Pilot Study Report

on

WRT's SMR™ Hexavalent Chromium Reduction and Removal System

conducted by

Water Remediation Technology LLC
Arvada, Colorado

for the

County of San Bernardino Water / Sanitation Division
Victorville, California

July 5, 2018

Executive Summary

California water district authorities have been working with water treatment researchers and water service/equipment providers in assessing available drinking water treatment methods for the removal of hexavalent chromium from their groundwater supplies. Water Remediation Technology LLC (WRT) has worked with California water districts in developing a hexavalent chromium removal system with the primary objective of reducing operating costs and waste treatment residual volumes when compared to standard anion exchange technology. The results have been very positive and led to the formation of WRT's Selective Metals Reduction™ (SMR™) hexavalent chromium removal system. This latest on-site SMR™ demonstration pilot test was conducted in cooperation with the County of San Bernardino Water/Sanitation Division in California at one of their drinking water service wells. Water produced from this well tests positive for hexavalent chromium in excess of the 2013 proposed California drinking water MCL standard of 10 µg/L. During the course of on-site testing, the State Water Resources Control Board (SWRCB), Division of Drinking Water (DDW) hexavalent chromium limit of 10 µg/L has been rescinded, thus returning the statewide MCL limits to 50 µg/L total chromium. It is however the expressed intent of the SWRCB Division of Drinking Water to revisit the hexavalent chromium MCL regulation in the immediate future. The County of San Bernardino Water/Sanitation Division continued the on-site SMR™ pilot work to conclude the testing should hexavalent chromium removal be implemented at a later date. The WRT SMR™ hexavalent chromium removal system specifically targets hexavalent chromium for chemical reduction and removal using a unique, high efficiency media contactor and simple, packed-bed media filtration for effective and complete removal of all chromium metal constituents from the raw water source.

WRT installed a 1.20 gallon per minute (gpm) pilot test system at CSA 70 Zone J Well 5; a County of San Bernardino Water/Sanitation Division groundwater well, which operates daily. The hexavalent chromium concentration of water produced from this well tests consistently between 18 and 22 µg/L. The pilot test equipment was placed into service in late June of 2017, treating a small bleed stream from the main well water supply. An automated control system accommodates interruptions in flow from the well water source.

The objectives of this pilot study are to 1) document the effectiveness of the WRT SMR™ hexavalent chromium removal system on the removal of chromium contaminant from the Division's well water to meet regulatory compliance and general chromium metal removal to non-detectable levels, 2) document the operational efficiency of the removal system with continuous service operation including shutdown and restart conditions, and 3) develop the water treatment residuals waste determinations for estimating waste material disposal requirements and overall operating costs.

The results of this study show very successful removal of hexavalent chromium contaminant from the well water on a continuous basis for water treatment to laboratory non-detection levels, well below the proposed SWRCB - DDW lower limit MCL. Once adjusted for the particular water conditions at the well and automated filtration backwash

rate requirements, the WRT proprietary media contactor performed very efficiently at rapid reaction for hexavalent chromium reduction with minimal chemical reagent addition rates. Non-detectable levels of chromium constituents in the finished water occurred in all conditions where the reagent injection system was operating as designed, and the media filter unit was operating within the recommended range. The WRT SMR™ proprietary media reactor performed very efficiently at rapid chemical reaction for hexavalent chromium reduction with minimal chemical reagent addition rates of less than 1.0 mg/L.

The solids waste collection analysis portion of the pilot study allowed full characterization of the waste residuals generated and removed in the treatment process. Non-hazardous disposal options are available for the waste material based upon the RCRA TCLP testing performed. The waste material quantity generated is quite modest, potentially allowing for economical disposal in California hazardous waste disposal.

Efficient removal of hexavalent chromium along with low quantities of waste material generated and requiring disposal are established characteristics of the WRT SMR™ process. We have successfully met and in some cases exceeded our objectives in developing this process through multiple site pilot testing and are at a point in process development for demonstration of full-scale well treatment.

The SMR™ Chromium Removal System and Study Overview

Water Remediation Technology is testing a hexavalent chromium removal system using select reducing agent addition, a high efficiency SMR™ media contactor and a media filtration system. Hexavalent chromium is quickly and safely reduced to trivalent chromium and adsorbed within a formed solid adsorbant to be collected on the downstream media filter. The solid adsorbant product is removed from the media filter with a backwash cycle for collection of solids and final settling, solids dewatering and preparation for disposal. Disposal material volumes are small; amounting to less than 40 grams per 1,000 gallons treated. The system is designed for water to move through the treatment equipment using the water pressure generated from the well source. Water treatment chemical reagent added to the water for the treatment process, the proprietary contactor media and post treatment filtration media are NSF/ANSI-44/60 and NSF/ANSI-44/61 certified for use in drinking water systems. The WRT proprietary contactor media is not regenerated and will have a nearly unlimited service life. Hexavalent chromium removal is simply based upon the consistent water treatment chemical reagent addition rate and effective adsorbant filtration and removal. WRT developed an on-site pilot test apparatus designed to simulate actual reagent chemical addition rates, the proposed high efficiency media contactor and an automatically operated downflow media filtration unit. Raw water and treated water testing for total and hexavalent chromium in addition to soluble iron are used to monitor system performance. The settled solids from a collected filter backwash is tested for California wet test leaching standard and TCLP criteria for characterization and suitability of non-hazardous solid waste disposal.

