TREATMENT OF BRINE THROUGH CHEMISTRY: LESSONS LEARNED

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Abstract

Brine discharge for inland desalination facilities creates hurdles that can affect reliability and efficiency of reverse osmosis (RO) operations. As treatment processes evolve, more complicated feed waters are treated through the purification process, higher recovery is pushed for the RO systems themselves, and concentrate recovery processes are implemented to minimize waste. The resulting supersaturated brine streams are pushed past previously established limits, as are the chemistries that have continually stretched and even broken the bounds of these limits for decades. This paper explores some of the approaches used to measure success as facilities tackle the evolving challenge that is brine transport and disposal.

The complex chemistry of reverse osmosis brine combined with multiple factors of influence throughout the disposal process lead to behavior that is difficult to model and predict, let alone control. Previous work explored preliminary success in remedying these difficulties in two RO facility brine streams, showing potential for long-term reductions on scale accumulation on brine disposal equipment, including piping, concentrate storage tanks, and deep well injection pumps. After years of application, this paper turns the focus on field data for confirmation of chemistry as a successful solution.

This paper presents field data used in the Inland Empire Brine Line in California's Chino Basin and at the Sterling Water Treatment Plant in Sterling, Colorado. The field data explored supports the managing agencies in verifying success of potential solutions. Various angles of operational data have been collected since the implementation of brine control chemistry at these facilities that are gaining ground in brine management. Pipeline level measurements, test pipe deposition records, deep well flowrates under vacuum, injection pump speed cycles – years' worth of patterns and deviations from historical data serve as repetitive evidence of successful improvements in facing the challenge of brine transport and disposal. Field data verifies sustained successful reductions to the amounts of precipitation and deposition of sparingly soluble salts in the brine streams studied. Maintenance cost savings testify to the impact of these advances. In addition to showing evidence of process improvements and cost savings, this paper reveals that monitoring the efficacy of control within the process of brine transport and disposal requires a multi-faceted approach and exposes the challenge water treatment facilities face in streamlining and standardizing testing and data collection for various discharge methods.

I. INTRODUCTION

The benefits of reverse osmosis (RO) as a water treatment method are vast and familiar, with the process taking a flow of questionable water deemed "dirty" and transforming it, providing a source of highly purified, clean water. The origins of modern-day RO date back to the late 1950's with the objective to turn saline solutions into potable water using semipermeable membranes. The first commercial RO desalination plant brought water to the small mountain community of Coalinga, California [1]. Since then, RO has expanded and is widely used in a multitude of applications and sectors including energy production, food and beverage, oil and gas, chemical, pulp and paper, and mining [2]. In fact, organizations around the world implement its capabilities to bring drinking water to communities who otherwise wouldn't have access.

Consequently, purified water does come with a price. A major repercussion of pure water production is the highly concentrated brine or "waste" which is left behind. Brine management and disposal is a complexity in maintaining reliable operation and challenging on both an environmental and economic front, with disposal costs ranging anywhere from 5-33% of total desalination costs [3]. How a facility discharges its brine is also heavily influenced by the volume, quality, geographical surroundings, proximity to discharge point, availability of receiving site, environmental regulations, capital investments, and operating expenses. There are numerous disposal methods, each with their own benefits and drawbacks. Surface water discharge is the most economical and is typically used for seawater applications. Disposal into the sanitary sewer can be an option depending on brine quality, costs and proximity to a wastewater treatment facility. Deep well injection is suitable for inland facilities but is more cost-efficient for larger volumes. Evaporation ponds are useful in drier arid regions where land is less expensive. While less common, brine can be used for irrigating salt tolerant species. Conventional crystallizers and zero liquid discharge operations can completely eliminate liquid waste where salts and minerals can be disposed of or extracted and repurposed, although this comes with high capital and operating expenses [4].

Further complicating brine disposal is the actual chemistry of the brine itself. Brine is made up of concentrated organic and inorganic dissolved solids including salts, metals and other particles which are either approaching or have surpassed their saturation limits. Typically, chemistry, such as antiscalants, have been introduced ahead of the RO which keep these particles dissolved throughout the pure water production process, but it is harder to predict how antiscalants interact with the brine as time passes. There are many factors which could potentially cause the dissolved solids to precipitate including temperature, retention time, stagnation, pH, and aeration [5]. The precipitate can collect in holding tanks and pipelines causing serious problems and further increasing the disposal costs.

Research, data, and experience has shown that managing scale control during brine transport and disposal can pose real challenges, and antiscalants are used to control the brine chemistry in concentrate lines [6], concentrate holding tanks, and during deep well injection [7]. Specifically, applications for which evidence exists of brine transport and disposal problems with scale formation include, desalination for drinking water, mining influenced water, and geothermal energy production [8]. This paper uses field data to explore the impact of fighting chemistry with chemistry at multiple facilities to prevent precipitation and deposition.

1.1 General Background

A previous paper introduced the process of chemistry-focused scale minimization for brine at two facilities working toward minimizing process interruptions caused by post-RO scale during brine transport. Various jar tests were performed and analyzed by reviewing deposition weights, as well as morphology of the precipitate. Following jar testing, implementation in the field provided preliminary process data at one facility, revealing the likelihood of reduced scale deposition [9]. Following these initial results, focus shifts to long-term effectiveness and the methods by which that can be validated, leading to consideration of various field tests and real-time data monitoring.

1.2 The Santa Ana Watershed Authority and the Inland Empire Brine Line

The Inland Empire Brine Line (IEBL) was established in the mid-1970’s to provide a solution in the Southern California Chino Basin for discharging high TDS water. This system consists of 73 miles of pipeline to serve inland municipal drinking water facilities and industry, ranging from commercial laundries to biotech and pharma. This pipeline was designed to transport 30 million gallons per day [10] to the Orange County Sanitation District for treatment suitable for final discharge into the Pacific Ocean.

1.2.1 Municipal Brine Discharge Challenges – Over the years, SAWPA has implemented significant efforts to sustain operation of the IEBL. One challenge has been to address the precipitation that occurs during the transport of the supersaturated brine created during the desalination process for drinking water production. When turbulence is reduced in the pipeline, whether in areas with elevation changes or sharp horizontal bends, or when water transport slows and flow becomes more stagnant, significant precipitation adheres and compacts on the pipe walls over time, resulting in restrictions in pipeline flow capacity [**Figure 1**].

Figure 1: Section of scaled 16-inch diameter pipe, showing significant reduction in available flow capacity.

As a result, SAWPA has gone to great lengths to address this precipitation, including installation of additional access points throughout the pipeline, acid application for dissolution of scale, drilling for physical removal of scale to be trucked off-site [**Figure 2**], replacing sections of severely scaled piping, realigning stretches of the pipeline to reduce the bends and elevation changes [**Figure 3**], and installation of remote sensors and CCTV for real-time monitoring of scale accumulation.

