter nozzles connected at roughly 45° angle. On the side of the vessel, there are two side ports located at 30-7/8″ and 66-3/4″ from the bottom of the skid. The side ports are connected with 6″ × 6″ flanges with 1-1/2″ piping and ball valves at the end. The side ports can be used during vessel draining, media removal, vessel cleaning, and vessel inspection. Due to the low ceiling height of the project location in the parking structure, access to the vessels from the top of the vessels is limited. Six sampling valves are installed on each skid to allow sample collection from different flow streams, namely the feed, the lead effluent, and the lag effluent of each pair of the vessels. An isometric view of Skid 1 and its four vessels is presented in Figure 6 as an example. Figure 7 shows the pictures of the installed vessels as seen from inside and outside of the project area.

Figure 6: Isometric View of the Skid 1 and the Four Vessels



Source: ___

Figure 7: Installed Arsenic Treatment Vessels

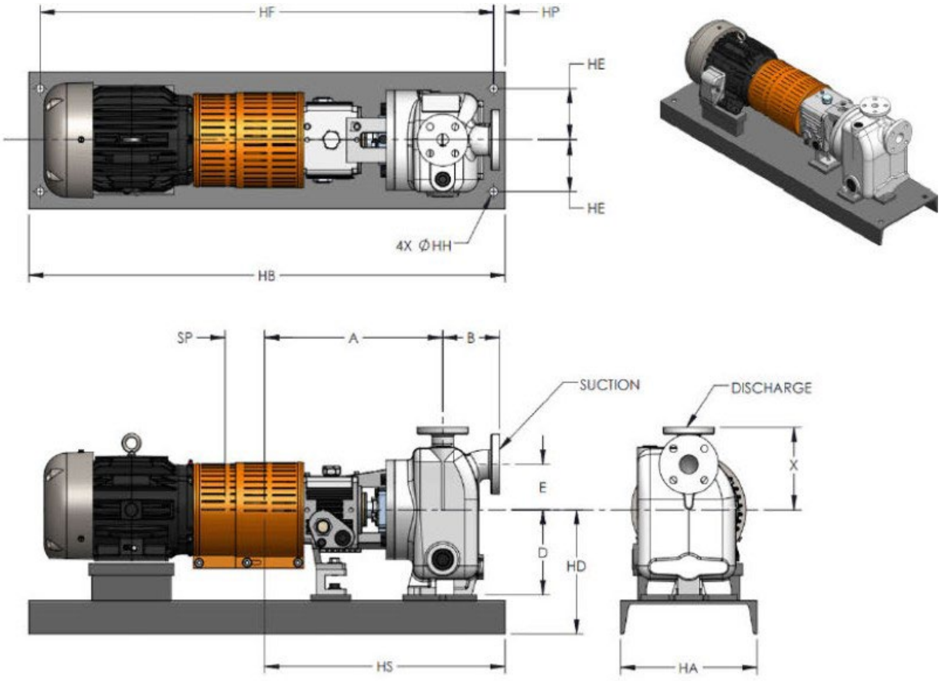
Inside and outside the project area.

Source: ___

Feed Pump

A horizontal self-priming process pump PWA-SP from Pumpworks is used as a feed pump to deliver influent water to the arsenic adsorption vessels. The pump has a 50 gpm capacity at 187 ft of head (~57 m), and a power rating of 15 hp (11.19 kW). Both the casing and the impeller are made of carbon steel ASTM A216, and the shaft is made of 316L SS. Figure 8 presents the pump dimensions and the isometric view.

Figure 8: Feed Pump Dimensions and Isometric View



Dimensions in inches (mm)

HA	HB	HD	HE	HF	HH	HP	HS	A	B	C	D	E	SP	X
18.00	52.00	12.08	7.50	49.50	0.75	1.25	20.50	15.50	5.00	0.00	7.50	4.00	3.75	7.88

Source: ___

The feed pump is installed on the floor near the dewatering cistern on a metal plate leveled and grouted with cement. The influent piping to the pump extends downwards into the dewatering cistern at approximately 2 ft from the bottom. A pump suction screen with an approximate opening of ~1mm was installed at the pipe intake to prevent large debris from entering and damaging the pump. A check valve is installed downstream of the pump. A 1/8" ball valve is also installed near the discharge side of the pump to serve as the vent a sampling port.

The pump operates based on the water level in the cistern. The treatment system receives the signal from the ultrasonic level sensor installed in the dewatering cistern (as described in Section 2.1.1). A 4-20 mA signal line is split from the control panel from the City to the control panel of the treatment system. The system uses a VFD (variable frequency drive) controlled by a PID (proportional-integral-derivative) controller that adjusts the pump rate of the feed pump to maintain the water level at the designated set point. The setpoint is adjustable; a set point of 22% of the total depth, or approximately 4 ft from the bottom, is most often used during system operation. The feed pump operates at a higher rate, up to a set maximum (usually set at 90% of maximum pump capacity), when the water level exceeds the set point; correspondingly the feed pump operates at a lower rate (down to 0%) when the water level falls below the set point.

Feed Flow Rate and Pressure Meters

Both a flow meter/transmitter and a pressure meter/transmitter were installed at the feed pipe to monitor the feed flow rate and pressure. The flow meter installed was an ABB WaterMaster FEW315 electromagnetic flowmeter (DN 50, SS316 electrodes, PTFE liner). The pressure meter installed was an Ashcroft GC517F0242CD100#G (0 – 100 psi, 1/2" connection, SS316 wetted material). Both meters were connected to the system's PLC via 4-20 mA signal connections and the readings were recorded every minute.

2.2.3 Chemical Dosing System

As was discussed in Section 2.1.2, in order to achieve satisfactory removal of arsenic, sodium hypochlorite was dosed to convert all of the As(III) in the source water to As(V) so they can be adsorbed by the media. A bench test was carried out to determine the sodium hypochlorite dosage needed to convert the As(III). Briefly, a series of source water samples with a predetermined volume were dosed with different concentrations of sodium hypochlorite to achieve different total chlorine concentrations (0.1, 0.5, 1.0, 2.0, and 5.0 ppm). As(III) and As(V) concentrations before and after the oxidation were measured. It was determined that a chlorine dosage of 1.0 ppm was able to achieve the complete As(III) oxidation in the source water. This was chosen as the chlorine dosage set point during system operation.

In addition, dosing of an acid, namely hydrochloric acid, was also implemented to control the pH of the feed water to neutral to slightly acidic levels (6.5 – 7.0). At a higher pH level, the arsenate adsorption is not as efficient compared with a lower pH at a neutral range. By adjusting the pH, the system optimizes the treatment efficiency and prolongs the lifetime of the media, resulting in the lower operating cost in media replacement and the energy required to replace the media from the vessel. The sodium hypochlorite and hydrochloric acid were injected via two 1/4″ ports on the feed water pipe with static mixers upstream of the pretreatment filters. On the effluent side of the arsenic adsorption system, a reductant, namely sodium metabisulfite, was dosed to neutralize potential residual chlorine that may be leaving the system from the sodium hypochlorite addition. It was injected via an injection port on the effluent discharge pipe prior to the discharge of the treated water to the parking garage's storm drain piping.

Chemicals are injected using Pulsatron LPB4MA diaphragm pumps. They have a maximum capacity of 1 GPH and a maximum pressure of 100 psi. The pumps have a maximum power load of 0.3 kW, and an adjustable flow rate with a turndown ratio of 1/100. The chemical injection was controlled by the pH and total chlorine levels in the water, as measured by the online pH and chlorine sensors (details in Section 2.2.4). The feed water chlorine level set point was 1.0 ppm, and the pH level set point was 7.0. The effluent water chlorine set point was 0.05 ppm. The diaphragm pumps adjust their pumping rates based on the chlorine and pH readings by the online sensors to maintain them close to the setpoint levels.

2.2.4 Water Quality and Energy Monitoring System

Four online water quality sensors/analyzers were initially installed in the treatment system. The sensors include 1) feedwater total chlorine sensor, 2) feedwater pH sensor, 3) effluent total chlorine sensor, and 4) effluent arsenic sensor. After approximately one year of operation, there were issues with the arsenic sensor due to the water quality challenges (details in Section 2.3 Project Challenges), the sensor was subsequently brought offline for the remainder of the project.

Chlorine and pH Monitoring

A Hach CLT-10 Total Chlorine Analyzer with a combination pH Sensor was used to provide both the feedwater total chlorine and pH monitoring. A Hach CLT-10 Analyzer without pH sensor was used for the effluent water total chlorine monitoring. The CLT-10 analyzers have flow chambers where the sensors are installed. Water sample flows through the flow chambers and the total chlorine and/or pH are measured by the sensors. The feed CLT-10 analyzer flow chambers were connected to a 1/4″ sample port downstream of the pretreatment cartridge filters from where feed water after chemical dosing is introduced into the flow chamber. The effluent CLT-10 analyzer flow chamber was connected to a 1/4″ sample port at the effluent discharge pipe approximately 5′ downstream of the chemical injection point.

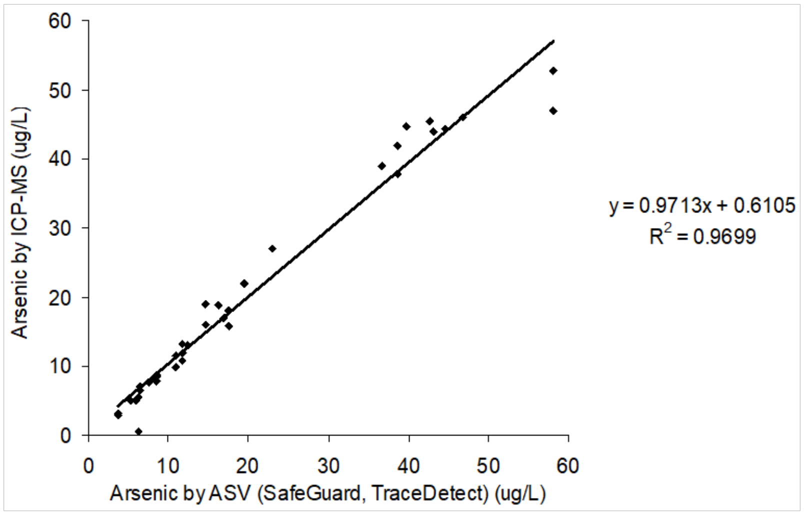
Each of the CLT-10 analyzers was equipped with a Hach SC200 controller for local controls as well as a connection to the treatment system's PLC. The analyzer readings were automatically logged by the PLC system every minute via 4-20 mA signal connections.

Effluent Arsenic Monitoring

The arsenic sensor used was a SAFEGUARD II Trace Metals Analyzer from Aqua Metrology Systems (AMS). The analyzer utilizes the Anodic Stripping Voltammetry (ASV) method to measure trace metal concentration in the aqueous phase. ASV is a voltammetry method for the quantitative determination of specific ionic species (Copeland & Skogerboe, 1974). The analyte of interest is electroplated on the working electrode during a deposition step, and then the electrode measures the current as the deposited analyte is oxidized during a stripping step. Specific analytes have specific current signals that will be registered as a peak at which the species begins to be oxidized. The peak position and peak area can then be used to determine and quantify the specific analyte.

Previously, the commercial ASV-based analyzer provided measurements that corresponded well with the standard method of 200.8 analyses, as shown in Figure 9. At lower concentrations, the correlation of this instrument was high, and even at higher concentrations, above 40 µg/L, the results differed only slightly from 200.8, where the variation was within a range of 5 percent (Min, et al., 2007). The analyzer was chosen as an effective tool to obtain relatively fast, onsite monitoring capability to the system's treatment performance for arsenic removal. The analyzer can generate a measurement result in approximately 45 minutes. Comparatively, a grab sample analyzed in a certified laboratory has a standard turnaround time of 5 – 10 business days, with the quickest expedited turnaround time of 1 – 3 business days.

Figure 9: Correlation of Analytical Results from Safeguard Instrument



Including a certified lab (MWH Lab) using ICP-MS. (Min, et al., 2007)

Source: ___

The SAFEGUARD II analyzer provided onsite water quality monitoring during the first year (with occasional downtimes and maintenances). After about one year, the reference electrode and sensor kept failing for undetermined reasons. AMS assisted with both remote and online troubleshooting initially. After the issue persisted for a couple of months, the analyzer was brought offline due to the budget constraints for the service and parts needed to fix the analyzer.

Energy Monitoring

Energy monitoring was conducted by a third-party certified energy auditor. Energy monitors were installed at the system panel, and these include a high voltage energy monitor (for 480V three-phase outputs, including the feed and effluent pumps), and a low voltage energy monitor (for 110V outputs, including the chemical dosing pumps, and other auxiliary systems such as electrical meters, sensors, etc.). Detailed setup of the energy monitoring system and energy data are included in Appendix A.

2.2.5 Effluent Holding and Pump System

A 1,500-gallon effluent holding tank (Snyder SII-WG46), with seismic restraint, was installed at the site to store the treated water. A vertical effluent pump (Grundfos CRI10-3, 3 hp, SS304 housing & impeller) was used to discharge the effluent from the holding tank to the City's storm drain discharge pipe in the parking garage. An ultrasonic level sensor (Siemens 7ML5221) was installed at the top of the holding tank to monitor the water level in the tank and provide a control signal to the effluent pump. The effluent pump operated on a VFD to maintain the fixed water level set point in the effluent holding tank.