Test Equipment Overview

The pilot test treatment equipment was erected in WRT's pilot operations facility in a self-contained enclosed trailer unit and transported to the County of San Bernardino Water Division's Well 5 site for setup. The pilot-scale treatment system consists of a prefilter, a reducing agent injection system to precisely meter reducing agent upstream of an in-line mixer, a 4-inch diameter by 40-inch vertical height contactor column, containing approximately 24-inches (4,500 grams) of WRT proprietary inorganic contactor media and a downflow 6-inch diameter by 48-inch vertical height media filter unit containing approximately 24-inches of sized filter media. Refer to Figure 1 for an illustration of the pilot test equipment. A final cartridge filter unit is used to assess the effectiveness of the media filter system. The source water enters the pilot test unit from a connection on the main well discharge piping through a flexible hose, a pressure reducing valve and a flow meter totalizer. The process is upflow through the media contactor, with the flow exiting the top of the column, then directed through flexible tubing to the downflow filter media column. During the service cycle the test samples were collected at the raw water source prior to the chemical addition and at the treated water discharge point downstream of the media filter unit.

The media filter column is backwashed automatically using one of several backwash trigger points set at the PLC controller. Set points for filter backwash can be initiated manually, by operating time interval, by treated volume throughput or by filter differential pressure loss. A filter backwash frequency of approximately once per operating day was chosen as a target set point with filter differential pressure not to exceed 4 psid. The well system is continually operational providing 24-hours of operation for the pilot system. Backwashing is accomplished by directing raw water upflow through the media column to expand the media bed and release the collected solids to exit the out of the top of the filter media column. The backwashed liquid and solids are collected separately in one of two cone bottom settling tanks for solids settling and final collection. Collected solids are further settled and clear liquid decanted from the solids that are retained for laboratory testing to determine solids settling rate, and for characterization.

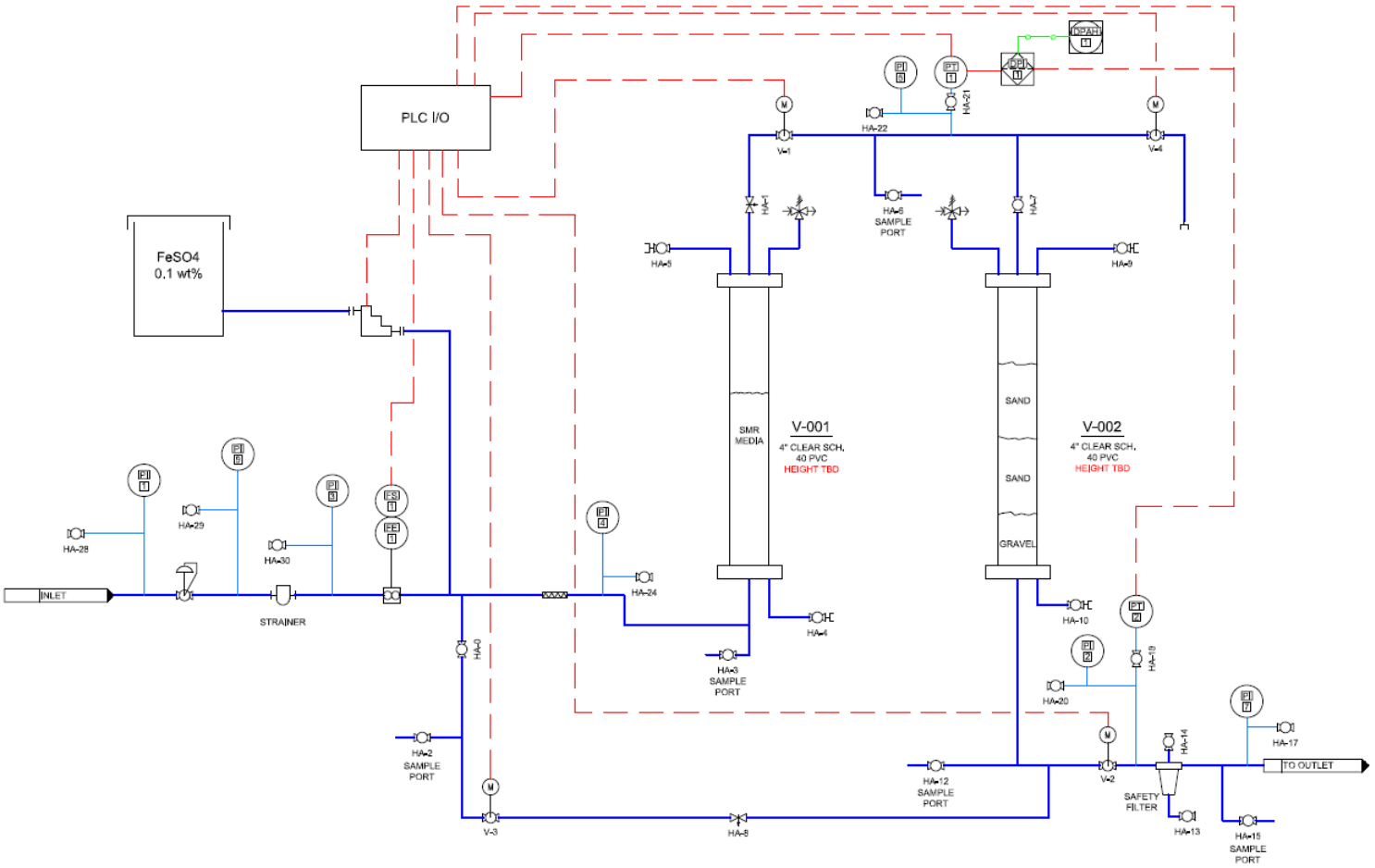

Figure 1. SMR™ Pilot Study Equipment Process flow diagram.