These efforts have been successful in recovering capacity within the pipeline [**Figure 4** and **Figure 5**], but they come at a significant cost. From June 2010 to January 2014, SAWPA installed 19 manholes throughout the system for easier access and performed pipeline realignments in sections with sharp bends at 6 locations, for a cost of $962,468. The general maintenance during that time, including line draining, line cleaning, line inspection, and disposal cost $737,144. The resulting 3.5-year total cost to maintain and improve the pipeline was $1,699,612. Each individual pipe cleaning effort alone resulted in costs of approximately $250,000-$300,000. To reduce these ongoing costs, some municipalities discharging into the IEBL have taken proactive measures by implementing supplemental antiscalant dosage directly into the brine prior to discharge.

Figure 2: Scale removed off-site by trucking.

Figure 3: Section of pipeline realigned to minimize bends and elevation changes.

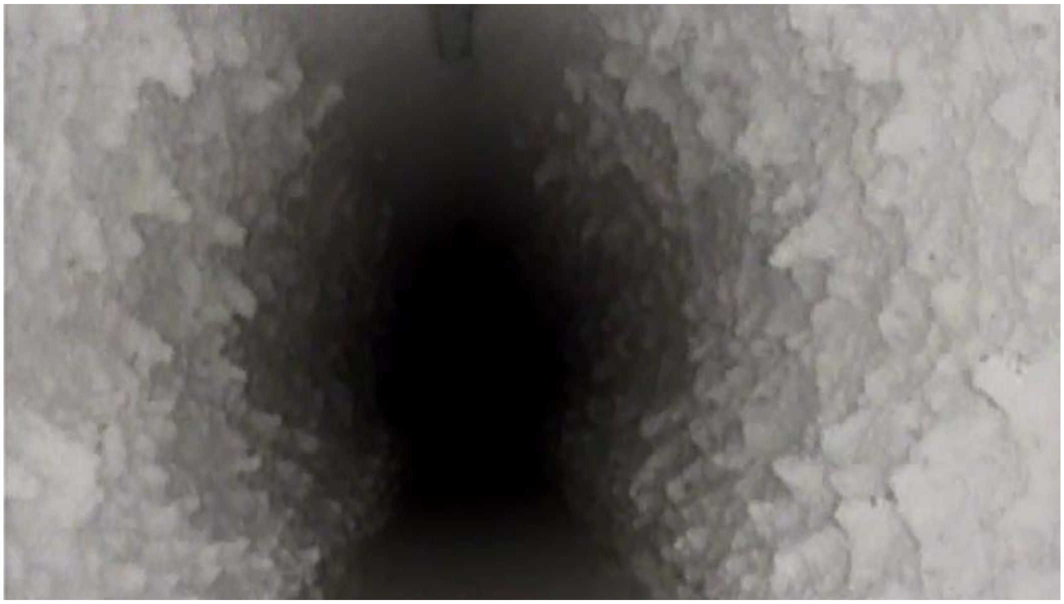

Figure 4: Section of heavily scaled pipe prior to cleaning.

Figure 5: Section of pipe from Figure 4 after cleaning.

1.2.2 Field Tests – Due to the costs for scale removal and the facility downtime required during maintenance periods to address the pipe flow restriction, SAWPA has prioritized the monitoring of scale deposition and pipeline capacity. At key locations where scale has been significant, test pipes have been suspended into the pipeline and partially submerged in the flow stream [**Figure 6** and **Figure 7**]. These test pipes can be periodically removed to evaluate the extent of scale accumulation.

Figure 6: Test pipe apparatus used to monitor in-line scale accumulation.

Figure 7: Test pipe apparatus submerged into pipeline flow to evaluate scaling.

In addition to tests pipe inspections, SAWPA implemented remote flow sensors and a float switch near known potential chokepoints to ensure water levels in the pipeline do not exceed capacity. They also initiated periodic flow tests to identify restrictions in capacity. These tests involve incrementally increasing the pipeline flowrate by supplementing facility discharge water with well make-up water. This continues until the water level reaches the top of the pipe at visible access points near sections known for severe scale accumulation in the past. This flowrate is then documented as the maximum capacity at that access point. This approach has allowed SAWPA to monitor capacity changes in sections of the IEBL that are at risk of scale-induced capacity reduction. Key chokepoints tend to change over time, depending on maintenance or scale build-up, but have been limited to areas with sharp bends that are difficult to address due to location (adjacent to freeway footings).

1.3 Sterling Water Treatment Plant Concentrate Tank and Deep Well Injection

Up to 1.6 MGD of the RO brine from the 9.6 MGD municipal drinking water facility in Sterling, Colorado is stored in a 230,000-gallon concentrate tank prior to injection into one of two deep wells. Well water chemistry indicates up to 228 ppm reactive silica in the concentrate exiting the reverse osmosis system. King Lee Technologies Pretreat Plus® 0100 antiscalant injected ahead of the RO has successfully inhibited scale throughout the RO process for years.

1.3.1 Deep Well Injection Challenges – The deep well injection process has proven to require supplemental attention due to residence time and air exposure that have led to difficult-to-remove scale within the concentrate tank, deep well injection pump filters, and piping. In 2014, the facility had the concentrate storage process analyzed for acid injection to minimize scale formation, resulting in a recommendation of up to approx. 2,000 ppm hydrochloric acid injected into the brine stream fed to the concentrate tank. Sterling decided to take a different approach and instead combined injection of the antiscalant ahead of the RO with injection of a supplemental King Lee Technologies antiscalant into the brine stream. In September 2017, an optimization of the treatment formulation initiated the injection of Nutreat™ 1700 as the supplemental chemistry for brine control.

1.3.2 Real-time Data Monitoring – Historically, significant recordkeeping has been performed to track the health of the deep well injection system and to monitor the inhibition of scale accumulation in the concentrate tank and deep well injection process. One of the trends monitored is the automatic backwash frequency for the filters in the deep well injection process. More frequent backwashes signify increasingly rapid accumulation and potentially less successful backwashes. In addition, the sustained flowrate into the deep well injection system under vacuum is recorded, with decreased flowrate indicating constricted flow and restriction within the line.

The injection of Nutreat™ 1700 into the concentrate stream began in September 2017 and since then, additional data has been used to determine the efficacy of the scale inhibitor throughout the concentrate disposal process. More extensive trends of the sustained flowrate under vacuum are being used to examine long-term patterns. Pump pressure required to meet flowrate setpoints help to identify restrictions in the process. The deep well injection pump speed required to maintain the flowrate setpoint increases with gradual accumulation of scale and should then be restored after backwash of the filter. These pump speed trendlines will show whether scale is accumulating more rapidly and when backwashes are not completely successful. The pH of the concentrate in the tank is also monitored to confirm that the antiscalant is effective over a wide range of concentrate pH's, as the pH will gradually increase when residence times are longer.

II. LONG-TERM FIELD VALIDATION

King Lee Technologies has partnered with a municipal drinking water facility that discharges into the IEBL to maximize control and minimize downstream impact and has partnered with the Sterling Operations Team to explore data that can tell the story of the deep well. Previous work detailed the process of selecting Nutreat™ 1700 as the most effective formulation tested, showing initial lab testing for both facilities, as well as preliminary field data for Sterling to verify reduced scaling in the concentrate tank and deep well injection system [9]. More than one year later, the long-term data confirms that scale control has improved in both processes.