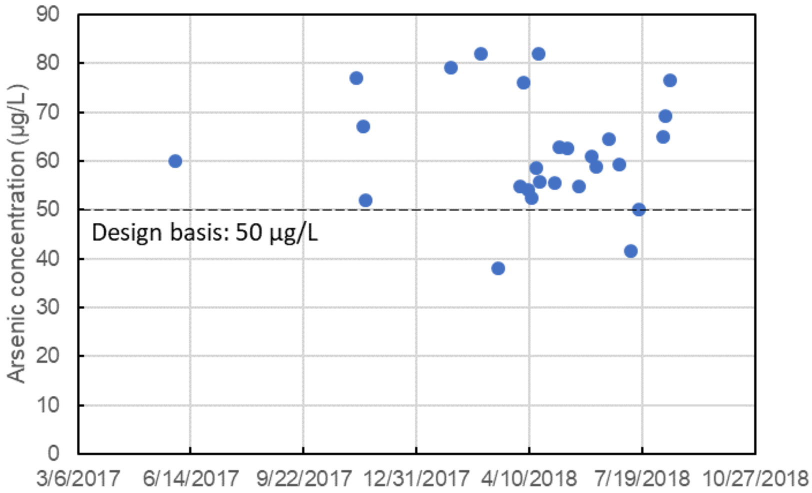
2.3 Project Challenges

The project team conducted a technology assessment and engineering design of the arsenic treatment system based on the water quality data provided by the host site City. After the construction of the treatment system was completed and operation began in January 2018, the treatment system has experienced challenges including water quality factors and site condition factors. Challenges are summarized below, and measures were taken to fully or partially address them in order to continue to evaluate the treatment system.

Arsenic

The arsenic concentrations in the source water were significantly higher than the concentration data provided as the design basis prior to the system design and installation. Figure 10 illustrates the arsenic concentration during the period of the initial operation. It shows that the arsenic concentrations ranged from 38 to 82 µg/L with an average of 62 µg/L. Of the total samples analyzed, 92% of the samples exceeded 50 µg/L arsenic concentration, and 48% of the samples exceeded 60 µg/L.

Figure 10: Arsenic Concentrations in the Source Water During Treatment System Operation



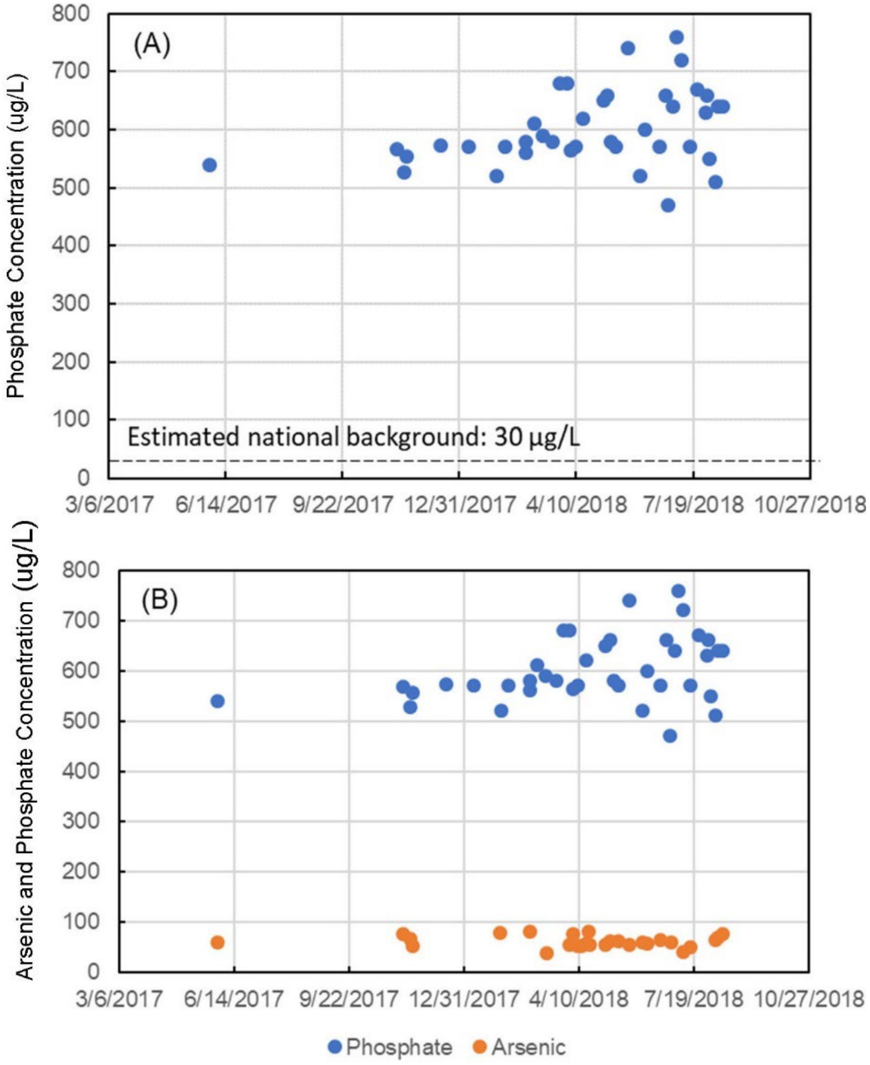
Source: ___

The treatment system was able to remove arsenic to below the compliance requirement level. However, the high concentration will shorten the designed life cycle of the adsorption media and will likely require more frequent media change out resulting in increased material, labor, and maintenance costs.

Phosphate

The source water was also confirmed to contain a high concentration of phosphate after the project start-up. The national background concentration for phosphate in the aquifer, found in 400 shallow wells across the country, is 0.03 mg/L (30 µg/L) according to the US Geological Survey report on groundwater quality (Dubrovsky, et al., 2010) and a high concentration of phosphate is uncharacteristic of typical groundwater. The measured phosphate concentrations in the source water were in the range of 470 to 760 µg/L, 15 to 25 times higher than the national background concentration (Figure 11).

Figure 11: Phosphate Concentration and Comparison in Source Water



(A) Phosphate concentration in source water and comparison with national background level. (B)

Comparison between phosphate and arsenic concentration in source water

Source: ___

Phosphate (PO_4^{3-}) is one of the ions in the oxyanion family, with a chemical resemblance to the dissolved arsenic in the form of arsenate (AsO_4^{3-}). Thus, phosphate competes directly with arsenic for the binding site when being removed by the adsorption media. The concentration of phosphate in the source water is approximately 10 times that of arsenic. As such, it significantly shortens the life cycle of the media and will require more frequent change resulting in the increased compliance cost.

Solids, Turbidity, and Oil and Grease

The water quality was also affected by infusions of various other streams around the project area, via the stormwater conveyance piping connected to the dewatering cistern. Based on the onsite observation and survey, there are a total of 16 stormwater drains around the Civic Center Parking area that collects surface runoffs and convey them into the dewatering cistern. During the heavy rain events in the first week of January 2018, significant changes in water quality were observed and caused severe contamination of the treatment system due to particles, oil and grease, and other debris. As a result, the system was shut down for cleaning and maintenance.

Water parameters, including total suspended solids (TSS) and turbidity, clearly reflected the influence of the infused surface runoff on the source water. Source water samples taken during a rain event from 01/08/2018 to 01/09/2018 have shown a peak TSS vales of 13.7 mg/L, significantly higher than the normal TSS conditions (<5 mg/L). Peak turbidity value was measured at 41 NTU, also significantly higher than those presented in Table 1 (0.45 – 0.59 NTU).

Three oil and grease measurements were carried out during the rain event, and the results were 3.4 mg/L, 1.6 mg/L, and 2.6 mg/L. However, due to the large volume of water processed by the treatment system, this level of oil and grease likely posed severe interference to treatment efficacy over time by coating the internal pipes, as well as adsorption media and blocking the passage of arsenic adsorption. Table 4 presents the comparisons of the above-mentioned parameters during the 2018 rain event.

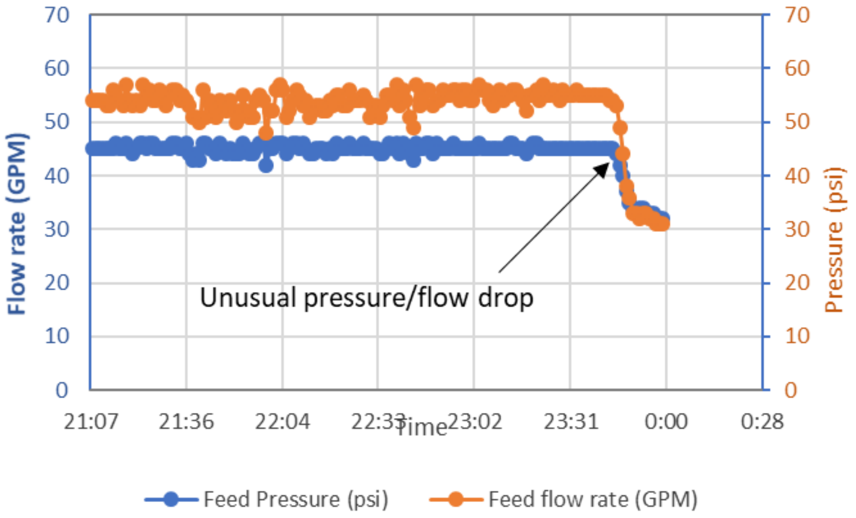
Table 4: TSS, Turbidity and Oil and Grease of Source Water During a Rain Event

Parameters	Units	Peak values during the rain event in January 2018	Design basis provided by the City
TSS	mg/L	13.7	< 5
Turbidity	NTU	41	0.45 – 0.59
Oil and Grease	mg/L	3.41	< 5

Source: ___

In addition, it was discovered that the City's irrigation system near the Civic Center parking area turns on around midnight, and the surface runoffs of the irrigation water carrying the debris, soils, etc. enter the dewatering cistern via the storm drains. The irrigation runoff contains particulate solids that will clog the foot valve screen on the intake piping and affect pump performance. Figure 12 presents an example of the feed flow and Figure 13 depicts the pressure curve of the feed pump which showed an unusual decrease at midnight due to solids clogging the intake screen.

Figure 12: Pressure and Flow Rate Decrease of Feed Pump at Midnight



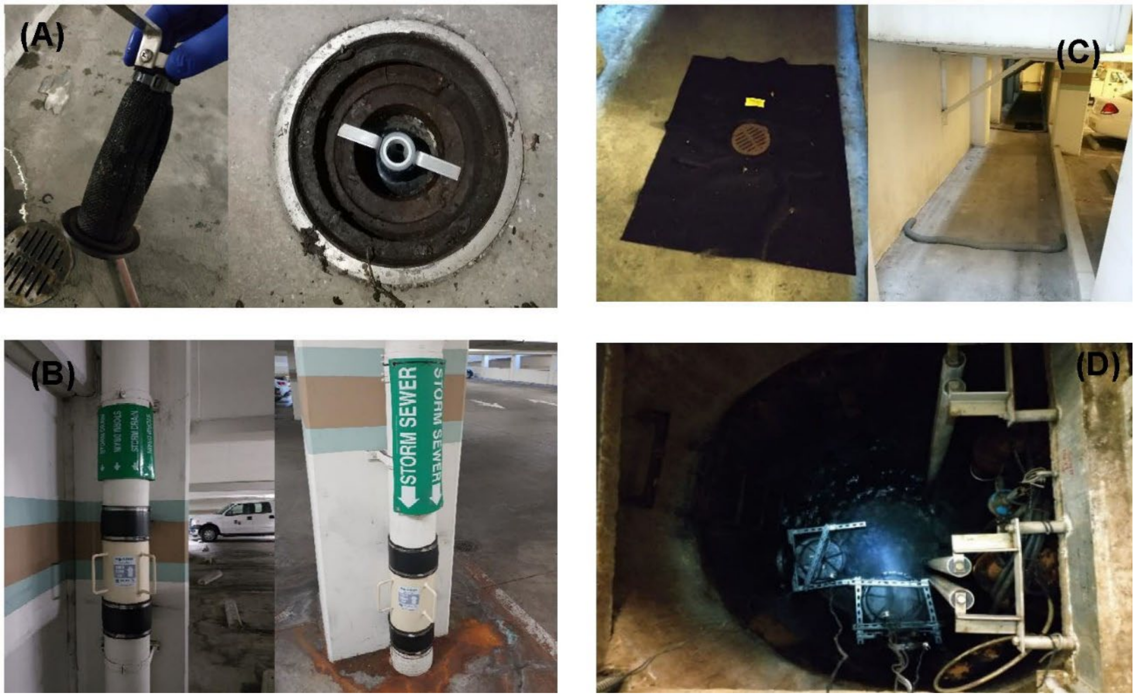
Source: ___

Figure 13: Observed Foot Valve Screen Clogging and After Cleaning

Source: ___

Measures have been taken to control the impact of the runoffs on water quality. Three different types of storm drain filters, as presented in Figure 14 show (A), (B), and (C), have been installed around the Civic Center parking area. In addition, two basket strainers were also installed at the outfall of the pipes in the dewatering cistern as shown in Figure 13 (D). These filters and strainers were implemented to mitigate the solids and oil and grease loadings from the surface runoffs to the treatment system. Periodic inspections and services were also conducted to maintain the proper functions of the filters and strainers. Lastly, during rain events at the project location, the system was turned off to avoid the impacts of high solids and oil and grease loadings on the system.

Figure 13: Different Types of Storm Drains



Insert, (B) inline and (C) fabric drain filters, and (D) basket strainers installed to control solids and oil and grease infusion to the source water

Source: ___

2.4 Test Plan

Operations

The treatment system was designed to operate continuously except for maintenance events. The flow rate, feed pressure, water quality parameters, and energy consumption of the system were recorded on a regular basis by the system PLC.

Maintenance

The maintenance tasks during the operation of the project can be separated into two categories. There were regular maintenance tasks, including 1) prefilter changeout; 2) chemical replacement; 3) media changeouts. Due to the challenges of the water quality, as described in Section 2.3., there were also additional maintenance tasks implemented to address the issues brought by the adverse water quality, including 4) media backwashing, 5) intake pipe screen cleaning.