Figure 2. Photographs of SMR™ Pilot Study Equipment and PLC Control panel.

Statement of Purpose

The hexavalent chromium levels in several County of San Bernardino Water Division wells exceed the 10 µg/L, which is the previously enacted MCL by the state of California. Hexavalent chromium levels in the raw water from Well 5 consistently test between 18 and 22 µg/L, exceeding this MCL.

The purposes of this study are to:

- Demonstrate the ability of the WRT SMR™ Hexavalent Chromium Treatment Process to consistently and effectively reduce the hexavalent chromium levels to near non-detect on water from the County of San Bernardino Water Division well water supplies.
- Demonstrate consistent hexavalent chromium removal through shutdown and restart.
- Comply with California SWRCB Division of Drinking Water regulatory testing requirements for process pilot testing protocol.
- Provide a solution to disposal concerns over collected chromium containing water treatment residuals and finalize estimated overall water treatment costs.

Analytical

Inorganic water analyses were performed by external laboratories certified by the National Environmental Laboratory accreditation Program. Hexavalent and total chromium in the raw and treated water were sampled normally three times weekly during continuous service runs between daily backwash operations and analyzed immediately. Test samples are submitted to the Clinical Laboratory of San Bernardino, Inc. using USEPA and California Water Resources Control Board recognized testing methods for drinking water.

Methods for analysis are:

Hexavalent chromium	EPA 218.6
Total chromium (low level)	SM 3113B
Iron (total and dissolved)	EPA 200.7

Results and Discussion

Pilot System Operation and Specifics

Operation of the pilot system consists of injecting the requisite quantity of the reducing agent prior to entering the SMR™ contactor vessel. The treated water exiting the contactor vessel must be filtered to remove adsorbant solids formed during the oxidation-reduction process. These solids contain the adsorbed chromate material. A downflow media filter unit is selected to achieve this, which provides simple backwash removal of the collected solids and immediate reuse of the filter for subsequent service periods. The media filter service period and filtration efficiency is wholly dependent upon the quantity, size and characterization of the solids collected. For the initial test equipment, a single size of silica sand media was selected from various filter media types and particle sizes. This first run test filter is not necessarily optimized for the specific particle size solids formed in the process but provides a starting point and backwash frequency method for determining the most effective filter media sizing for the conditions involved. Media filter backwash frequency can be varied to control collected solids accumulation within the filter media and optimize the media filter service run length.

Pilot testing at the County of San Bernardino Water Division well site was conducted in three phases of study corresponding to changes or modifications in pilot test apparatus in response to analytical performance results obtained in periodic water sampling of the treated water. An approximate one-week time delay between water sample submittal and return of the analytical test report is typical. As a result of this delay, three sampling days may be submitted before a treatment process change can be implemented. The testing phases reflect these periods of time.

In response to results obtained during testing and some observed iron solids leakage from the downflow filter unit, two modifications were made to the filtration step of the SMR™ process. These changes are best described in the analytical results obtained, categorized by the separate phases of the pilot test. All the iron collected and sent in for testing was analyzed to be fully oxidized ferric oxide form. This suggests that the media filter is not performing full filtration of the iron particle but allowing some passage of filterable solids. revised media filter backwash schedule, increasing the backwash frequency to an equivalent once per day frequency, was enacted after the first two weeks of operation. Some improvement of the filtration efficiency was observed but residual iron particulates are present in some samples. Following the 8/7/2017 sampling it was decided that a modification of the filter media was necessary to assure full iron particle filtration to non-detect levels in all final treated water samples as has been demonstrated on a number of samples.

The Phase 1 portion of the pilot system operated from the initial start of testing for 25 consecutive days. The pilot equipment was comprised of the components and design originally constructed. Data obtained from sampling during this operating period are provided in Table 1. It became clear at the return of the 8/2/2017 sample results that the process was no longer functioning in reducing the hexavalent chromium for removal. Two additional samples were drawn before the results could be analyzed and the pilot system was stopped to assess the problem. Data provided showed adequate hexavalent chromium reduction during the first 2 weeks of operation. However, filtration of the reactant products is incomplete as shown from the continued passage of total chromium (trivalent species) in the filter discharge. Of more relevant concern was the 8/2/2017 and subsequent results suggesting that the reduction reaction of hexavalent chromium was no longer occurring. A complete evaluation of the chemical injection system was scheduled and completed. It was initially thought that the filter was passing much of the suspended reactant products. A decision was made to additionally test for total iron (the primary reactant product of chemical reduction) in the discharge water. All samples drawn of the discharge water would now include total iron analysis from the 8/2/2017 sampling.