2.1 Inland Empire Brine Line

One of the municipal drinking water facilities that discharges into the IEBL has battled significant scale formation in their four-mile section of the discharge pipe. This section of piping consists of 16- and 18-inch diameter pipe that has historically faced significant capacity reduction due to difficult-to-remove scale accumulation. The concentrate stream studied has up to approximately 240 mg/L silica as SiO2, given the feed concentration and RO concentration factor, and a potential LSI of approximately 2.8. During recent years, the facility had intermittently trialed supplemental scale inhibitor dosages into the concentrate stream. By early 2018, they partnered with King Lee Technologies to dose the proposed Nutreat™ 1700. Since this time, SAWPA has verified that scale accumulation is minimal and easily removed, as shown by previously described test pipe inspections and pipeline flow capacity testing.

2.1.1 Test Pipe Inspections – Original test pipe inspections clearly validated that scale growth and accumulation can be confirmed with this approach. **Figure 8** is a photograph taken in 2015, before brine transport scale control measures were implemented.

Figure 8: Test pipe verifying significant scale accumulation within the discharge stream in 2015.

Historically, test pipes have been inspected approximately every 3-6 months, most recently every 6 months because of the significant reduction in the presence of scale. The most recent test pipe inspection verified that there has been no scale accumulation since the facility initiated supplemental scale control directly into the brine stream [**Figure 9**].

Figure 9: Test pipe verifying minimal scale accumulation within the discharge stream.

2.1.2 Flow Tests – The permit discharge limit for this water treatment facility is 972 gpm, and efforts are made by the facility and by SAWPA to ensure that the full permitted capacity is available for discharge, should it be necessary. This is done by addressing the potential scale formation in the downstream piping. The flow tests regularly performed by SAWPA have shown an access point downstream of the facility being a typical chokepoint in the pipeline. At this location in September 2015, the full pipe capacity was noted as 1,010 gpm. Since that reading, pipe cleaning efforts were performed and brine antiscalant injection was implemented. The September 2018 flowrate was recorded as 1150 gpm, which has been maintained through the flow testing in early 2019. Observations have been made by SAWPA that the rate of scaling in this previously flagged section of piping is less dramatic, and the scale is softer and easier to flush.

2.1.3 Pipe Level Sensors and Float Switch – Historically, pipe level sensors and a float switch for alarm were used at sections of the pipeline known for scale-induced capacity reduction. These efforts were initiated to ensure that there were no exceedances of pipeline capacity. However, since the scale accumulation has been drastically reduced, this real-time continuous monitoring is considered unnecessary. Instead, periodic visual inspections of the pipeline at critical locations have been sufficient to initiate cleaning efforts, when necessary.

2.1.4 Cleaning Costs – In addition to observations of the pipeline to verify improved brine control, considering ongoing cleaning costs reveals the impacts of those potential improvements. Since the addition of antiscalant into the brine stream, ongoing maintenance costs have been significantly reduced to approx. $50,000 per year, at most.

2.2 Sterling Water Treatment Plant Concentrate Tank and Deep Well Injection

The addition of Nutreat™ 1700 into the Sterling Water Treatment Plant concentrate, as it enters the storage tank prior to deep well injection, began in September 2017. Having been implemented for almost two years, additional data has allowed verification of deposition control in the deep well injection system.

2.2.1 Year-over-Year Snapshots of Concentrate Deep Well Sustained Flowrate Under Vacuum – One parameter monitored by Sterling is the sustained flowrate into the deep wells when the pump is not operating, and the lines are under natural vacuum. When comparing months of similar production demand, Sterling can minimize potential influences of reservoir levels on the data. A higher flowrate into the well is used to indicate less restriction in the piping. **Figures 10-12** show screen shots taken from the Sterling Water Treatment Plant monitoring system. The red vertical line marks a snapshot of the sustained flowrate (blue trendline) under natural vacuum pressure (black trendline) into Deep Well #2 on one day in the month of January 2017, January 2018, and January 2019, respectively. The sustained flowrate under vacuum in January 2017 was approximately 168 gpm with a natural vacuum pressure of approximately -4 psi. In January 2018, after the supplemental treatment chemistry was optimized, the sustained flowrate was 196 gpm, approximately 17% greater, with a slightly stronger natural vacuum pressure of -6 psi. This increased flowrate under vacuum was confirmed again in January 2019 at approximately 197 gpm and -7 psi.

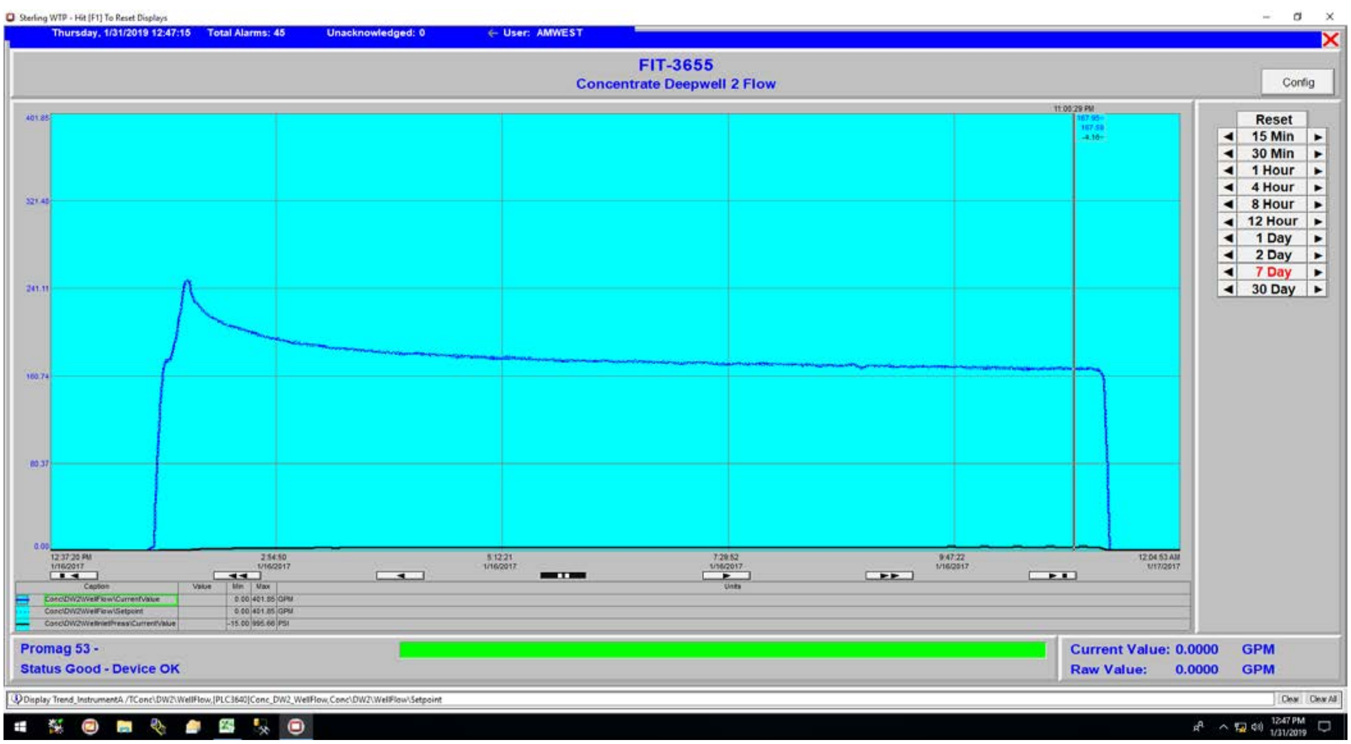

Figure 10: Sustained Flowrate into Deep Well #2 under vacuum in Jan. 2017 at approx. 168 gpm.