1) Prefilter changeout

As the system operates, the suspended solids, organic matters, and mineral precipitations in the feed water will slowly clog the prefilters, causing feed pressure to increase and flow rate decline. The prefilters will need to be replaced with new ones to restore the performance of the system. The changeouts are based on the pressure drop across the prefilters, which is set at 40 psi. When a filter needs to be changed, the valves at the prefilter skid were adjusted to bypass the filter to allow filter change without interruption to the system operation. Each filter change duration was approximately 30 min. The changeout frequencies for both the bag filters and the cartridge filters were approximately twice to three times per week, due to the water quality challenges described previously.

2) Chemical Changeout

Chemicals used for the systems were shipped in 50-gallon drums and were placed on their respective leak-containment pallets. Two drums of the same chemical were stored on-site, one is used for system operation and the other one served as a backup. A chemical-compatible level sensor is placed in the container in use and an alarm is triggered when the chemical level hits below approximately 10%. After the drum is empty, the chemical intake tube is switched to the backup chemical drum. The empty drum is replaced with a new one using an electric stacker with a drum gripper attachment.

3) Media Changeout

In order to maximize the media utilization and reduce the operation cost, the adsorption systems are configured in a lead-lag fashion. That is the vessels run in series where the first (lead) vessel continues to treat the feedwater until the media becomes saturated. The second (lag) vessel is exposed to lower feed concentration as the lead vessel removes the bulk of the contaminants.

When the media in the lead adsorption vessel becomes near saturation and cannot remove any more arsenic, the media in that vessel is replaced with fresh media. For unloading of the spent media, a slurry method was used at first to flush out the media. The media slurry was drained from the bottom side port of the vessel. A porous fabric was used to separate the media from the water. The water was drained to a container underneath the filtering fabric. A submersible pump was placed in the container to recirculate the slurry water back to the top port of the vessel. The slurry method continued until the media slurry level in the vessel drained below the bottom port. After the media slurry level in the vessel dropped below the bottom port, a shop vac was used to remove the remaining media. The media slurry was firstly being suctioned out of the vessel into the shop vac. Then the slurry was emptied with a shop vac onto the fabric filter to separate the media from the water. The process repeated until all of the media in the vessel was removed. Figure 15 presents the setup used for the slurry method.

Figure 15: Set up for Spent Media Removal

Source: ___

For loading the fresh media to the emptied vessels, a funnel setup was used, as shown in Figure 16. The containers for fresh media were raised on a pallet to the height of the top side port of the vessel by an electric pallet stacker. Then the media was slurried into the vessel via the funnel with tap water. Excessive water in the vessel was drained from the bottom drain port of the vessel when necessary. A total of 22 cubic feet of the media were loaded into each of the vessels. It should be noted that this media replacement setup was unique in that the vessels were located in a parking structure with extremely limited headspace, so a normal procedure for the vessels housed in open space was not feasible.

Figure 16: Set Up for Fresh Media Loading

Source: ___

After fresh media was loaded, the system was brought back online for operation. The two vessels that were originally used as the lag vessels were now used as lead vessels fresh media. The two vessels that had the media that were partially used becomes lead vessels.

4) Media Backwashing

The adsorption system was originally designed as a single-use system without the need for backwashing. Due to the high levels of iron and manganese in the source water, which pass through the prefilters and gradually precipitate in the media bed after sodium hypochlorite oxidation, several incidents of media bed clogging were observed that required gentle backwashing to relieve pressure. Media backwashing was conducted using the effluent water and the effluent discharge pump. The drain port of the vessels to be flushed was connected to the effluent pump discharge. The backwash flow rate was gradually increased, starting at approximately 15 GPM for 1 min, 20 GPM for an additional minute, then finally at 30 GPM for approximately 2 min. The backwashing water exited from the top discharge port of the vessel and was collected in a 350-gallon tote. This gentle backwashing is used to relieve the pressure caused by media compaction. Aggressive backwashing can disturb the concentration profile of the media bed, resulting in premature leakage of arsenic.

5) Intake Pipe Screen Cleaning

The intake piping of the system extends approximately 1-ft below the lower water surface set point at the dewatering cistern. As mentioned, a PVC screen was installed at the pipe intake to protect the pump from any debris and large particles. Over time, due to the excessive amount of particles, debris, and mineral precipitations, the screen would be clogged, and a confined space entry was needed to take out the pump intake pipe and clean the screen with a pressure washer. The clogging results in a low feed pressure combined with a low feed flow.

When the pipe screen cleaning is needed, the City's Water Division staff would assist onsite and serve as the supervisor for the confined space entry. The project team conducted the entry with the necessary equipment including a tripod, harness, gas monitor, and extension ladder. The City's confined space entry protocol was strictly followed to meet the safety guideline.

A section of the intake pipe in the cistern was disconnected from a union and taken to the outside of the sump to conduct the cleaning. Figure 17 presents the intake screen prior to and after the cleaning.

Figure 17: Intake Screen Before and After Cleaning

Clogged (left) and cleaned (right) screen at the end of the intake pipe in the sump.

Source: ___

6) Storm Discharge Filter Cleaning

As was introduced in Section 2.3, in order to control the solid loading from stormwater runoff into the cistern, three different types of storm drain filters, as presented in Figure 13 (A), (B), and (C), have been installed around the Civic Center parking area. Two basket strainers are also installed at the outfall of the pipes in the dewatering cistern as presented in Figure 13 (D). As these filters collect solids, they were cleaned periodically to restore their filtering capacity. The insert-type drain filters were visually inspected once per month and cleaned as necessary. The sump baskets were inspected weekly and cleaned as necessary. The City conducted a sump cleaning at the beginning of the project, but over time it is likely that debris such as the ones shown in Figure 16 would have been settled to the bottom of the sump. The City is planning a regular follow-up sump sediment cleaning to prevent the clogging of the intake screen.

Challenge Tests

An event that would cause significant problems for the proposed adsorption system may arise in the form of chemical injection failure. Failing to ensure a proper amount of chlorine is added to the system will affect the media's adsorption capabilities impacting the system performance.

Acid chemical injection failure presents the most consequential outcome due to a possibility that a fluctuation of the pH in the system could cause desorption of arsenic from the media. Unlike precipitation or separation treatment processes, media adsorption retains and accumulates arsenic in the treatment train until the spent media is changed out. This presents a potential problem of chemical failure in the acid injection causing a spike in arsenic concentration to values higher than in the feed water due to the condition known as "peaking" when desorption happens as a result of chemical imbalance, particularly when the media is near saturation.

In addition, the effect that is closely examined during the chlorine injection failure is how rapidly and to what extent the effluent arsenic level would be if arsenic is not oxidized to be removed by the adsorption media. Failure in either chemical injection system will lead to an inefficiency in the media's ability to remove arsenic from the groundwater and instability in the pH that could lead to desorption of arsenic from the media under certain operating conditions.

To test what changes will occur in the system in the case of a chemical injection failure, a small-scale pilot skid is implemented (Figure 18) to generate comparable data to the treatment system in place at the City of Cerritos. The pilot skid consists of two media columns oriented in a lead-lag mode. Each column is 2.5 inches in diameter and 22 inches tall. The depth of adsorption media in each column is 10.5 inches, creating a media bed volume of approximately 51 cubic inches per column. Using a flow rate of 65-70 mL/min, the empty bed contact time (EBCT) is 12-13 minutes per vessel. The 12.5 percent solution of sodium hypochlorite injected into the full-scale system is diluted and injected into the system at a flow rate of 2 mL/min. The intended outcome would be the addition of 0.325 mg of Cl/min. Acid addition will likewise be performed by the dilution of the 31 percent HCl solution used in the full-scale system diluted and injected into the system at a flow rate of 2 mL/min. The intended dosage will ensure the pH of the challenge skid remains 6.8-7.0 while the acid injection is running.

Figure 18: Column Set-up for Challenge Testing

Source: ___

Chemical injection failure testing is set to examine the effect of compromising and discontinuing the 12.5 percent solution of sodium hypochlorite and/or the 31 percent solution of hydrochloric acid on system performance. A major parameter to be examined is how rapidly the system would become out of compliance. Testing of each chemical injection failure would be examined sequentially. Initially, the chlorine will be discontinued while the acid continues to be supplied. Following this test, the treatment system will return to its normal operation (with both chlorine and acid addition) to re-establish the baseline condition. The next test conducted will halt the acid addition while chlorine continues to be injected. After each failure test, another recovery period will take place to restore normal operating conditions. Throughout the testing, various water quality parameters will be measured to ensure proper correspondence with the full-scale system when assessing breakthroughs at the effluents of the lead and lag columns.

The testing schedule used during the challenge test is shown in Table 5 Challenge Testing Schedule. Testing will commence with the establishment of the system baseline, wherein both chemicals will be injected into the system as intended. During the testing, pH and flow will be checked hourly to ensure that both parameters are within the targeted range. Testing of the flow will be done using the attached flowmeter as well as manual confirmation with a graduated cylinder and stopwatch, and the pH will be tested using a calibrated pH probe. Arsenic samples will be taken at half-hour intervals for the first two hours, followed by hourly samples. Arsenic samples will be taken from three locations: feed, lead, and lag. Samples are to be taken in 250 mL bottles with a nitric acid preservative. Sample analysis will be conducted by Enthalpy Analytical using EPA Method 200.8. Once the baseline conditions of the skid are determined, the chlorine failure test will begin by removing the chlorine injection of the system while continuing to add hydrochloric acid. Sampling for all segments of testing will closely resemble the baseline schedule.

Table 5: Challenge Testing Schedule

Task	Day								
	1	2	3	4	5	6	7	8	9
Baseline	🟦								
Chlorine Failure		🟧	🟧						
Chlorine Failure Recovery				▨					
Acid Failure					🟨	🟨			
Acid Failure Recovery							🟦		
Both Failure								🟩	
Both Failure Recovery									⬛

Source: ___

Overall Project Schedule

The project was initiated at the end of 2016. After the project had commenced for a few months, a major change in team members occurred due to a change of personnel in ES Engineering and caused a few months of delay in 2017. The project resumed in 2017 with the system fabrication, delivery, and onsite installation were completed by the end of 2017. The treatment system was online in January of 2018, and a total of 24 months of operation was conducted. The Challenge Testing with the small-scale pilot testing columns was conducted from January to February of 2020.

CHAPTER 4: Project Results

4.0 Feed Water Quality

4.1 Overall Feed Water Quality

Table 6 presents the summary of the water quality parameters of the feedwater entering the treatment system. The typical arsenic concentration in the feed averaged at 62 µg/L, exceeding the NPDES compliance level of 10 µg/L. The feed water also contains a high level of phosphate at 0.60 mg/L. As discussed previously in Section 2.3., this is uncharacteristic of groundwater and poses a challenge to the treatment process as phosphate competes with arsenic for the adsorption sites on the media. Lastly, iron and manganese also exist in the feed water at high levels (0.13 mg/L and 0.70 mg/L). These minerals will slowly precipitate under an oxidative environment and cause clogging to the prefilters and media bed. Detailed discussions of these water quality parameters are included in the following sections.

Table 6: Typical Water Quality Parameters of Feed Water

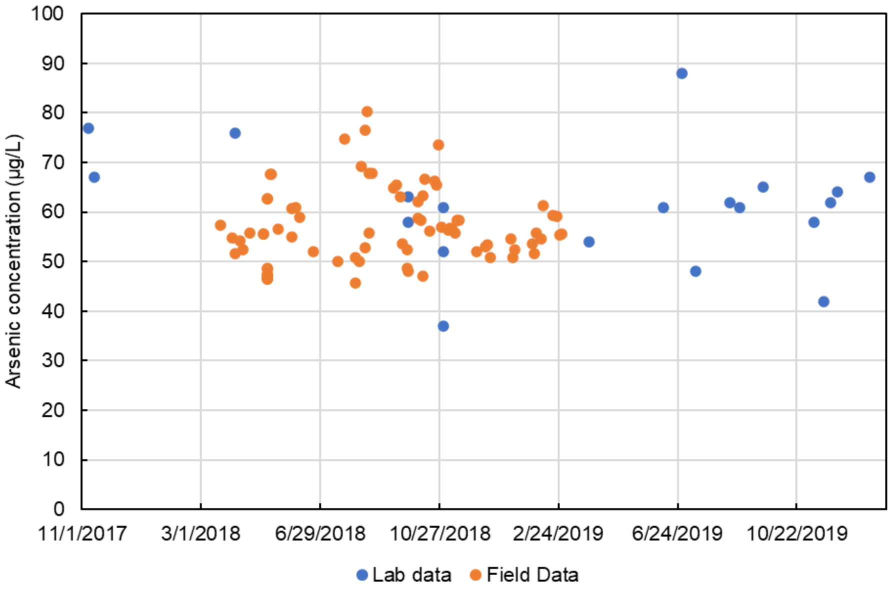
Parameter	Result	Unit
pH	7.05	
Arsenic	62	µg/L
Silicon	17.9	mg/L
Vanadium	<0.005	mg/L
Nitrate	0.61	mg/L
Phosphate	0.60	mg/L
Iron	0.13	mg/L
Manganese	0.70	mg/L

Source: ___

4.1.1 Arsenic

Figure 19 presents the arsenic concentrations measured during the duration of the project. As introduced in Section 2.2.4, an AMS SafeGuard II arsenic analyzer was installed at the project site that allowed onsite arsenic analysis until February 2019 before it was brought offline due to a recurring instrument issue. The figure presents both the onsite measurement results and the grab sample results as analyzed by a certified laboratory.