		Raw Water		Treated Water		
Sample Date	Cummulative Throughput (gal)	Hexavalent Chromium (Cr^{6+} µg/L)	Total Chromium (Total Cr µg/L)	Hexavalent Chromium (Cr6+ µg/L)	Total Chromium (Total Cr µg/L)	Iron (Fe µg/L)
7/14/2017	2,936	21	21	ND	3.7	
7/17/2017	6,509	20	22	ND	6.6	
7/19/2017	8,687	19	19	ND	2.3	
7/21/2017	10,980	19	19	ND	4.0	
7/24/2017	15,346	20	20	ND	6.8	
7/26/2017	18,248	20	21	ND	6.0	
7/31/2017	25,268	19	19	ND	6.1	
8/2/2017	27,757	19	19	14	15.0	ND
8/4/2017	30,763	19	19	13	14.0	ND
8/7/2017	35,974	18	18	14	18.0	130

Table 1. Phase 1 SMR™ Pilot Testing Raw and Treated Water Analytical Results

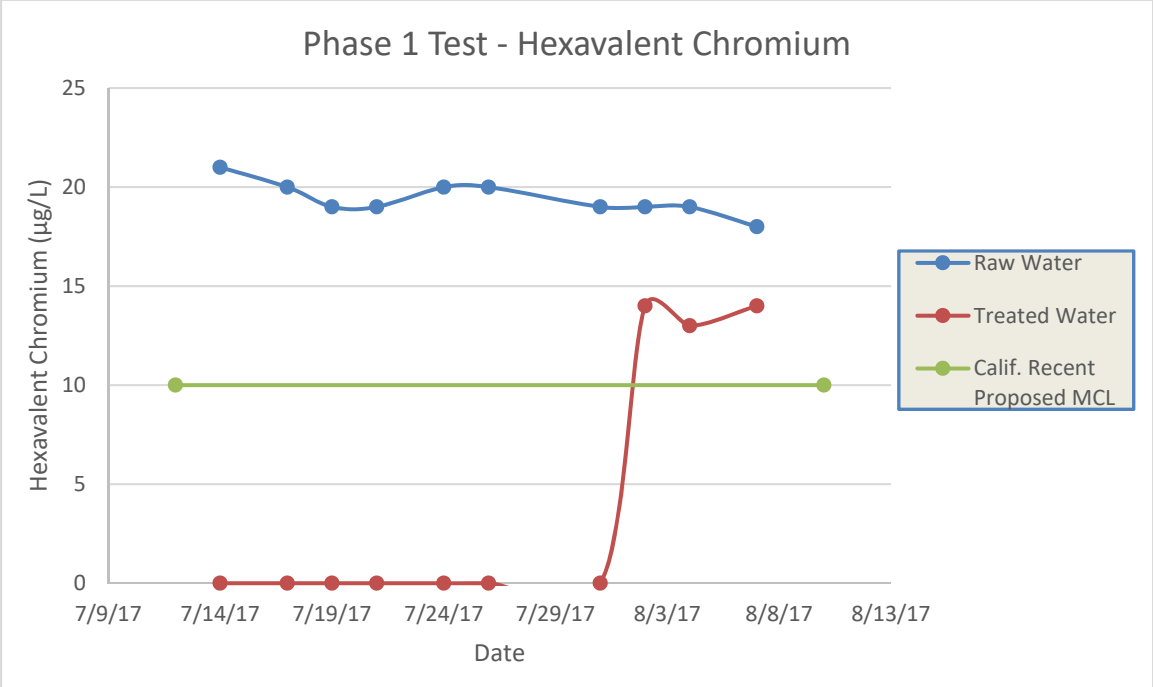

Figure 3. Phase 1 SMR™ Pilot Testing Raw and Treated Water Analytical Results

The incomplete filtration of the treated water was addressed using a slightly larger filter unit containing smaller filter media to provide more effective impedance of very small entrained particulates. The filter operation remained as originally envisioned with estimated backwash frequency at 24 hours of operation, although a greater backwash flow rate is required to obtain equivalent filter media bed expansion and full purging of particulate contaminants from the media. The changes to the chemical injection system involved correcting injection rates to avoid excessive reagent pre-dilution. A newly installed reagent injection pump, now sized for less than one-half the initial flow rate range, provided the ability to inject a more concentrated chemical accurately at very low volumes. The fact that such low volumes of reagent chemical are needed at these low pilot test flow rates, the 5 percent chemical concentration required more than 50 to 1 dilution for a 2.5 mL/min injection rate. The pre-dilution of the reagent chemical allowed the mixed solution to become unstable. The reagent prematurely oxidized in the reagent holding tank rendering the chemical nearly ineffective. A revised reagent injection pump sized to accurately meter 1.2 mL/min of reagent allowed for less pre-dilution of the reagent chemical. As a precaution, premixed reagent chemical volumes were kept very small and distilled water was used for all subsequent reagent chemical dilutions. This concern is a symptom created by the reduced flow rate of the pilot scale system and should not be an issue with larger full-scale treatment as pre-dilution of the reagent chemical is not required. The correction to the chemical injection system was completely successful as no further results were obtained showing inadequate hexavalent chromium reduction in the discharge water.

Phase 2 of the pilot testing is defined from the restart date of the test unit on 8/28/2017 through the 9/29/2017 sampling. During this part of the pilot testing, the pilot unit operation was suspended over weekend days and restarted on the following Monday as weekend daily monitoring of the test equipment would not be continued. The analytical results for Phase 2 testing are tabulated in Table 2.