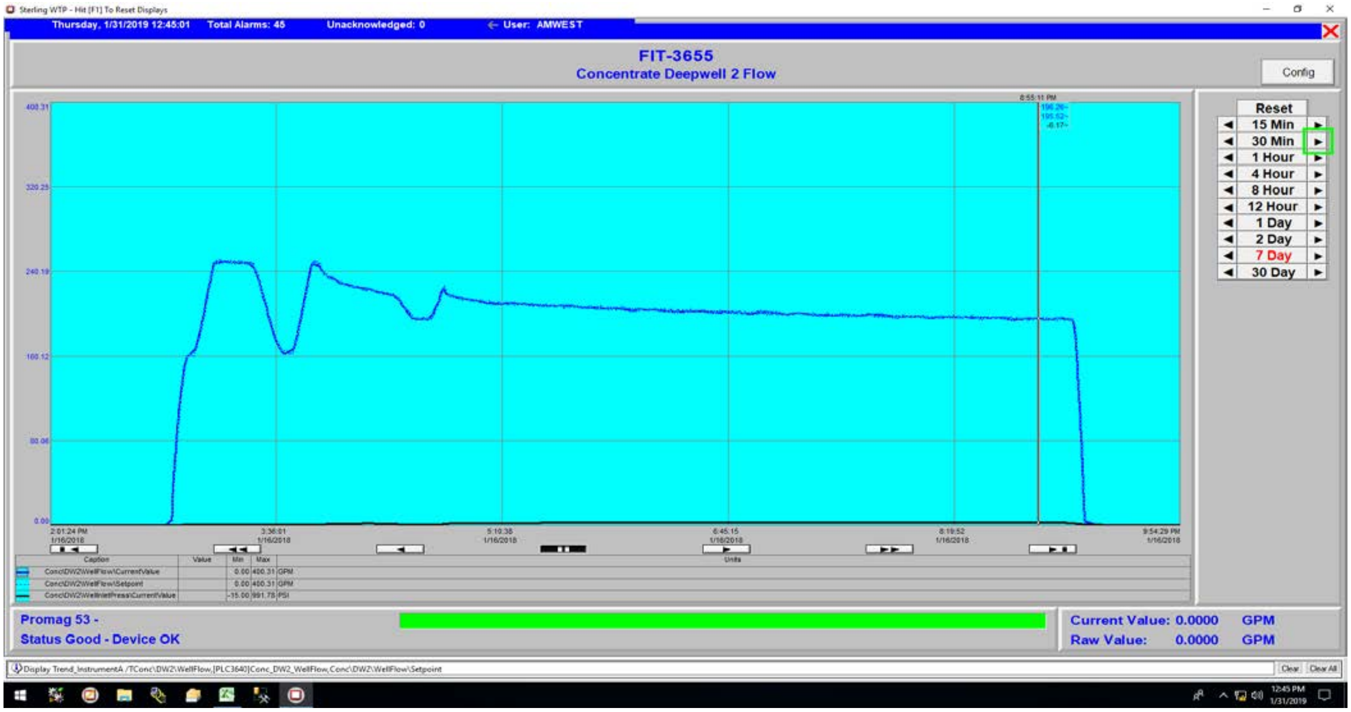

Figure 11: Sustained Flowrate into Deep Well #2 under vacuum in Jan. 2018 at approx. 196 gpm.

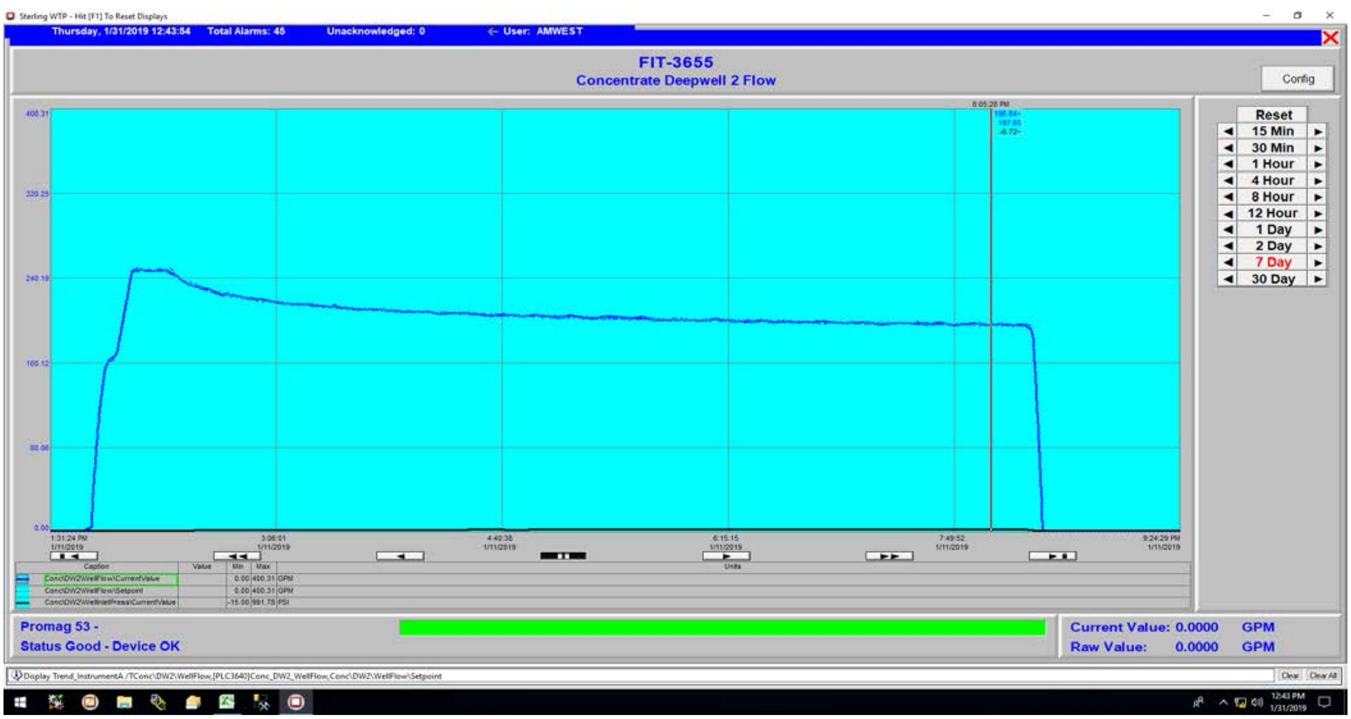

Figure 12: Sustained Flowrate into Deep Well #2 under vacuum in Jan. 2019 at approx. 197 gpm.