Figure 19: Arsenic Concentrations in the Feed Water



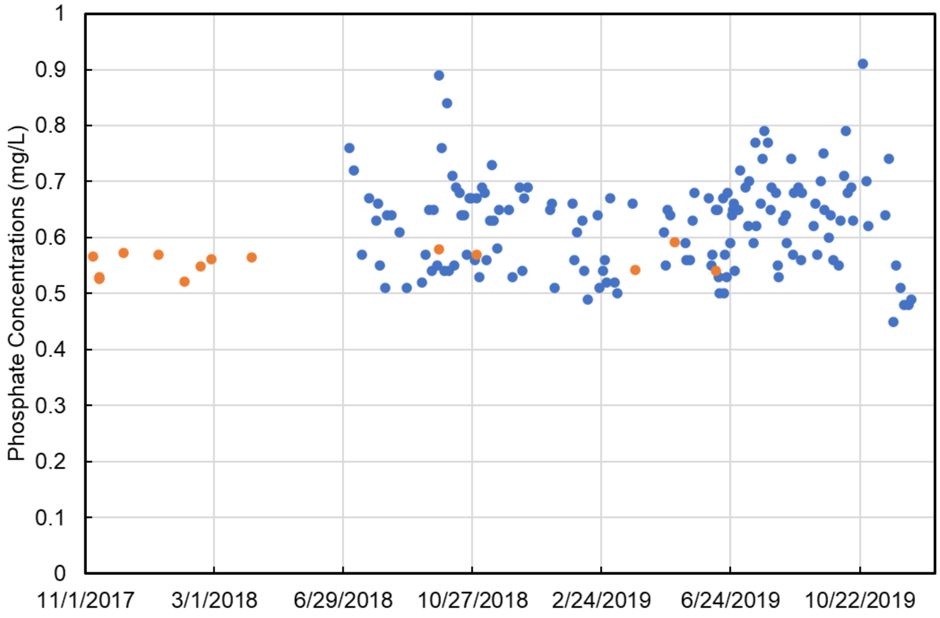
Source: ___

The onsite analyzer and the lab measurements showed comparable arsenic levels. Feed arsenic concentrations fluctuated between 42 and 88 µg/L during the duration of the project, with an average of approximately 62 µg/L. No obvious upward or downward trends were observed during the project period.

4.1.2 Phosphate

Figure 20 presents the phosphate concentrations measured during the project. A Hach DR900 multi-parameter portable analyzer was used for onsite phosphate analysis. Additional grab samples were taken periodically for phosphate analysis by a certified laboratory. The onsite analysis and lab analysis results are presented.

Figure 20: Phosphate Concentrations in the Feed Water



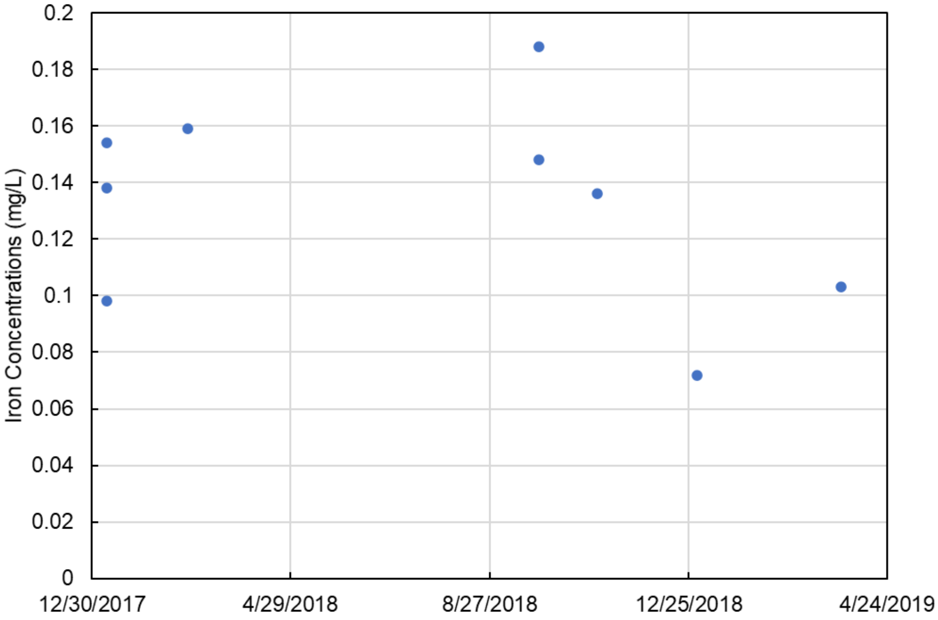
Source: ___

The concentrations measured by the field-portable analyzer were, on average, slightly higher than those measured by the lab (0.63 mg/L vs. 0.56 mg/L). Overall, feed phosphate concentrations had an average level of approximately 0.62 mg/L, with high levels approaching 0.9 mg/L and low levels at 0.45 mg/L. Similar to arsenic, phosphate concentrations appear to be stable, although fluctuating, with no upward or downward trend during the project duration. This high concentration of arsenic would interfere significantly as the binding sites are masked by phosphate.

4.1.3 Iron and Manganese

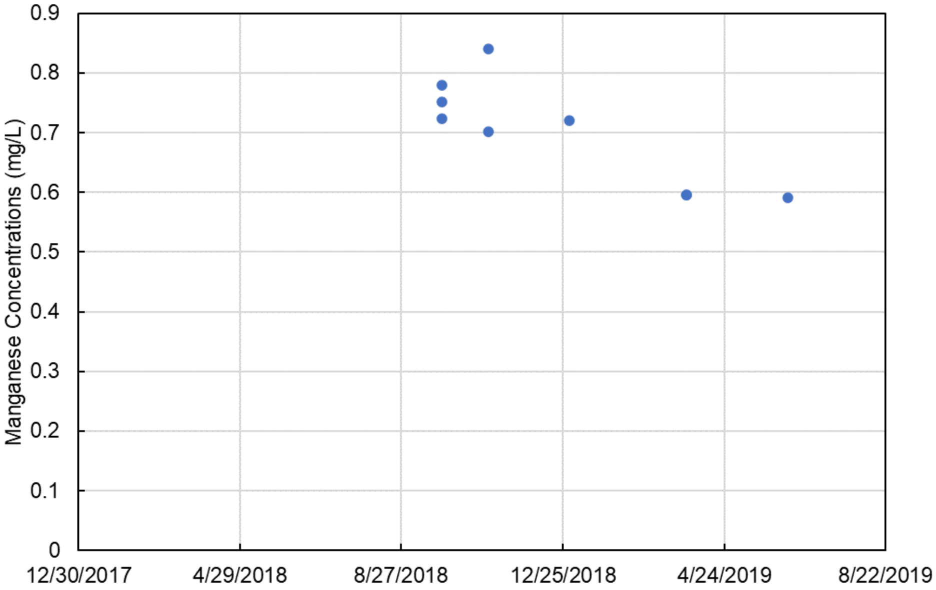
Iron and manganese concentrations in the feed water were included as the monitored feed parameters since the rapid filter clogging and media bed clogging were initially observed. Iron concentrations were averaged at 0.13 mg/L and manganese at 0.70 mg/L. For two sampling events in January and September of 2018, multiple samples were taken on the same day to observe the daily fluctuation of iron and manganese. More significant daily fluctuations were observed for iron (30%). Manganese levels were more consistent with only 7 percent daily variation. The results are presented in Figure 21 and Figure 22.

Figure 21: Iron Concentrations in the Feed Water



Source: ___

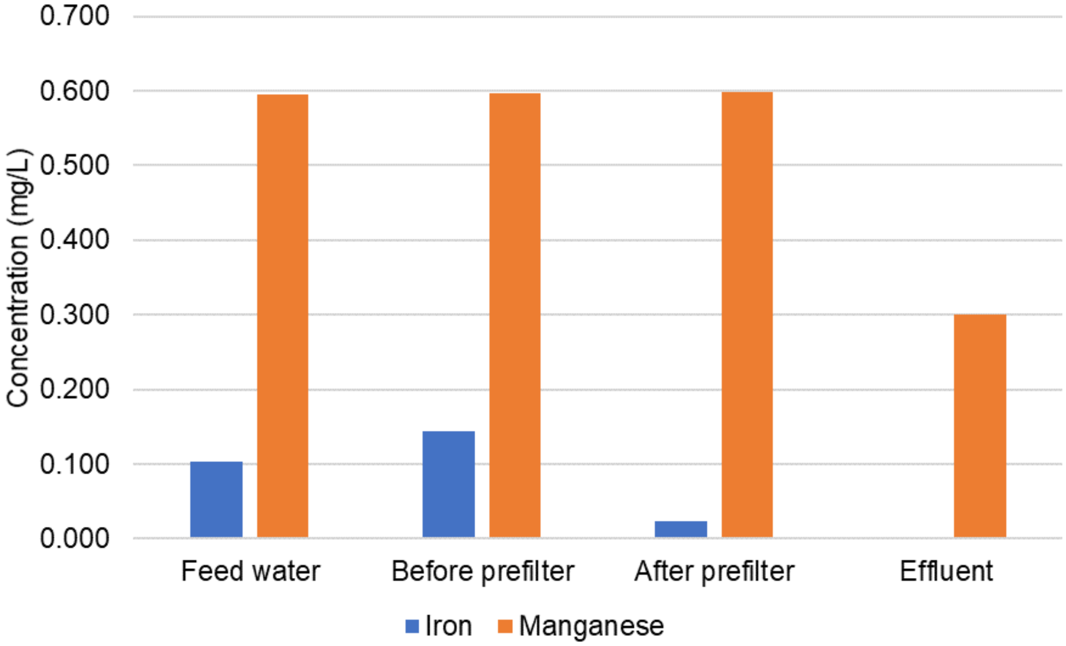
Figure 22: Manganese Concentrations in the Feed Water



Source: ___

To understand the fate and impact of iron and manganese in the treatment system, a sampling event was carried out that examined water samples taken from multiple points of the treatment process, namely the source water, upstream of the prefilter, downstream of the prefilter, and the effluent. The result is presented in Figure 23. It can be observed that the most significant drop in iron concentration is before and after the prefilter. No concentration change of manganese was observed before and after the prefilter, but a significant decrease was observed at the effluent. The observation suggests that the majority of iron in the feed water was captured by the prefilter, while the manganese mostly ended up in the media bed. This observation is consistent with the chemical properties of these two minerals, as iron oxidizes and precipitates more rapidly than manganese. The injection of sodium hypochlorite caused the iron to rapidly precipitate as particles and entrap in the prefilters. While the manganese precipitate more slowly, it passes the prefilters as mostly dissolved species but slowly precipitates and ended up embedded in the media bed creating head loss through the media bed.

Figure 23: Iron and Manganese Concentrations at Different Points of the Treatment Process

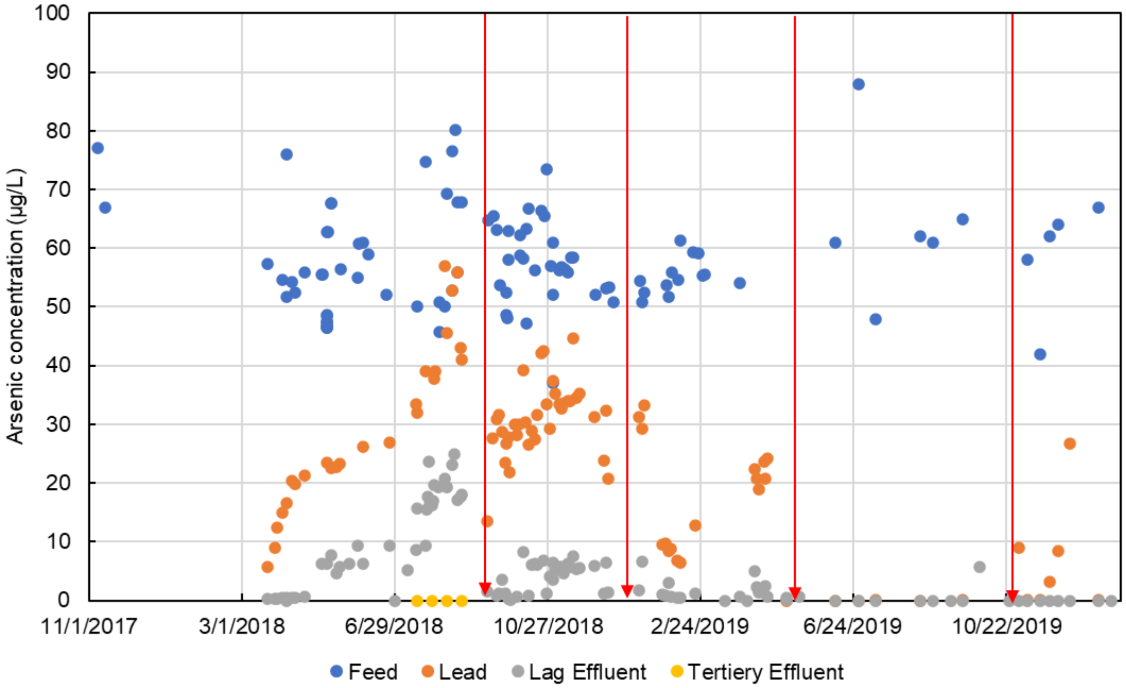


Source: ___

4.2 Effluent Water Quality

The effluent arsenic concentration is presented in Figure 24. As for comparisons, the arsenic concentrations in the feed and lead vessel outlet are plotted in the same figure. It is noted that during July and August of 2018, a pair of backup tertiary vessels were engaged downstream of the lag vessels. This was to mitigate the arsenic breakthrough of the lag vessels. Due to the water quality issues described in Section 2.3, mainly the high concentration of arsenic, phosphate and the oil and grease which fouled the media, the adsorption capacity and breakthrough behavior of the media for the source water could not be accurately predicted initially. As a result, lag effluent arsenic rapidly climbed since June 2018. A pair of tertiary vessels were partially filled with 1/4 vessel of media and operated downstream of the lag vessels to further polish the lag effluent arsenic. The tertiary vessels were disengaged after the media changeout in August 2018.