		Raw Water		Treated Water		
Sample Date	Cummulative Throughput (gal)	Hexavalent Chromium (Cr^{6+} µg/L)	Total Chromium (Total Cr µg/L)	Hexavalent Chromium (Cr6+ µg/L)	Total Chromium (Total Cr µg/L)	Iron (Fe µg/L)
8/28/2017*	51,649	19	19	ND	ND	ND
8/29/2017*	52,748	18	19	ND	ND	ND
8/30/2017*	54,572	19	19	ND	2.3	130
8/31/2017*	56,178	20	20	ND	2.5	110
9/1/2017	57,907	17	19	ND	ND	ND
9/6/2017	59,562	19	19	ND	ND	ND
9/8/2017	62,861	19	20	ND	1.8	ND
9/11/2017	63,136	19	19	ND	1.4	ND
9/13/2017	66,310	19	19	ND	ND	ND
9/15/2017	69,946	18	20	ND	4.1	190
9/18/2017	70,039	18	21	ND	2.8	120
9/20/2017	73,688	18	18	ND	1.6	ND
9/26/2017	77,272	19	19	ND	2.1	110
9/29/2017	82,316	20	22	ND	2.1	ND

* Analytical samples drawn by WRT during the pilot test service period

Table 2. Phase 2 SMR™ Pilot Testing Raw and Treated Water Analytical Results

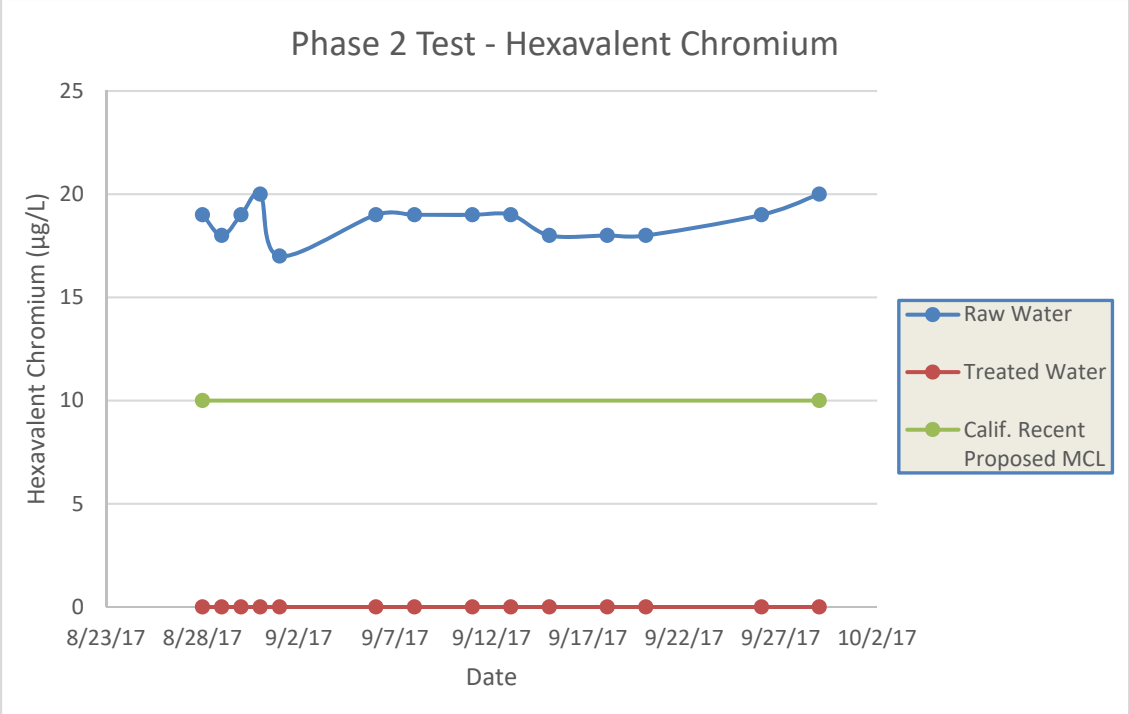

Figure 4. Phase 2 SMR™ Pilot Testing Raw and Treated Water Analytical Results

Pilot test samples from the Phase 2 portion of the testing show mixed performance results. All treated water sample analyses returned hexavalent chromium results at or below the EPA 218.6 reportable limit of 1.0 µg/L. Reduction of hexavalent chromium in the raw water appears to be complete. Revised chemical injection measurements and monitoring were structured to maintain measurable ferrous entering the SMR™ media column below 0.50 mg/L. The results also indicate that a small fraction of the reduced chromium exits the filtration unit. Occasional samples showing measurable reactant product iron from 0.1 to 0.2 mg/L suggest some passage of small particulate from the filter. This reactant products passage is most likely accounting for the presence of measurable particulate chromium. The passage of total chromium averaged less than 2.0 µg/L, never exceeding 5 µg/L at any point of the testing. After review of the results with the County of San Bernardino Water Division management, a final pilot system equipment change was decided upon for a final optimization of the filtration system in an attempt to approach near non-detect chromium and reactant product results in the finished water.

The changes proposed for this final portion of testing involved replacement of a smaller filtration media type into the final media filter. Although many filter media types and sizes are commercially available, a compromise between operating pressure loss, backwash volume requirements and particle size range limit the selection to a few common filter media types. It was decided to replace the filter media with an incrementally smaller, similar material to tighten the pore volume of the media bed in an attempt to trap smaller suspended particulate from the water exiting the SMR™ reactor column. Phase 3 of the pilot testing includes results obtained using the revised filter media column.

Phase 3 testing occurred from the restart of the pilot test unit on 10/5/2017 until the pilot study was terminated on 11/1/2017. Results are shown in Table 3.