2.2.2 Long-term Concentrate Deep Well Sustained Flowrate Under Vacuum – Over time, the data shows that the flowrate under vacuum has been consistent without decline, as represented in **Figure 13** and **Figure 14**, which show the flowrate setpoint (blue) and the natural vacuum pressure (black) for

Deep Well #1 during one-month and three-month periods, respectively. These data trends are used to confirm that there is no long-term accumulation on the deep well injection pump filters or piping and that the deep well operation remains healthy.

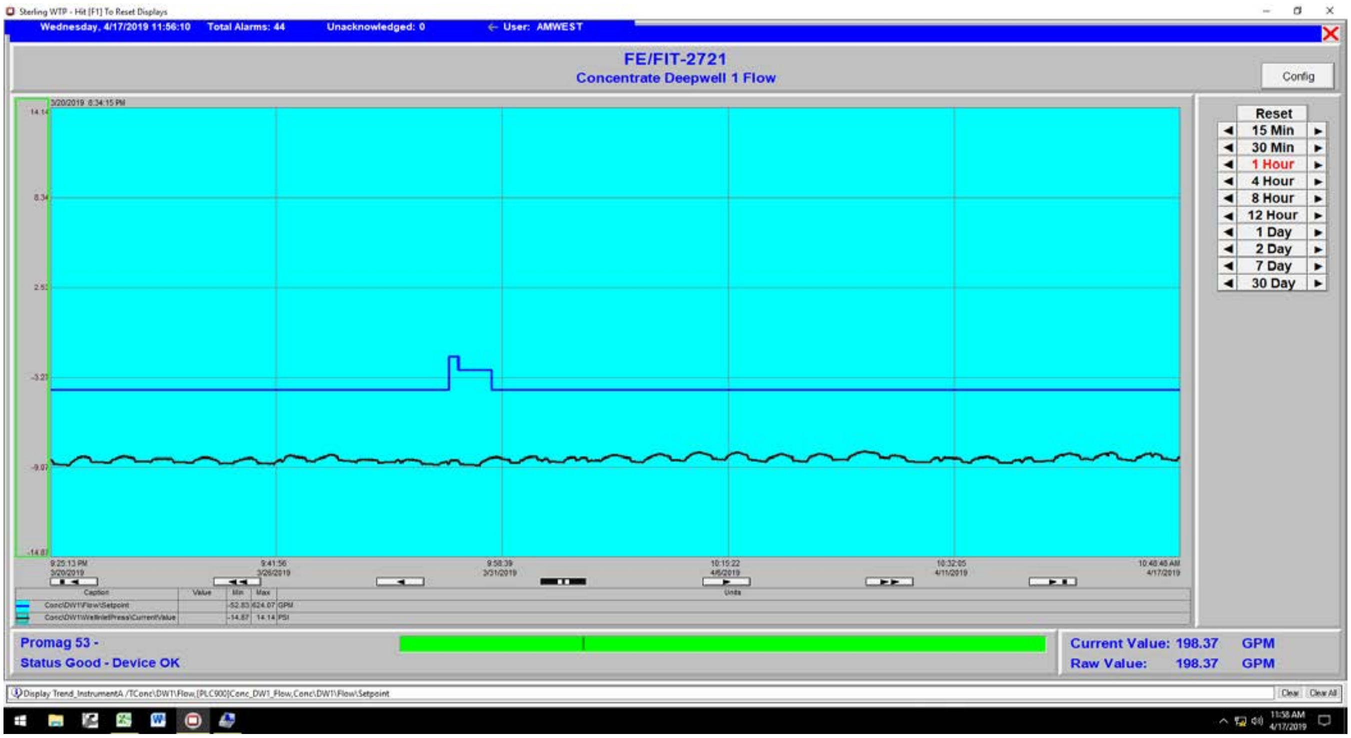

Figure 13: One month of consistent behavior - Deep Well # 1 sustained Flowrate under vacuum.

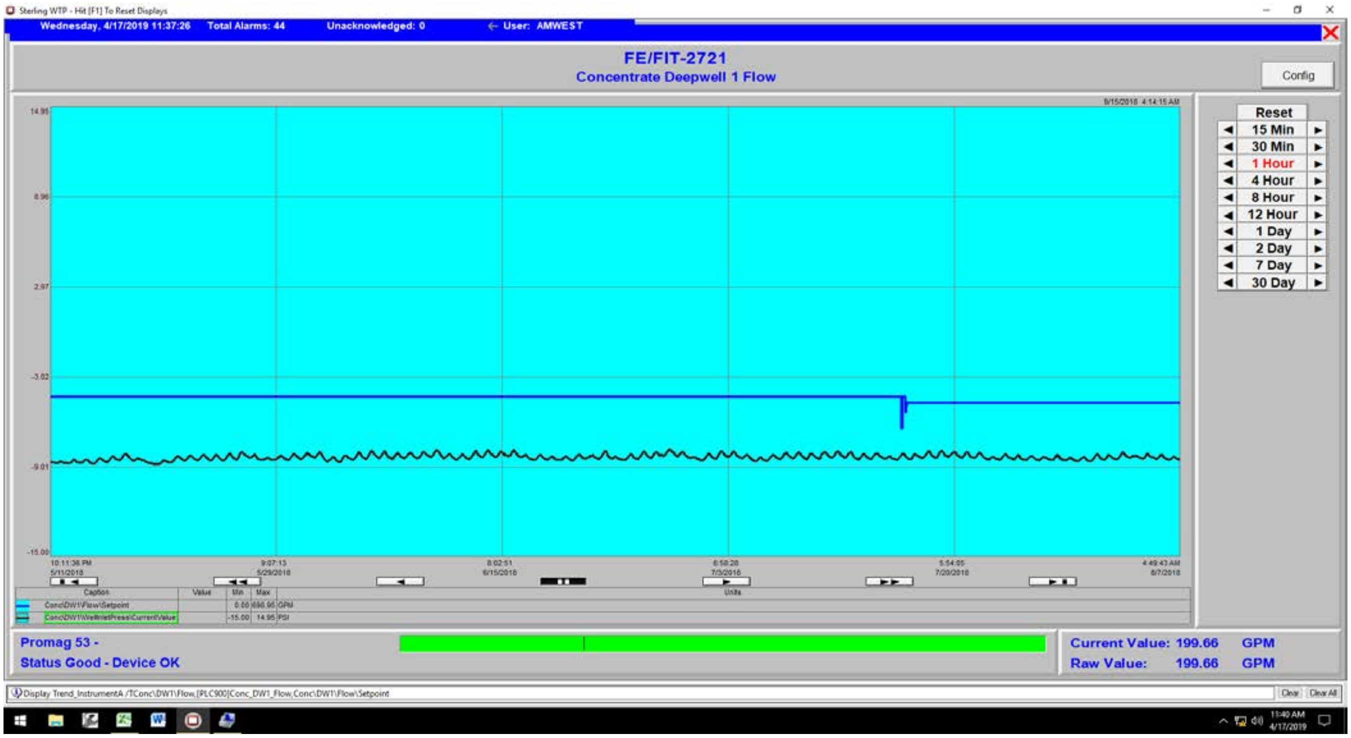

Figure 14: Three months of consistent behavior - Deep Well # 1 sustained Flowrate under vacuum.