Figure 24: Feed, Lead, and Effluent Arsenic Concentrations

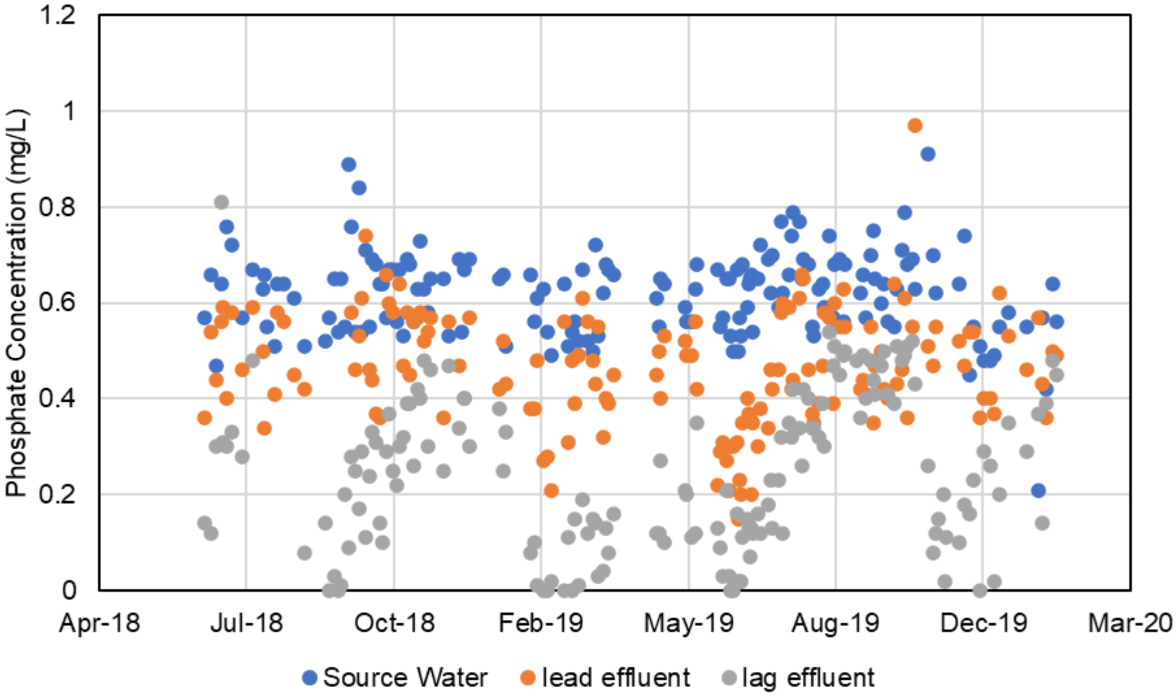


Source: ___

The red arrows indicate when media changeout had occurred. In between each changeout period, the concentrations of arsenic in the lead and lag effluent increased over time. Overall, the system was able to treat the source water and control the effluent arsenic to below the discharge limit of 10 µg/L.

The feed, lead effluent, and lag effluent phosphate concentrations are summarized in Figure 25. It can be seen that due to the high feed concentration, the lead vessel broke through fairly quickly, with typical effluent concentrations at 0.2 to 0.4 mg/L. The lag effluent phosphate concentration was low after each media change (<0.1 mg/L). However, it started to increase steadily, and typically reached a level of 0.4 mg/L prior to media change-outs.

Figure 25: Feed, Lead, and Effluent Phosphate Concentrations

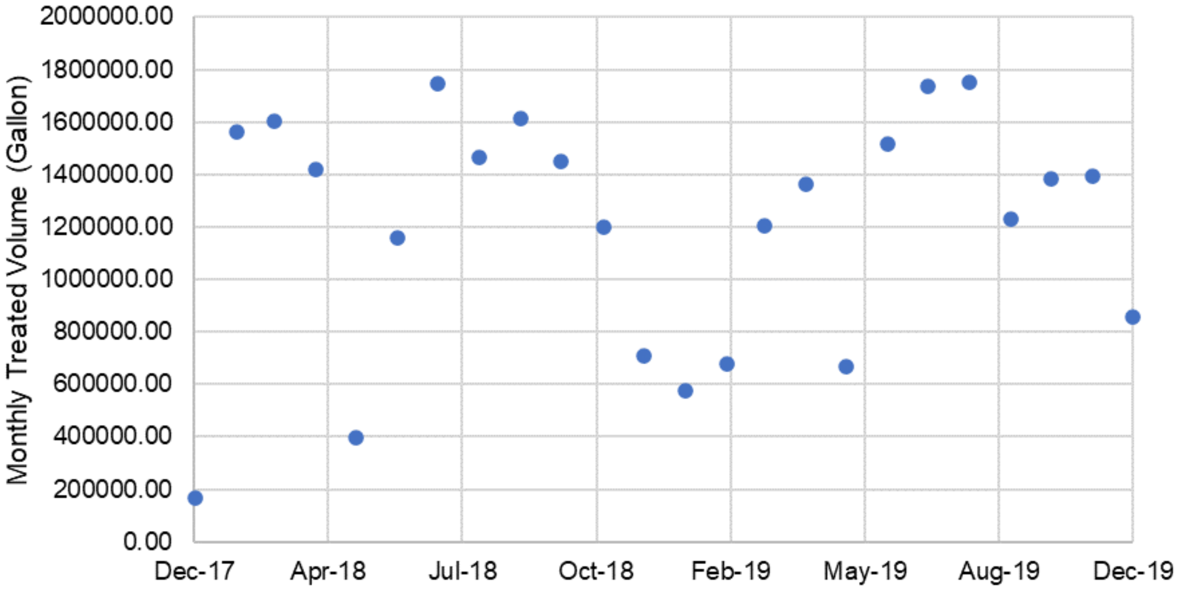


Source: ___

4.3 Treated Flow

Figure 26 presents the monthly treated volume during the project duration from January 2018 to December 2019. As previously described in Section 2.3, due to the water quality challenges and the impacts of the surface runoff, the system went through extensive cleaning and maintenance process during the startup in January 2018. The system was also turned off during rain events during the project as there was no other way to divert the surface runoff with oil and grease entering the sump and thus the treatment system. This caused low treated volumes in some of the months such as November, December, January, and February. The monthly treated volume also fluctuates due to the clogging of the prefilters. If the prefilters were clogged when no operator was onsite (such as at night or during weekends), the system's treatment capacity would decrease and would not be restored until the prefilters were changed. Overall, the system was able to treat on average approximately 1.2 million gallons of water on a monthly basis.

Figure 26: Monthly Treated Volume During the Project Duration

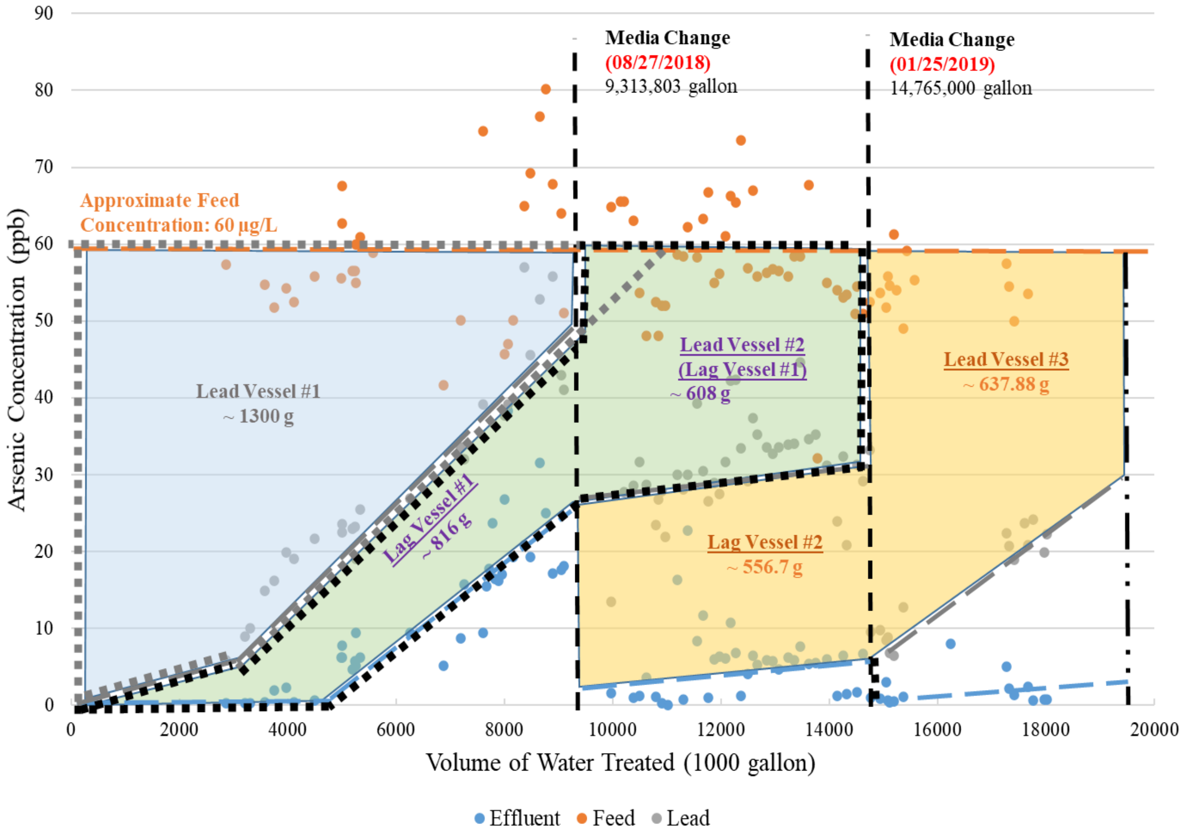


Source: ___

4.4 Arsenic Adsorption Capacity

The arsenic adsorption capacity was estimated by the approximate areas between the arsenic concentration profiles for the feed, lead effluent, and the lag effluent plotted against the volume of water treated by the system. Essentially, the area (concentration × volume) between the feed concentration curve and the lead concentration curve gives the mass of arsenic adsorbed by the lead vessel. And the area between the lead effluent and lag effluent concentration curves gives the mass of arsenic adsorbed by the lag vessel. After each media change at the lead vessel, the vessel that was used as lag vessel previously would then be used as the new lead vessel. The area calculation is then adjusted to reflect the change of vessel configurations. Figure 27 illustrates how each of the areas was calculated. In order to simplify the calculation, a straight line at the average value of 60 µg/L was used as the feed concentration profile, while the linear approximations of the lead and lag effluent concentrations were used as their respective concentration profiles. The first three batches of media in the first 20 million gallons of water treated were used to carry out the calculation.

Figure 27: Arsenic Concentration vs. Volumes of Water Treated



The areas between the curves show the mass of arsenic adsorbed by the media.

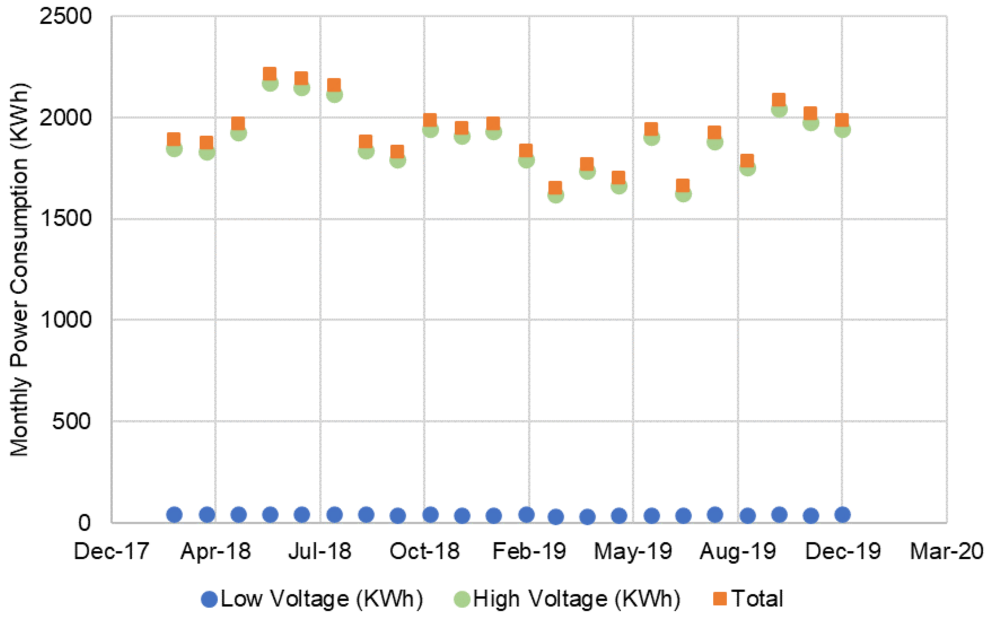
Source: ___

The results showed that the approximate arsenic adsorption capacity of the three batches of media was comparable at 1.3 kg, 1.4 kg, and 1.2 kg, with an average of 1.3 kg per batch (22 cfs per vessel), or about 60g/cfs of media. It is noted that the water quality challenges, including the high concentration of phosphate which competes with arsenic adsorption, as well as oil and grease or manganese which may foul the media, would negatively impact the adsorption capacity of the media. It is expected that when treating a higher quality groundwater source, the adsorption capacity of the media would be higher than shown in this project.

4.5 Energy Consumption and Comparison

Figure 28 presents the monthly energy consumption of the treatment system. A detailed description of the setup of the energy monitoring system and the energy data can be found in Appendix A. Expectedly, the majority of the energy consumption was due to the high voltage power components (mainly feed and effluent pumps), taking up close to 98 percent of the total energy consumption. The average monthly power consumption was about 1,882 KWh. The calculated energy consumption per volume of water treated was approximately 1.09 KWh/1,000 gallons. Under the concentration levels of the current project, the calculated energy consumption per mass of arsenic removed is approximately 4.8Wh/mg arsenic removed.