		Raw Water		Treated Water		
Sample Date	Cummulative Throughput (gal)	Hexavalent Chromium (Cr^{6+} µg/L)	Total Chromium (Total Cr µg/L)	Hexavalent Chromium (Cr6+ µg/L)	Total Chromium (Total Cr µg/L)	Iron (Fe µg/L)
10/5/2017	87,930	19	21	ND	ND	ND
10/10/2017	91,395	19	19	7.3	7.9	410
10/11/2017	93,140	18	19	ND	3.1	150
10/18/2017	99,936	18	19	ND	1.5	ND
10/19/2017	101,615	18	20	ND	1.4	ND
10/20/2017	102,998	19	22	ND	2.4	100
10/23/2017	104,799	20	21	ND	1.6	ND
10/25/2017	108,300	18	18	ND	1.6	ND
10/27/2017	111,491	19	20	ND	1.2	ND
10/31/2017	114,725	20	20	ND	1.7	ND
11/1/2017	116,628	19	19	ND	1.7	ND

Table 3. Phase 3 SMR™ Pilot Testing Raw and Treated Water Analytical Results

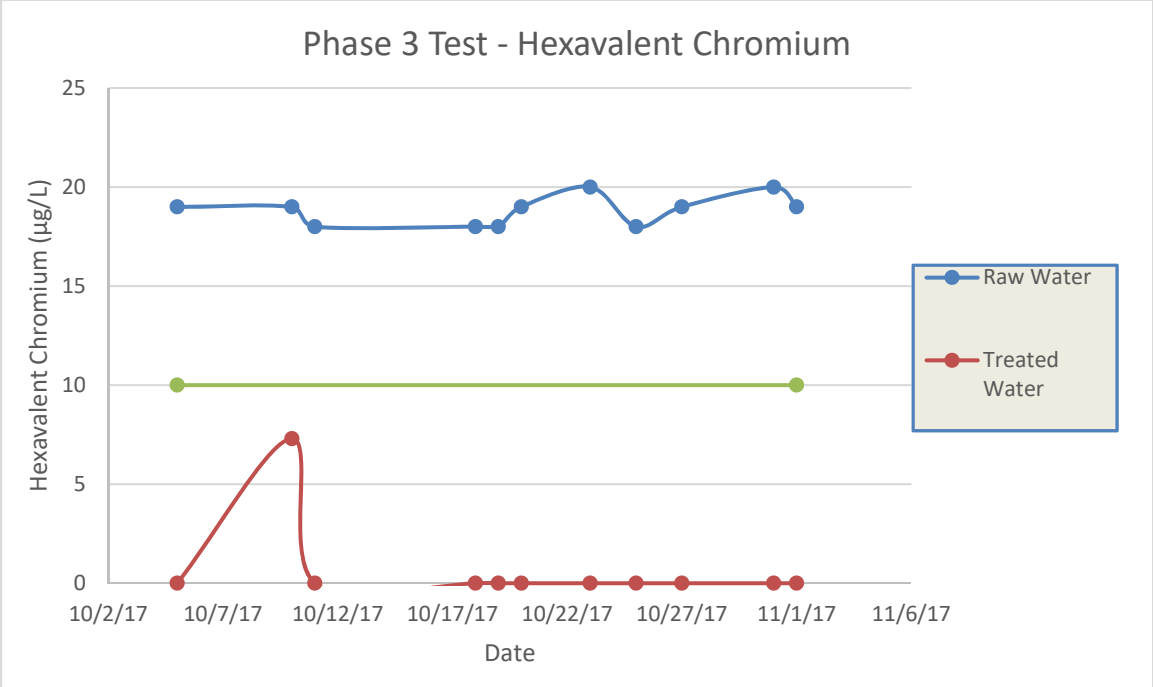

Figure 5. Phase 3 SMR™ Pilot Testing Raw and Treated Water Analytical Results

Apart from the 10/10/2017 and 10/11/2017 sampling, the effluent results were improved averaging 1.4 µg/L total chromium. The 10/10/2017 and 10/11/2017 sample results were a concern and initiated a review of the pilot equipment. It was revealed during this review that a malfunctioning backwash control valve was not allowing daily filter cleaning. This condition precipitated high solids and carry-through of precipitated reactant products and chromium. The malfunctioning valve was refurbished, put back into service and the testing resumed. The media pressure filter functioned very well for the remainder of the testing; performing iron solids removal to at or below 0.10 mg/L.

This final version of the pilot testing equipment performed very well, averaging selective removal of greater than 99.4 percent of hexavalent chromium and 90 percent of total chromium during the testing including the pilot test malfunctioning equipment. The results are very consistent with reagent injection rates of less than 0.5 mg/L reducing agent entering the SMR™ contact reactor column. Phase 3 testing results are most representative of optimized operation of the SMR™ process and can be expected in a full-scale system installed at this well site.

A volume of water processed and treated at the County of San Bernardino Water Division well site from the start of testing totaled 116,600 gallons. Reagent addition rates varied between 0.3 and 1.2 mg/L measured reducing agent sampled downstream of the injection point. All reactant product collected through daily filter backwash operations were settled and separated from the decanted water for characterization and laboratory testing.

Reactant Solids Filtration, Collection and Analysis

The SMR™ process utilizes coprecipitation of reactant products and reduced chromium solids which exit the top of the upflow SMR™ media contactor. These solids contain the converted chromium solids and are separated from the treated water using common downflow media filtration. Filtration and solids removal efficiency can be measured using a simple total iron sampling of the untreated and treated water. Should iron particles remain in the treated water, the filtration of the chemically treated water is incomplete. From the 8/2/2017 sampling, the effluent sample was tested for total iron content. Refer to Table 4 for the residual total iron in both the raw untreated water and the finished treated water. Occasionally treated water samples showed a residual iron up to 0.170 mg/L and during a malfunctioning filter backwash valve, a single effluent sample measured 0.419 mg/L total iron. Much attention was given to the downflow media filter performance to reduce passage of reactant solids as low as possible. When the filter operated as designed with a full deep cleaning backwash cycle and consistent reagent injection to the reactor contact column, the effluent results could reasonably be predicted as non-detectable low-level chromium and non-detectable total iron values. When detectable quantities of low-level chromium were present, it would usually be accompanied with measurable total iron. Presence of either material is an indication of incomplete particulate filtration and therefore the pilot testing phases were specifically obtaining results for particulate filter modifications and changes. In general observation, the filtration system did function more efficiently post changes in each case.