2.2.3 Year-over-Year Snapshots of Deep Well Sustained Flowrate Under Pressure – Similar to the deep well sustained flowrate under vacuum, comparing months of similar high production demand when the deep well pumps are operational but the reservoir level is still minimal so as to not likely significantly influence the data, allows for a comparison of pressure required to maintain a set flowrate. The injection flowrate and pressure required to maintain that flowrate during a day in June 2017 (pre-Nutreat™ 1700 injection) versus those values during a day in June 2018 (post-Nutreat™ 1700 injection) verifies a reduction in flow restriction [**Figure 15** and **Figure 16**]. The flowrates (blue) into Deep Well #2 in June 2017 and June 2018 are approximately identical, at 401 gpm and 407 gpm, respectively. The corresponding pump pressures (black), however, show that this flowrate is achieved with almost 8.5% less pressure in 2018 at 411 psi, than in 2017 at 449 psi. Any difficult to flush restrictions in the line, such as scale, are expected to be more apparent when the system is operating at a higher capacity, but this data does not show evidence of such restrictions.

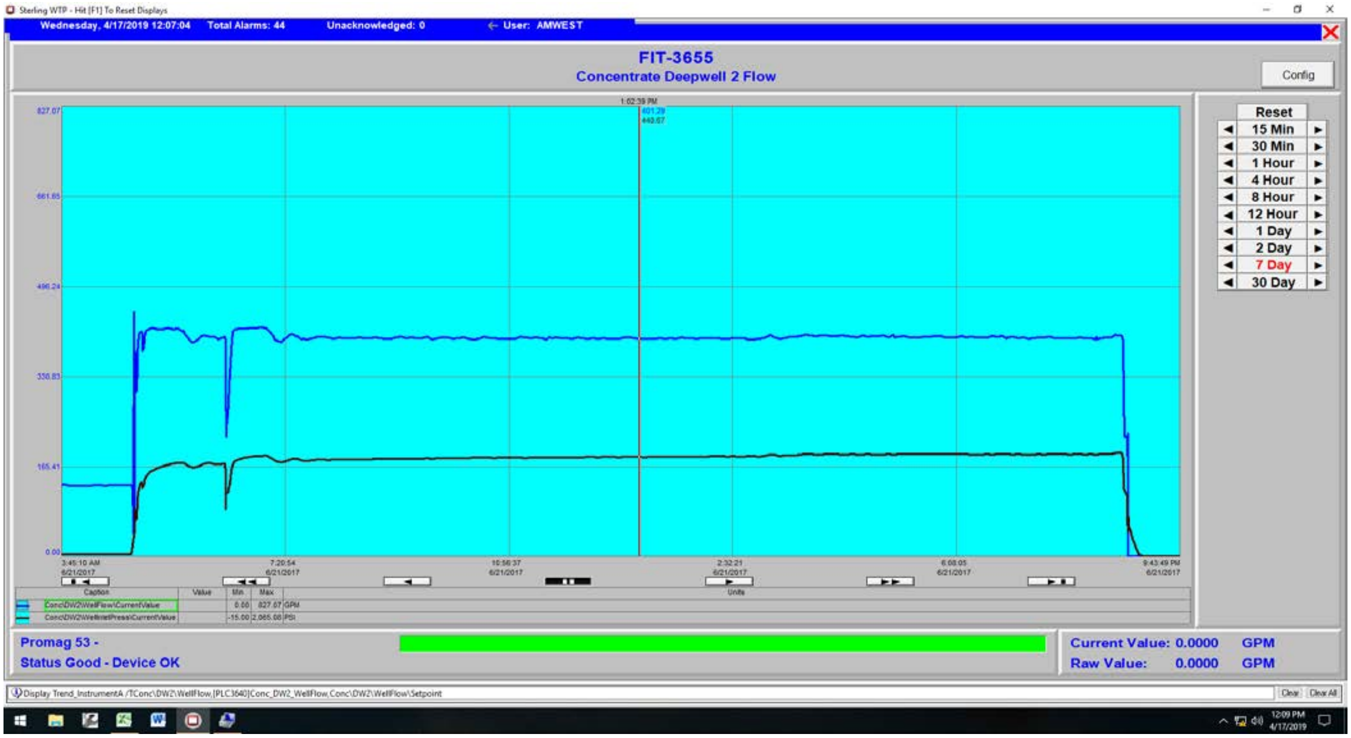

Figure 15: Pump Pressure required to sustain flowrate into Deep Well #2 in June 2017.