Figure 28: Energy Consumption of the Treatment System



Source: ___

To compare energy consumptions of the treatment system to other conventional treatment technologies for arsenic removal, energy data of a reverse osmosis treatment system and a conventional coagulation filtration system was used as a comparison (details in Appendix A). It is shown that the coagulation filtration system consumed approximately 1.34 KWh/1,000 gallon water treated, while the reverse osmosis system consumed about 6.63 KWh/1000 gallon water treated. The current adsorption treatment system consumed 22.6 percent and 83.6 percentless energy compared with the above two processes, respectively.

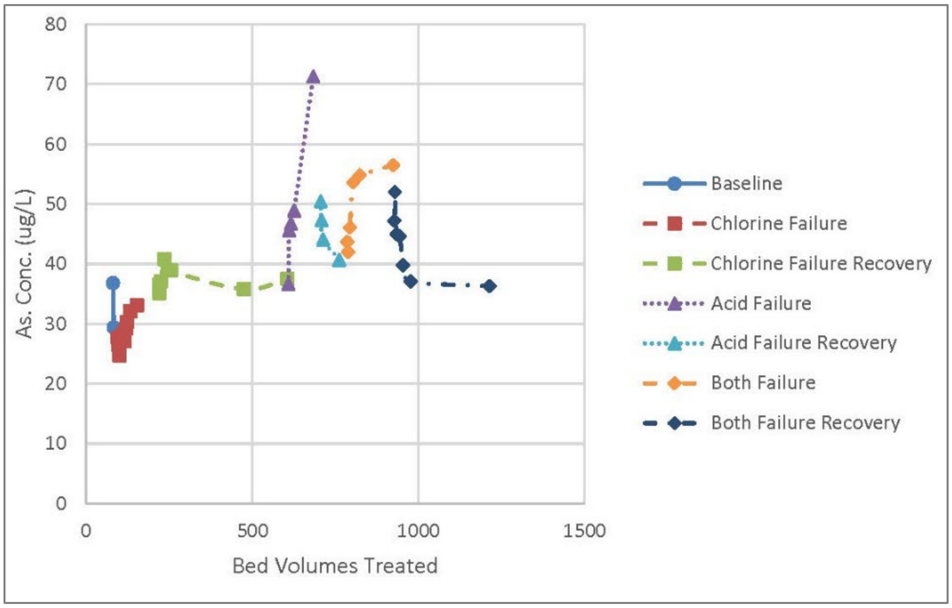
4.6 Challenge Tests

Arsenic concentration for the full challenge tests is presented in this section for the lead column effluent and the lag column effluent, respectively. Each section of the challenge test is represented in an individual color to illustrate the different tests. Arsenic values are presented in terms of Bed Volumes Treated (BV).

4.6.1 Baseline Performance

The baseline segment of the challenge test is presented in Figure 29 and Figure 30 in circles as points connected by an unbroken line. Three hours after commencing the baseline test, the lead vessel showed a breakthrough of arsenic at a concentration of 36.8 ppb and decreased back down to 29 ppb, meanwhile, the lag vessel had measured no arsenic in the effluent. 29 ppb of arsenic was used as the minimum effluent of the lead column and 0 ppb was understood to be the baseline for the lag column. Baseline testing continued for a day before the chlorine failure test began, during this time, the pH remained 7.0.

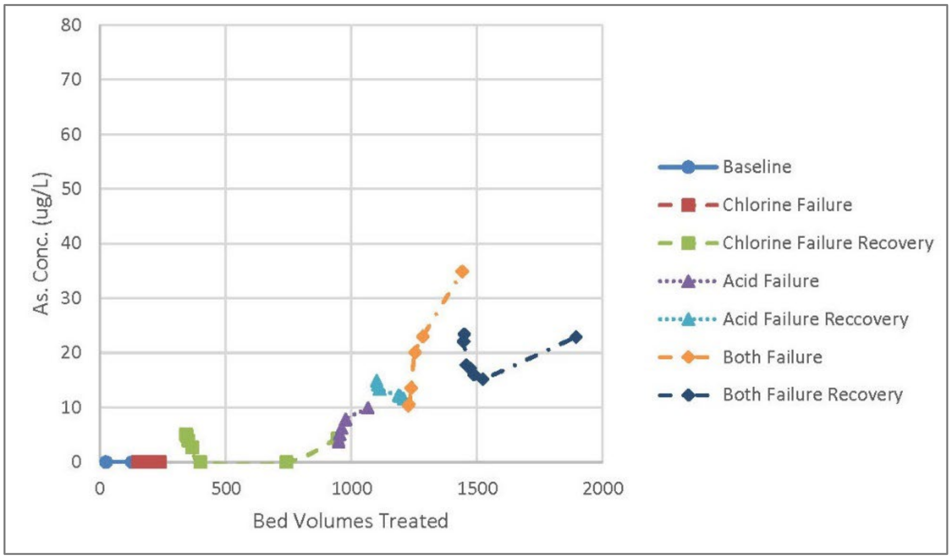
Figure 29: Lead Column Effluent Arsenic Concentration vs Bed Volumes Treated



For the duration of challenge testing.

Source: ___

Figure 30: Lag Column Effluent Arsenic Concentration vs Bed Volumes Treated



for the duration of challenge testing

Source: ___

4.6.2 Chemical Injection Failures

4.6.2.1 Chlorine Failure

The sodium hypochlorite injection failure segment of the challenge test is shown in Figure 29 and Figure 30 using squares as points connected by a dashed line. The first chemical failure test conducted was the failure in the 12.5 percent solution of sodium hypochlorite injection, while continuing to inject hydrochloric acid for acid control. After approximately 100 BV of treatment, the lead column effluent was measured to have an arsenic concentration of 24.7 ppb. By the end of the chlorine failure test, the lead column effluent had increased to 33.1 ppb. During this stage of the challenge test, it can be observed that after chlorine injection failure, the lead effluent arsenic increases steadily, likely due to the As(III) passing through the column without any adsorption. However, it was observed that the lag column was still able to capture the leached As from the lead column. The testing showed that the process is able to withstand chlorine failure for the duration of the test period for overall compliance.

4.6.2.2 Acid Failure

The acid injection failure segment of the challenge test is presented in Figure 29 and Figure 30 using triangles as points connected by a dotted line. The acid failure test was conducted by stopping the injection of hydrochloric acid into the system while continuing to inject chlorine. An expected result of the continued injection of sodium hypochlorite was an increase in the pH of the system. The pH of the system was measured to be consistently 7.3 during this segment of the testing. During the acid failure test, the effluent arsenic concentration in both the lead and lag columns increased dramatically. By the end of the acid failure test in the lead column (700 BV), the highest effluent arsenic concentration was observed 71.3 ppb due to the condition known as peaking. A greater significance must be paid to this arsenic concentration value considering the feed arsenic concentration was measured to be 54.1 ppb. With a higher lead column effluent concentration than what was observed in the feed, it is understood that the variance of pH caused arsenic to desorb from the media. It is observed during the acid failure test that the system's ability to remove arsenic is reduced, while the sudden shift in pH was shown to cause arsenic desorption due to loss of equilibrium in the water. As such, corrective action must be in place to address the situation during acid chemical injection failure.

4.6.2.3 Chlorine and Acid Failure

The final section of the challenge test conducted was the failure in both chemical injection systems. This segment of the challenge test is presented using diamonds as points connected by a dashed/dotted line. For this portion of the testing, feed water was directly pumped through the lead and lag columns without any chemical insertion. During this period, the pH was unchanged from the feed and measured to be 7.2 during testing. Similar to the acid failure test, an increase in the effluent arsenic concentration was observed in the lead and lag columns. In the lead column effluent, the arsenic concentration rose from 43.7 ppb to 56.5 ppb. This could be attributed to the leakage of As(III) through the adsorption media when chlorine is not injected or could be due to a pH imbalance that results in peaking. By the end of this segment of the challenge test, the highest arsenic concentration measured in the lag column effluent was 34.9 ppb. The system was generally recovering after the chemical injections were restored, but there is one outlier that exhibited a high concentration of arsenic in the lag vessel. It is not clear what may have caused the elevation in arsenic during the recovery period after both chemical failure tests.

4.6.3 Impact of Chemical Injection Failures

It was observed during the challenge testing that disruption of either chemical injection has a negative effect on the system's ability to remove arsenic from the water. The loss of the acid injection was demonstrated to have the greatest effect on the system performance due to peaking. The rapid change of the system pH allowed for the occurrence of arsenic desorption. Arsenic desorption was identified during the acid injection failure, as measured values of the lead column's effluent arsenic concentration greatly exceeded the measured value of arsenic in the feed water. It should be noted that this episode is pronounced when the media has enough arsenic adsorbed in the bed when the failure occurs. If the media bed is relatively new, the peaking impact does not happen even under a fluctuating pH condition.

CHAPTER 5: Technology/Knowledge/Market Transfer Activities

One of the main objectives of this project was to disseminate the knowledge gained from the research with various stakeholders so the information could be used by professionals in the industry who are evaluating solutions for treating contaminated water. The knowledge could also benefit regulatory agencies in developing expectations and understanding the efficiency of treatment systems. In addition, knowledge transfer can help future professionals understand the challenges associated with transferring scientific knowledge to applied engineered solutions.

Successful implementation of any new technology requires the adoption of the proposed technology by the mainstream industry. For water treatment technology, technical feasibility is only one of many aspects required for successful adoption. The technology must also support ease of operation, be stable, and minimize logistics required to manage waste, trouble shoot, adhere to budget, and other factors. As such, market transfer of new technologies requires education to early adopters and decision makers, as well as those involved in product manufacturing, shipping and delivery, local storage of key components, and customer response.

As part of the knowledge transfer, the project team worked with two University of California, Irvine, senior design teams. One team was involved in refining the treatment process, particularly in optimizing the treatment condition, and the other team conducted hands-on laboratory testing with the water collected from the host site to gain experience in the treatment process.

In addition, a small-scale model of the treatment system used at the project site was fabricated for display in the library next to the project site (Figure 31). Students from Cerritos High School across the street from the library, the general public, local professionals, and others frequent the library. The treatment model and a short summary, as well as additional information, were displayed in the library at two rotations based on the themes that the library uses around the year.

Figure 31: Display Model of the Treatment System at the City of Cerritos Library

Source: ___

The final project results were compiled for presentation at a local host site workshop as well as relevant conferences in 2020. A workshop was planned for the library, with a tour of the model display, followed by the visit to the actual project location. The target audiences were small utilities facing water treatment challenges similar to those studied in the project and professionals in the area. Due to the COVID pandemic, all of the activities were canceled, including conference presentations and site tours.

Throughout the project period, the project team held a series of meetings and workshops and maintained communication with the host site and regulatory agencies, providing project status updates and discussing the many challenges facing the treatment system, such as debris entering the sump, unexpectedly elevated levels of arsenic, and high concentrations of competing contaminants—all of which affected the system.

CHAPTER 6: Conclusions/Recommendations

Current treatment for a number of groundwater contaminants relies on conventional technologies such as chemical addition and filtration, membrane treatment using reverse osmosis, and others. Such treatment systems are not only complex in terms of equipment needs and associated operator training but also energy intensive and costly. Other factors driving the higher costs for conventional treatment are the need for daily management of the high volume of contaminant-laden waste streams and active process control that requires constant monitoring and adjustment.

This project uses adsorption media capable of removing target contaminants from groundwater and other waste streams. This treatment process requires only a feed pump and some chemical injection pumps, thereby eliminating many steps normally associated with the operation of conventional technologies and thus saving electricity—and costs—required to manage daily backwash and waste collection. During the demonstration phase, the project team successfully processed water contaminated with elevated levels of arsenic as well as other contaminants including phosphate and manganese. Although the project team encountered unexpected challenges associated with the water quality and site limitations, the system generally performed well, meeting the discharge level imposed by the local permit limits.

The energy evaluation conducted by a third-party team demonstrated that over the adsorption treatment process could save more than 22 percent of energy compared with a more conventional treatment system and suggested even higher saving for multi-contaminant removal using a membrane type of system. Thus, this demonstrated treatment process provides a low-energy water treatment option to reduce the energy demand associated with the treatment process.

Although the target contaminant at the host site was arsenic, other water quality issues limited the treatment's efficacy, including phosphate, which competes with arsenic thus limiting the treatment efficiency, and manganese, which oxidizes to insoluble fraction increasing the head loss through the system. In addition, is the location of the project research in an underground public parking structure meant that groundwater, drainage water from the irrigation system, stormwater, and other waters collected in a centralized underground sump, causing synthetic oil and debris to end up in the water and compromising the media. Therefore, future projects implementing a similar type of adsorption treatment system must consider total water quality and environmental conditions and a more extensive pre-treatment system in the design phase to ensure that the system

The system can also be tested for other contaminants such as chromium and selenium that affect many valuable resources throughout the state. In addition, the adsorption media can be modified to target specific contaminants, and future projects can evaluate the variability of this system for other water quality compliance issues. Also, future projects can modify the vessel to ensure easy replacement of the media and to minimize the energy involved.

Finally, the online sensor helped greatly to monitor the performance of the proposed system and advancement of the technology. Monitoring the system’s performance will make the system more cost-competitive and free from regular maintenance, making the analyzer a valuable tool for compliance.

CHAPTER 7: Benefits to Ratepayers

The proposed project will provide important benefits to California ratepayers by reducing the energy demand associated with the treatment of groundwater and drainage water contaminated by emerging contaminants. It will also provide benefits in terms of reduced chemical and greenhouse gas emissions, lower costs, and greater access to purified water.

The typical treatment system for contaminants relies on a chemical-based system, which requires multiple steps involving chemical addition, mixing of chemicals and chemical reactions, and multiple separations of chemicals from insoluble and then dewatering solids, all of which require additional energy to improve water quality. A conventional treatment system also involves the transportation of chemicals and would generate as much as 40,000 pounds of sludge per year.