The media filter backwash operations consisted of isolating the filter column from service, introducing raw water to the bottom column collector nozzle and opening the top backwash outlet valve. Backwash flow regulation was automatically controlled and adjusted to provide approximately 30 percent filtration media bed expansion to release the collected solids from the filter media bed. About 20 gallons of backwash water volume was generally required to purge the media bed of collected particulate solids to the point where the backwash water runs essentially clear. The backwash flow was set to 2.8 gpm for a total time of 8 minutes. This volume corresponds to a 5.6 BV of total filter backwash water.

a. 

b. 

Figure 6. Photographs of recovered filter backwash water as a. first collected and b. after 2 hours settling time.

Waste solids collected can be described as very small particulate iron oxide material having deep reddish-brown color. All filtered solids were collected in one of two backwash collection tanks where the solids were allowed to settle, and the supernatant backwash water decanted from the settled solids. Initially the backwashed solids were settled without coagulant aids. A backwash frequency of once per 24-hour operating period proved to be too numerous and did not provide sufficient settling time for the solids. A small addition of a cationic polymer was then used to assist in clarification of the backwash solids. After a 0.6 ml addition of 100:1 diluted cationic polymer, the solids quickly settled within 2 hours for backwash collection tank decanting in preparation for the next backwash sequence. Weekly, the settled solids were drawn off the bottom of the backwash tank in a collection bucket for further concentration. At the conclusion of the pilot test, all solids sludge was consolidated in a single mass sample. At each treated water sampling, the backwash supernatant liquid was submitted for chromium analysis.

Given adequate time (greater than 24 hours), the waste solids will settle in quiescent holding. Settling was found to be remarkably improved using a small addition of a polymer coagulant filtration aid. Suspended solids settling in the backwash collection tank volume visually clarified within 2-3 hours of settling sufficient for decanting of the clear supernatant liquid. 7 to 8 drops of 100:1 diluted coagulant polymer was used in each backwash collection of approximately 20 gallons.

The results of the decanted backwash supernatant liquid analysis are provided in Table 4. In general, the backwash supernatant liquid did contain some chromium material. In all samples analyzed, the hexavalent chromium content never exceeded that measured in the

raw water. Some chromium in trivalent reduced form was present. Most likely this material was bound to the small reactant solids still present in the sample as suspended material. Clearer samples from the decanted supernatant were observed to test lower in total chromium over more turbid decant samples. The conclusion from these results should provide support for full recovery of the backwash water volume to the treatment process. Reinjection of the backwash supernatant to either upstream of the reaction contact vessel or just upstream of the particulate solids filter will have no measurable effect on the treated water chromium concentration once reinjection dilution ratios are realized.

	Decant Water	
Sample Date	Hexavalent Chrome (Cr^{6+} µg/L)	Total Chrome (Total Cr µg/L)
7/17/2017	19	360
7/19/2017	18	130
7/26/2017	14	22
7/31/2017	10	21
8/4/2017	9	55
8/7/2017	20	99
8/31/2017	12	
9/1/2017	4.2	19
9/6/2017	4	23
9/11/2017	1.7	16
9/13/2017	2	22
9/15/2017	3	62
9/18/2017	11	17
9/26/2017	16	26
9/29/2017	16	61
10/5/2017	9.2	9.4
10/10/2017	7.8	19
10/11/2017	9.4	24
10/18/2017	9.5	31
10/19/2017	12	50
10/20/2017	12	35
10/23/2017	10	31
10/25/2017	14	55
10/27/2017	8	35
10/31/2017	13	16
11/1/2017	0	58

Table 4. Decant supernatant water chromium content sample analysis.

Reactant Solids Characterization

A total of 7,925g of settled sludge of approximately 7,500 mL volume was collected over the course of the pilot testing. About one third of the total wet sludge (2,500 mL) was filtered to concentrate a wet cake for laboratory solids and leachate testing. Vacuum filtration yielded an 18 percent solids cake. Two small samples of the cake were dried at 300 deg. F in a laboratory oven for solids surface analysis. An additional small dried sample was prepared and submitted for elemental solids surface analysis using X-Ray Fluorescence (XRF).

Elemental Constituents

Dried solids XRF analysis as expected revealed elevated metals for chromium. 0.48 percent by weight of the dry solids sample is chromium metal. However other metals measured significantly high. Copper, zinc, arsenic and notably vanadium were present in elevated quantity. Refer to Appendix B for the detailed XRF laboratory report. This does show the concentrating effect the SMR™ process has on selectively removing trace metals from the water stream. Presumably, most of the metal materials collected in the SMR™ waste solids not attributed to the precipitated iron contribution of the reagent material originate from the source water as the SMR™ contactor media and the post treatment filtration media through NSF 61 certification testing show negligible metal leaching characteristics. The clear majority of the waste solid material is iron oxide with more than 10 percent of the solids silica and titanium oxide sand from the well water. The balance being insoluble calcium, magnesium and potassium salts.