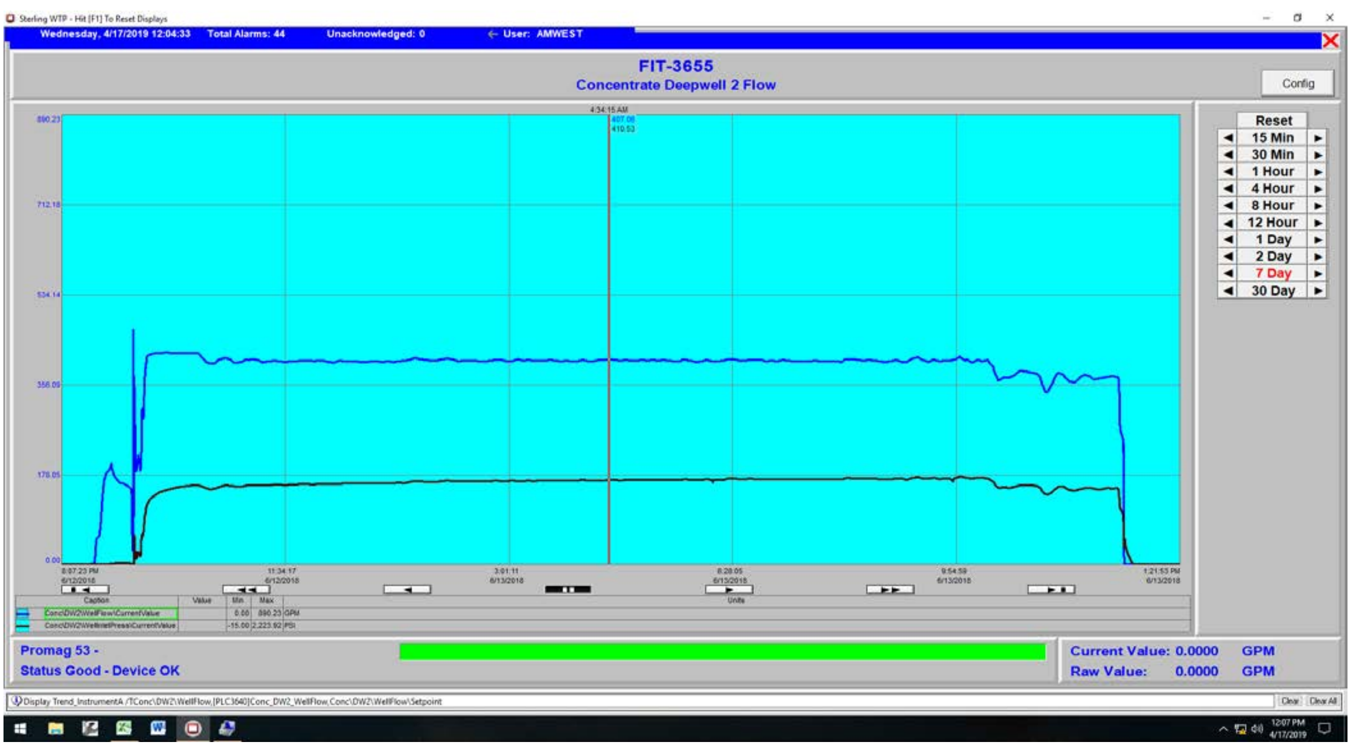

Figure 16: Pump Pressure required to sustain flowrate into Deep Well #2 in June 2018, approx. 8.5% less pressure required than in June 2017 prior to chemistry optimization.

2.2.4 Deep Well Pump Speed – During active transfer from the concentrate tank, the deep well pump works to maintain a set flowrate into the deep well. An increase in the speed of that injection pump during transfer indicates some anticipated accumulation on the pump filter, which ultimately leads to a differential pressure-triggered backwash. If the speed increase were to become more rapid from cycle to cycle, or if it were not restored to baseline upon backwash of the filter, this would be an indicator of accumulation on the filter or in the piping that is not being removed by backwash. **Figure 17** shows the flowrate into Deep Well #1 (red), which has a setpoint of approximately 200 gpm, and the pump speed of "Conc Pump 2" required to maintain that setpoint (blue). The pump speed starts at approximately 73% and gradually increases to maintain the flow setpoint during a typical 15-hour run. The speed increases by almost 13% until a filter backwash is triggered, and the pump speed returns to its original value, still achieving the flowrate setpoint. The cycles that follow do not show more rapid increases in speed, and the pump speed consistently returns to the baseline value, verifying that accumulation that is occurring is successfully removed with backwashes.

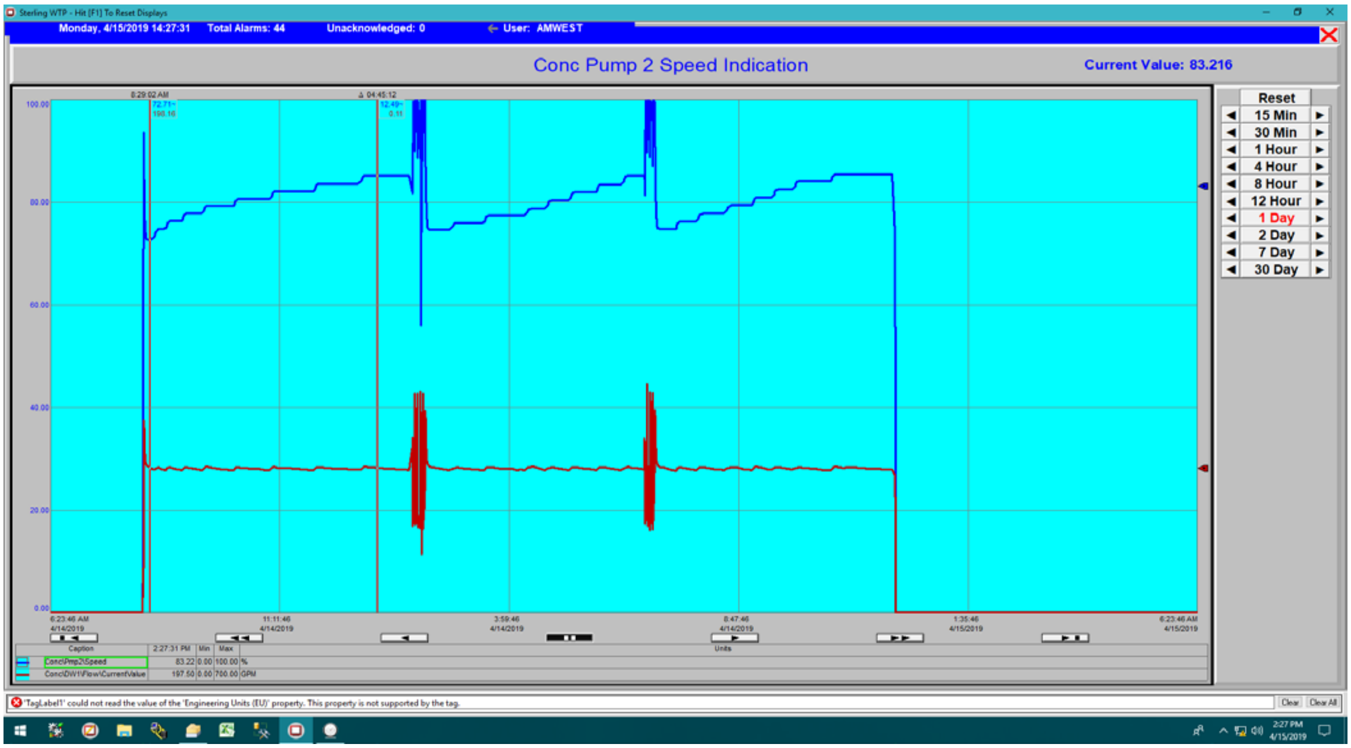

Figure 17: Deep Well #1 Pump2 Flow Setpoint approx. 200 gpm (Red) and Pump Speed to maintain setpoint (Blue). Speed increases are consistent and restored to baseline with backwash.

2.2.5 Concentrate pH – During times of low demand, production is halted overnight, and eventually the pH probe in the concentrate tank detects an increase in pH. **Figure 18** shows an example of the typical behavior seen on overnight shutdowns using a night in April 2019. The blue trendline shows the concentrate flowrate into the storage tank, the red shows the concentrate tank level, and the black shows the pH in the concentrate storage tank. As concentrate flows into the tank (steady blue trendline), the storage tank level (red) increases and the pH of the liquid in the tank (black) is constant. Once production stops and no additional concentrate flows into the storage tank (blue trendline drop), the tank level (red) begins to drop due to the natural vacuum pressure in the deep well. The pH remains constant for 8 hours, then begins to climb for the next 8 hours and generally increases from approx. 7.6 to approx. 8.1 [**Figure 19**]. Eventually production is restarted, and the pH rapidly returns to normal. This behavior is consistent during times of regular overnight shutdowns [**Figure 20**] and, although this increase in pH indicates an increased likelihood of calcium carbonate precipitation potential, irreversible precipitation accumulation has not been detected, as verified by the other parameters monitored.