The demonstration project using a single-use adsorption media eliminates a number of these steps, reducing energy use and the need for new electricity production infrastructure for such steps and avoiding cost increases for ratepayers for treating contaminated water sources to comply with regulations.

To calculate potential benefits California ratepayers, the energy consumption of the single-use adsorption media system was compared to that of a typical coagulation filtration system and suggested that energy savings from use of adsorption systems could equal $75 million per year, a 30 percent reduction in electricity costs over comparable, commercially available chemical-based treatment systems. Avoiding deliveries of chemicals would result in a savings of some 4.4 metric tons of carbon dioxide. Coupled with estimated savings of 54.3 metric tons of carbon dioxide avoided by using an adsorption treatment system, the air quality benefits of reducing greenhouse gas emissions are significant.

In summary, the energy savings an adsorption treatment system offers decrease demand on the electrical grid, provide cost savings and environmental benefits, and deliver qualitative benefits to ratepayers by enabling the provision of safe drinking water.

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CHAPTER 3: APPENDIX A: Energy Monitoring Reports

Energy Monitoring Report #1, April 2, 2018

KKC
Engineering, Procurement, Construction
1601 Corsica Place
Costa Mesa, CA 92626
(714) 206-3358 khalilkairouz@att.net

April 2, 2018

Joon Min
Montrose Environmental
ES Engineering Services LLC
1 Park Plaza, 10th Floor
Irvine, CA 92865

Subject: **Energy monitoring and Audit- Power consumption of the Demonstration of a Low-Energy and High Water-Efficiency Treatment System for Metal Contaminant Removal Using an Innovative Adsorption / Biosorption Process. California Energy Commission GFO-15-323**

Dear Sir:

This is to confirm that KKC has reviewed and conducted energy assessment regarding the energy monitoring and consumption of the Demonstration plant at the City of Cerritos which consists of a Low-energy and High Water-Efficiency Treatment System for Metal Contaminant Removal using an Innovative Adsorption / Biosorption Process.

KKC is a consulting firm with primary focus on Engineering, procurement, and Construction. It is also specialized in the energy monitoring and data acquisition management and audits. KKC conducted numerous energy audits of residential, commercial, industrial and public water and waste water treatment plants and is certified as energy manager and audit, and Leed AP. We are also licensed in the state of California as a Mechanical Professional Engineer.

The full operation of the demonstration plant was started in Feb of 2018. The energy monitoring started from March 05, 2018 and will continue until March 05, 2019, this is a full year of energy data that will be collected. The purpose of the energy monitoring and audit is to demonstrate potential energy and cost savings, including economic and environmental benefits. Figures 1 and Figure 2 shows the energy monitoring and data acquisition setup for the 240 volts and 480 volts electrical subpanels that power the equipment for the demonstration plant.

Energy data measured and calculated include: volt-hour, Amp-hour-watt-hour, Power factor, Volts, Amp, watt, kilowatt, and kilowatt-hour. The data are then calculated and summarized to show the energy consumption in kwh/1000 gallon of water treated. The energy data are then compared to a water treatment system that uses different treatment technology. For this evaluation, the energy data from a coagulation filtration treatment system which use multimedia filtration of sand, and anthracite media are compared with the energy consumption data from the demonstration plant at the city of Cerritos. In a coagulation filtration system, backwash pumping and polymer chemical feed pumping are required whereas it is not required for the demonstration plant which uses hydrogel media single use adsorption process.

The following presents the comparison summary of the energy consumption for the period from 3/05/2018 to 3/31/2018. However as stated above, the energy monitoring will continue for a one year and all the data will then presented in the final report.

Table 1. Energy consumption comparison

Period	Water flow	Hydrogel Media Adsorption (Single use with spent media reduction)			Conventional Coagulation Filtration (Backwash and Cleaning)		
	(gallon/day)	Wh	kWh	Wh/gallon	Wh	Kwh	Wh/gallon
3/5/2018	62321	53359	53.359	0.8562	66699	66.70	1.0702
3/6/2018	60753	55796	55.796	0.9184	68071	68.07	1.1205
3/7/2018	64644	65880	65.88	1.0191	79715	79.71	1.2331
3/8/2018	64659	75682	75.682	1.1705	90818	90.82	1.4046
3/9/2018	66240	69899	69.899	1.0552	82481	82.48	1.2452
3/10/2018	66240	61214	61.214	0.9241	71008	71.01	1.0720
3/11/2018	29487	47055	47.055	1.5958	58819	58.82	1.9947
3/12/2018	39629	36402	36.402	0.9186	46595	46.59	1.1758
3/13/2018	65132	64703	64.703	0.9934	76997	77.00	1.1822
3/14/2018	56604	63707	63.707	1.1255	80271	80.27	1.4181
3/15/2018	57988	64354	64.354	1.1098	81730	81.73	1.4094
3/16/2018	59853	59765	59.765	0.9985	72913	72.91	1.2182
3/17/2018	47873	54074	54.074	1.1295	68133	68.13	1.4232
3/18/2018	48022	57896	57.896	1.2056	68317	68.32	1.4226
3/19/2018	37992	42237	42.237	1.1117	52796	52.80	1.3897
3/20/2018	58276	63479	63.479	1.0893	77444	77.44	1.3289
3/21/2018	52050	54191	54.191	1.0411	65571	65.57	1.2598
3/22/2018	60682	62723	62.723	1.0336	75268	75.27	1.2404
3/23/2018	52781	58421	58.421	1.1069	68937	68.94	1.3061
3/24/2018	65678	68030	68.03	1.0358	78915	78.91	1.2015
3/25/2018	58629	65967	65.967	1.1252	82459	82.46	1.4064
3/26/2018	59608	64835	64.835	1.0877	82989	82.99	1.3922
3/27/2018	64231	72685	72.685	1.1316	86495	86.50	1.3466
3/28/2018	39992	48985	48.985	1.2249	59762	59.76	1.4943
3/29/2018	45724	52956	52.956	1.1582	65665	65.67	1.4361
3/30/2018	57979	63322	63.322	1.0922	81052	81.05	1.3980
3/31/2018	62856	73498	73.498	1.1693	92607	92.61	1.4733
Average Power Consumption			1.09 kwh/1000 gals				1.34 kwh/1000 gals

From table 1, the average energy consumption for the hydrogel adsorption treatment system at the City of Cerritos is 1.09 kwh/1000 gals while the coagulation filtration treatment system is 1.34 kwh/1000 gals for the entire period listed. The calculated energy savings would be as follow:

Energy savings: (1.3357 - 1.0899)/1.0899 X100%= 22.55 %

The Energy savings calculations show that the Hydrogel media single use water treatment system provided a 22.5 % energy savings over the Coagulation filtration treatment system. However there are additional potentisl savings this system can offer, such as the following.

1. Reduction in demand response enabled by automated demand response technology
2. Reduce Operation and maintenance costs since there are less pumping required (no backwash or polymer feed pumping)
3. Redcution in wastes since backwash waste are not generated with the new treatment system.
4. Increase in water production since there is no interruption of treatment for backwash cycle.
5. Air pollution emissions reduction since there are less equipment required than the conventional coagulation filtration system.
7. When compared to other treatment systems such as Reverse Osmosis and conventional Ion Exchange treatment, the hydrogel media adsorption technology will provide greater energy saving, economical, and environmental benefits. This is due to substantial lower waste generation and disposal, and lower energy pumping requirements.

Should you have any questions, please contact me.

Sincerely,

Khalil Kairouz

Khalil Kairouz Consulting
KKC
California USA

Registered Professional Engineer
Khalil Antoun Kairouz
No. 28941
Mechanical
State of California

Khalil Kairouz, Ph.D., P.E., CEM, LEED AP
President
Certified Energy Manger, AEE #13607

Exp: 6/20/2018
Signed on: April 2, 2018

KKC
Engineering, Procurement, Construction
1601 Corsica Place
Costa Mesa, CA 92626
(714) 206-3358 khalilkairouz@att.net

January 28, 2020

Joon Min
Enova Water
5716 Corsa Ave, #110
Westlake Village, CA 91362

Subject: Energy monitoring and Verification- Power consumption of the Demonstration of a Low-Energy and High Water-Efficiency Treatment System for Metal Contaminant Removal Using an Innovative Adsorption Process. California Energy Commission GFO-15-323, Project No. EP16-006

Dear Sir:

This energy verification and measurement report presents analysis of energy monitoring and consumption data of the Demonstration plant at the City of Cerritos. The plant consists of a Low-energy High Water-Efficiency Treatment System for Metal Contaminant Removal using an Innovative Adsorption Process.

KKC conducted the energy monitoring and data acquisition management and audits for the demonstration plant. KKC is a consulting firm specialized in energy conservation systems design, measurements and verifications and energy auditing. KKC conducted numerous energy audits for residential, commercial, industrial and municipal water and wastewater treatment plants. KKC is certified as energy manager, Leed AP, and licensed in the state of California in Mechanical Professional Engineering.

The full operation of the demonstration plant was started in Feb of 2018. The energy monitoring and verification started from March 05, 2018 and continued until December 2019. The purpose of the energy monitoring and verification plan is to measure and demonstrate potential energy and cost savings of the demonstration plant, including economic and environmental benefits. Figure 1 and Figure 2 shows the energy monitoring and data acquisition setup for the low voltage (240 volts, single phase) electrical subpanel, and the high voltage (480 volts, 3 phase) electrical subpanel. These panels power the equipment associated with the demonstration plant.

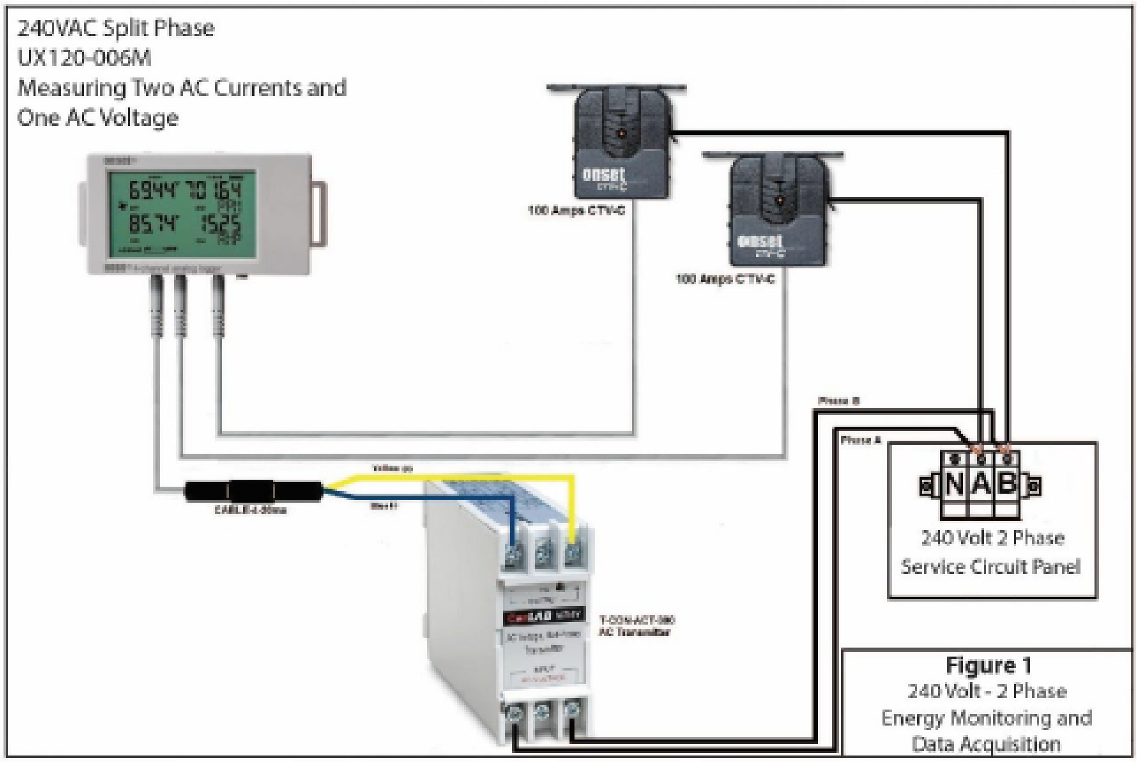

Figure 1
240 Volt - 2 Phase
Energy Monitoring and
Data Acquisition

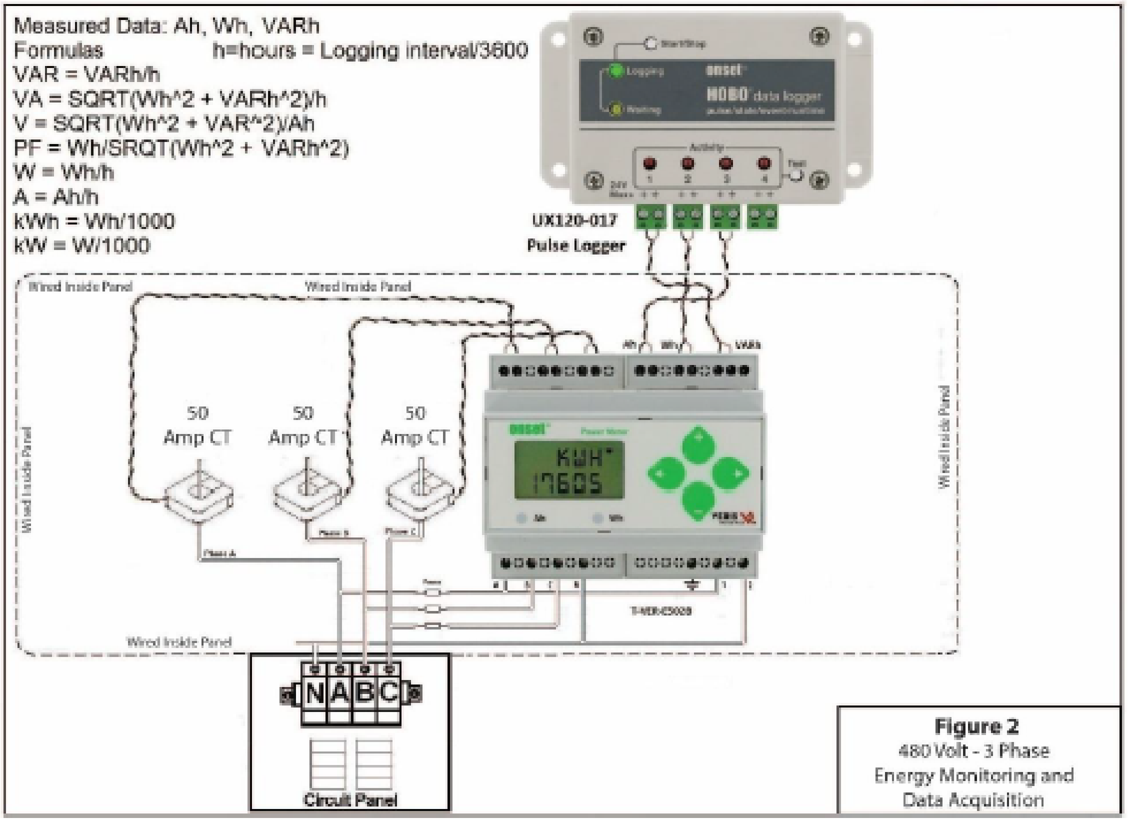
Measured Data: Ah, Wh, VARh
Formulas h=hours = Logging interval/3600
VAR = VARh/h
VA = SQRT(Wh^2 + VARh^2)/h
V = SQRT(Wh^2 + VAR^2)/Ah
PF = Wh/SRQT(Wh^2 + VARh^2)
W = Wh/h
A = Ah/h
kWh = Wh/1000
kW = W/1000