The vanadium content in the collected solids measure more than twice the chromium content at 10,000 ppm or approximately 1% by weight of the solids on a dry weight basis. Although vanadium is not a RCRA regulated metal it is listed as a Detection Limit for Reporting (DLR) as a drinking water constituent. In the event the decanted water is reinjected to the SMR™ treatment process, we can estimate the carryover concentration of the vanadium contained in the entrained solids to be approximately twice the chromium content. Not accounting for filtration efficiency on the reinjected solids, the dilution effect of the backwash volume in comparison to the treated water throughput of more than 80 to one or about 1.2 percent, the net effect of reinjection could potentially raise the vanadium concentration less than 1 µg/L. Decant water reinjection can be employed in this process for nearly complete water savings without consequence to the treated water quality.

Waste Disposal Criteria Testing

The waste sludge material submitted for leachate testing returned mixed results consistent with those on previous pilot tests. Refer to Appendix C for the leachate testing report. Samples from this collected sludge showed no hits or leached RCRA metals from the TCLP Leachate SW846 1311 test. All metal constituents tested below the leachate MCL criteria. This is not the case with the California specified STLCE Extraction test. Here the sample is subjected to a more rigorous leaching medium.

The test results reveal leachate results above reportable limits for several metals. As expected the concentration of chromium in the leachate exceed reportable limits by greater than two orders of magnitude. In addition, limits for arsenic, beryllium, copper, mercury and zinc all exceed the allowable reportable limit concentrations. It can be surmised that waste sludge material generated at this well using the SMR™ process will require disposal as hazardous metal waste by California waste disposal standards.

Quantitative Waste Analysis

Based on the total waste material generated throughout the duration of the pilot study, an estimated expected quantity in full-scale system operation can be extrapolated. This value is subject to operational conditions originally selected and modified in the testing. Careful attention to the collection of all waste solids was exercised with no known loss of waste solids apart from trace suspended solids in the decanted supernatant.

116,628 gallons of water was recorded as the throughput from the start of testing. The total volume of 7,500 mL of collected sludge, weighing 7,925 grams was collected. 113.7 grams of dried solids was extracted from a 2,500 mL settled sludge sample. The total volume of settled sludge of 7,500 mL thus calculates to 341.1 grams of dried solids collected from the pilot test or an extrapolated equivalent of 2.92 Kg of dried solids for every 1 million gallons treated. The settled sludge volume for this treated water throughput is 64 liters or 17 gallons. As the settled sludge is allowed to further settle and concentrate, some portion of this volume will be naturally reduced.

Alternatively, filter press dewatering can significantly reduce the total volume of material for more infrequent disposal periods. The 2,500 mL sample of settled sludge was vacuum filtered to simulate equivalent filter press concentration of the solids where the filter cake dewatered to approximately 18 percent solids. This solid material will meet solid waste disposal requirements for free moisture content.

Conclusion and Summary of Testing Objectives

The results obtained for WRT's SMR™ chromium removal treatment have demonstrated consistent and effective removal of chromium contaminant from the San Bernardino well water to very low levels. Some improvements to the overall chromium removal were accomplished through the course of the testing. The removal of hexavalent chromium is complete, providing non-detectable levels in the treated water. The pilot testing revealed effective levels of reagent injection for optimizing chemical use rates. Additional reductions in the reagent injection rate are for all intents and purposes unnecessary, as the reagent injection cost is comparatively small. The modifications to the post media filtration system were fully capable of filtering all solids generated in the reactor process without filtration aids. Simple media sand filtration of the treated water is all that is required. The SMR™ pilot test unit operated reliably during all phases of testing without concern of water supply shutdown or interruption. Restart following a service flow interruption was immediate with no noticeable increase in residual solids carryover from the filter unit. A single backwash inlet valve failure did cause some processing issues resulting in three errant sample results. This type of valve failure is unlikely on a full-scale treatment system and is not representative of a system-wide single point failure concern.

CWRB requirements for hexavalent chromium testing of the decanted supernatant filter backwash water revealed little chromium residual reoxidation to hexavalent state. All

water used for filter backwash tested lower than the raw water inlet hexavalent chromium concentration and can be easily returned to the treatment process. This operational option provides a zero-liquid wastewater process where no wastewater volume collected requires disposal.

The concept of using simple chemical reduction and post waste adsorbent solids filtration appears to generate the least quantity of water treatment residuals per water volume treated. Manageable volumes of waste solids are characterized as containing elevated contaminate metal precipitate and are suitable for non-hazardous waste disposal in all state jurisdictions except California. The WRT SMR™ treatment process specifically targets easily reduced trace metal anion constituents in the raw water without bulk dissolved solids removal or exchange removal of untargeted anion constituents. The final testing objectives for this pilot testing included full system concept verification to provide data for full-scale process development. With the data obtained from waste solids characterization for further developing waste disposal options, these objectives were fulfilled.

WRT continues development of a full-service arrangement for waste residual handling and dewatering methods that should reduce the operating costs and limit the required on-site solids handling equipment at each treatment location. The results of the County of San Bernardino Water/Sanitation District pilot testing for WRT's SMR™ chromium removal process has led us to the conclusion that this treatment method offers the water provider the most cost effective and simple process for reliable hexavalent chromium treatment compared to other more complex and traditional water treatment technologies. The results of our pilot testing here confirm the results obtained in previous pilot testing for this unique and novel treatment method. WRT is confident that the process is ready for full-scale treatment implementation of all portions of the process. Should the County of San Bernardino Water/Sanitation District be prepared to install full-scale hexavalent chromium treatment, we trust that the WRT SMR™ treatment process is given proper consideration.

Appendices available upon request.