Figure 2
480 Volt - 3 Phase
Energy Monitoring and
Data Acquisition

Energy data are measured and calculated for the components associated with the low voltage 240 V, subpanel and for the high Voltage 480V sub panel. The low voltage sub panel typically includes the chemical pretreatment (such as acid, Bleach and Sodium Metabisulfite) feed system. The high Voltage sub panel includes the energy feed to the components for the pumping, water treatment, and any associated storage instruments.

The measured and calculated values of energy consumptions include; volt-hour, Amp-hour, watt-hour, Power factor, Volts, Amp, watt, kilowatt, and kilowatt-hour. The measured data are then summarized to show the energy consumption in kwh/1000 gallon of the water treated.

For this energy data analysis, the energy consumption data are then compared to a typical energy consumption of a Reverse Osmosis (RO) Membrane Filtration treatment technology to show the energy efficiency and savings comparison between both treatment technologies.

Figure 3 shows a schematic of the components of the Hydrogel single use media ion exchange system. The Enova adsorption system vessels are operated in lead-lag format (four vessels in total, two lead and two lag).

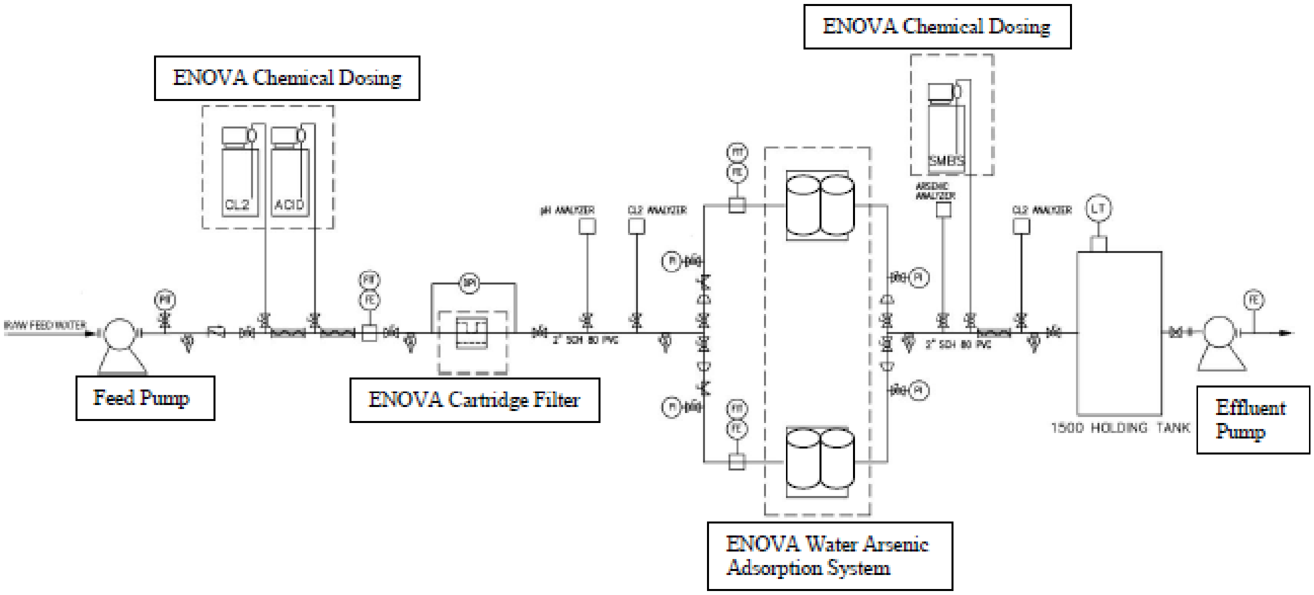

Figure 3. Hydrogel single use spent media adsorption system

Figure 4 shows a schematic of the basic components of an RO membrane technology system.

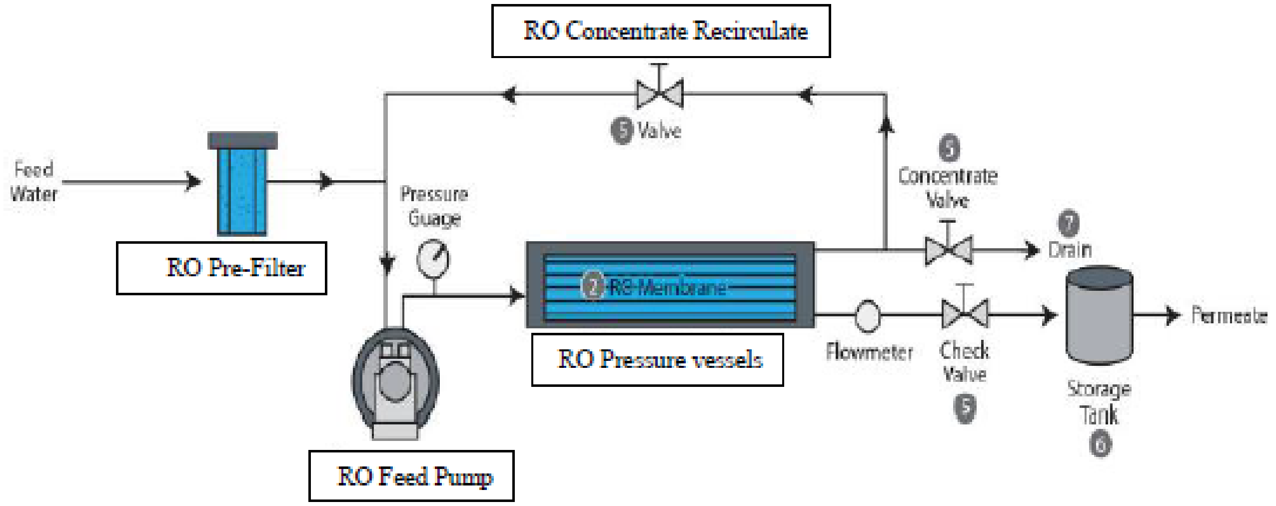

Figure 4. RO membrane treatment system technology

A typical low voltage components for the chemical pretreatment for an RO membrane treatment system includes Disinfection, Coagulant flocculants, scale inhibitor, dechlorination, and activated carbon to remove chlorine and organic compounds.

The major advantages and components of the Hydrogel low energy single use spent media adsorption technology in comparison to the RO membrane treatment system technology include the following:

Equipment Description	RO Membrane technology	Hydrogel Single use media spent adsorption technology
Feed Pump	High pressure energy (250 to 350 psig)	Lower pressure energy (35 to 50 psig)
Membrane Cleaning pumping system	- High pressure energy (50 to 100 psig) - Chemical pump energy (25-50 psig) - Cleaning chemical storage mixer energy	N/A
Chemical feed pumping systems	Chemical metering pumps energy (50-100 psig)	Chemical metering pumps energy (40-50 psig)

The following tables 1 and 2 presents a comparison summary of the energy consumptions for the Hydrogel low energy single use media spent adsorption technology and the RO membrane treatment system technology period from March 2018 to December 2019.

Table 1. Energy consumption data for the Hydrogel Media Adsorption (Single use with spent media reduction).

Period	Water flow	Hydrogel Media Adsorption (Single use with spent media reduction)			
Date	Monthly flow (gallon)	Power (Kwh) Low Voltage, 240 Volt sub panel	Power (Kwh) High Voltage, 480 Volt sub panel	Total Power (Kwh)	Power (Kwh/1000 gal)
March 2018	1869630	44.31	1850.77	1895.08	1.01
April 2018	1822590	43.20	1834.88	1878.08	1.03
May 2018	1939320	45.95	1926.4	1972.35	1.02
June 2018	1939770	45.96	2170.46	2216.42	1.14
July 2018	1988700	47.12	2148.95	2196.07	1.10
August 2018	1987200	47.09	2114.93	2162.02	1.09
September 2018	1884610	44.65	1835.65	1880.3	0.99
October 2018	1688870	40.02	1792.06	1832.08	1.08
November 2018	1953960	46.30	1941.09	1987.39	1.02
December 2018	1698120	40.24	1911.21	1951.45	1.15
January 2019	1739640	41.22	1930.62	1971.84	1.13
February 2019	1795590	42.55	1792.95	1835.5	1.02
March 2019	1436190	34.03	1622.22	1656.25	1.15
April 2019	1440660	34.14	1736.88	1771.02	1.23
May 2019	1657680	39.28	1667.11	1706.39	1.03
June 2019	1748280	41.42	1904.37	1945.79	1.11
July 2019	1561500	37.00	1625.73	1662.73	1.06
August 2019	1820460	43.13	1881.69	1924.82	1.06
September 2019	1583430	37.52	1752.63	1790.15	1.13
October 2019	1970340	46.69	2040.9	2087.59	1.06
November 2019	1758870	41.68	1979.01	2020.69	1.15
December 2019	1788240	42.37	1945.05	1987.42	1.11
				Average power (kwh/1000 gals)	1.09

Table 2. Energy consumption data for the RO Membrane Treatment System

Period	Water flow	Reverse Osmosis Membrane Filtration System (With Energy Recovery)			
Date	Monthly flow (gallon)	Power (Kwh) Low Voltage, 240 Volt sub panel	Power (Kwh) High Voltage, 480 Volt sub panel	Total Power (Kwh)	Power (Kwh/1000 gal)
March 2018	1869630	76.2	12925.23	13001.43	6.97
April 2018	1822590	80.82	13422.38	13503.2	8.00
May 2018	1939320	83.55	13439.52	13523.07	7.74
June 2018	1939770	87.33	15439.12	15526.45	7.63
July 2018	1988700	94.77	15292.86	15387.63	6.41
August 2018	1987200	94.68	15061.52	15156.2	7.59
September 2018	1884610	78.05	11999.22	12077.27	6.80
October 2018	1688870	72.87	12742.08	12814.95	7.70
November 2018	1953960	83.52	13199.41	13282.93	7.59
December 2018	1698120	75.57	12996.22	13071.79	6.83
January 2019	1739640	71.04	13128.21	13199.25	7.73
February 2019	1795590	77.64	12192.06	12269.7	8.25
March 2019	1436190	70.44	11031.09	11101.53	5.23
April 2019	1440660	70.02	11810.78	11880.8	7.45
May 2019	1657680	54.27	8616.34	8670.61	7.13
June 2019	1748280	76.5	12949.71	13026.21	7.07
July 2019	1561500	73.32	11054.96	11128.28	7.57
August 2019	1820460	81.42	12795.49	12876.91	7.09
September 2019	1583430	74.1	11917.88	11991.98	7.70
October 2019	1970340	88.98	13878.12	13967.1	7.44
November 2019	1758870	79.26	13457.26	13536.52	6.97
December 2019	1788240	85.2	13226.34	13311.54	8.00
				Average power (kwh/1000 gals)	6.63

From tables 1 and 2, the average energy savings comparison between both treatment technologies are as follow:

Average Energy savings: ((6.63 - 1.09)/6.63) X 100%= 83.56 %

The Energy savings calculations show that the Hydrogel single use media spent adsorption technology provides around **83.56 %** over the RO membrane treatment system technology.

However there are additional potential savings the Hydrogel single use media spent adsorption technology can also offer, such as the following.

1. Reduction in demand response enabled by automated demand response technology
2. Reduce Capital cost and Operation and maintenance costs since there are less equipment and pumping required (no cleaning chemicals, backwash or additional chemical feed pumping)
3. Reduction in wastes since no reject waste with the hydrogel single use system.
4. Increase in water production since there is no reject as the recovery of an RO system is around 80-85% at best.
5. Air pollution emissions reduction since there are less pumping consumption and no chemical cleanings.

Should you have any questions, please contact me.

Sincerely,

KHALIL KAIROUZ CONSULTING
KKC
CALIFORNIA USA

REGISTERED PROFESSIONAL ENGINEER
KHALIL ANTOUN KAIROUZ
No. 28941
MECHANICAL
STATE OF CALIFORNIA

Khalil Kairouz, Ph.D., P.E., CEM, LEED AP
President
Certified Energy Manger, AEE license #13607

Exp: 6/30/2020