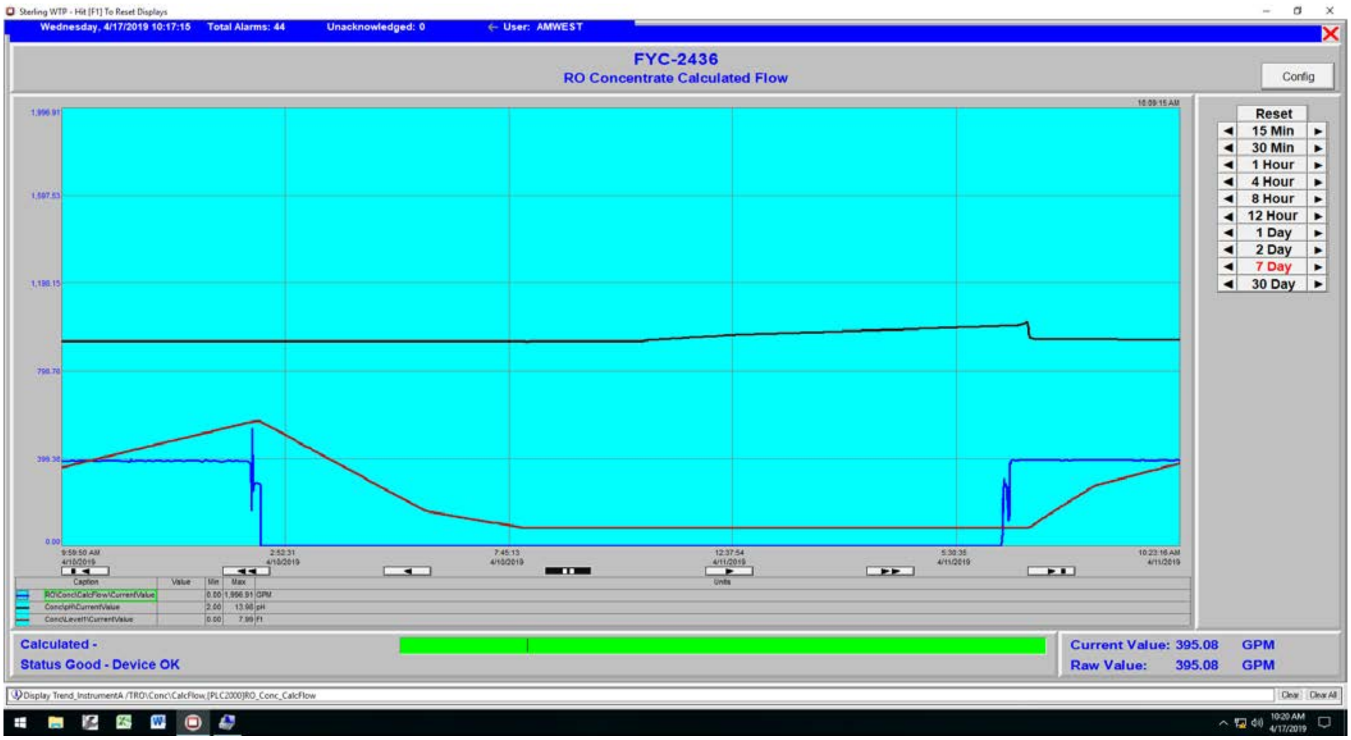

Figure 18: Sterling Concentrate Flowrate into storage tank (Blue); Concentrate Tank Liquid Level (Red); Concentrate Tank pH (Black).

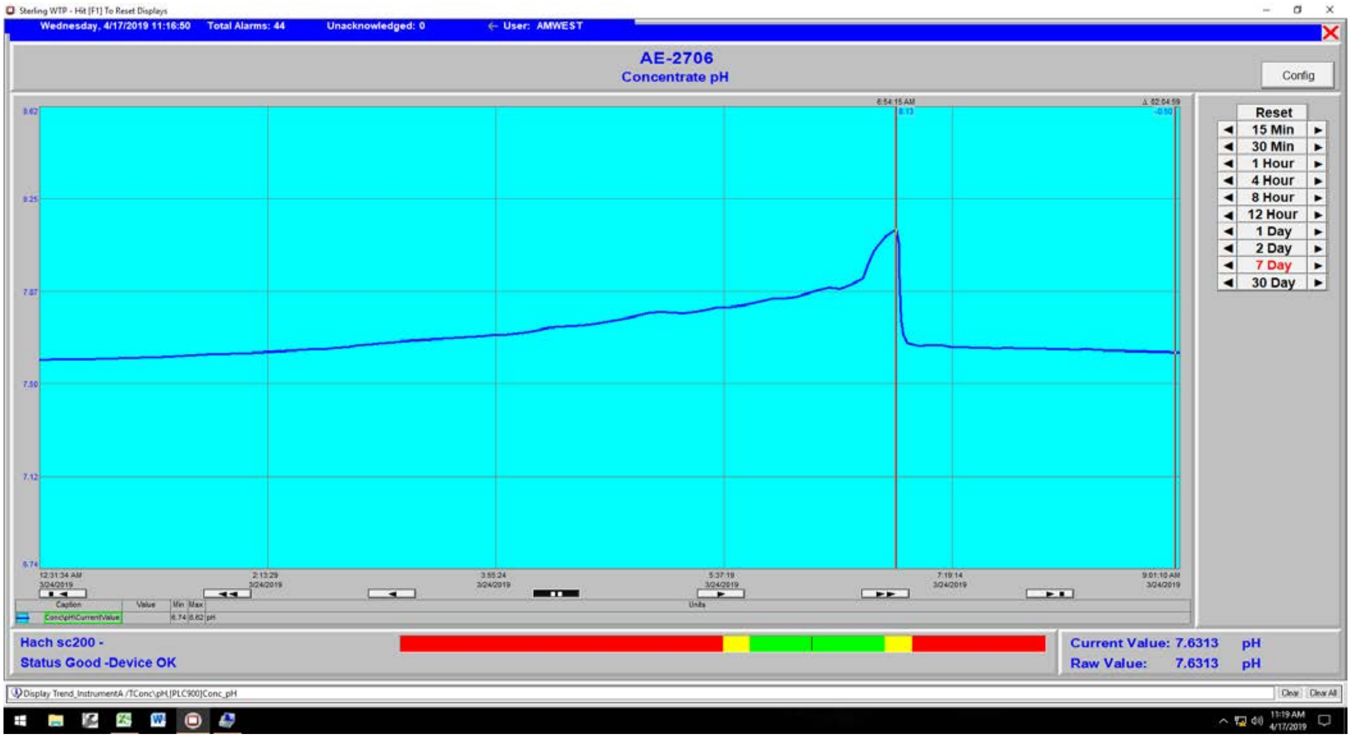

Figure 19: Sterling Concentrate Tank pH increasing from 7.6 to 8.1 during overnight shutdown.

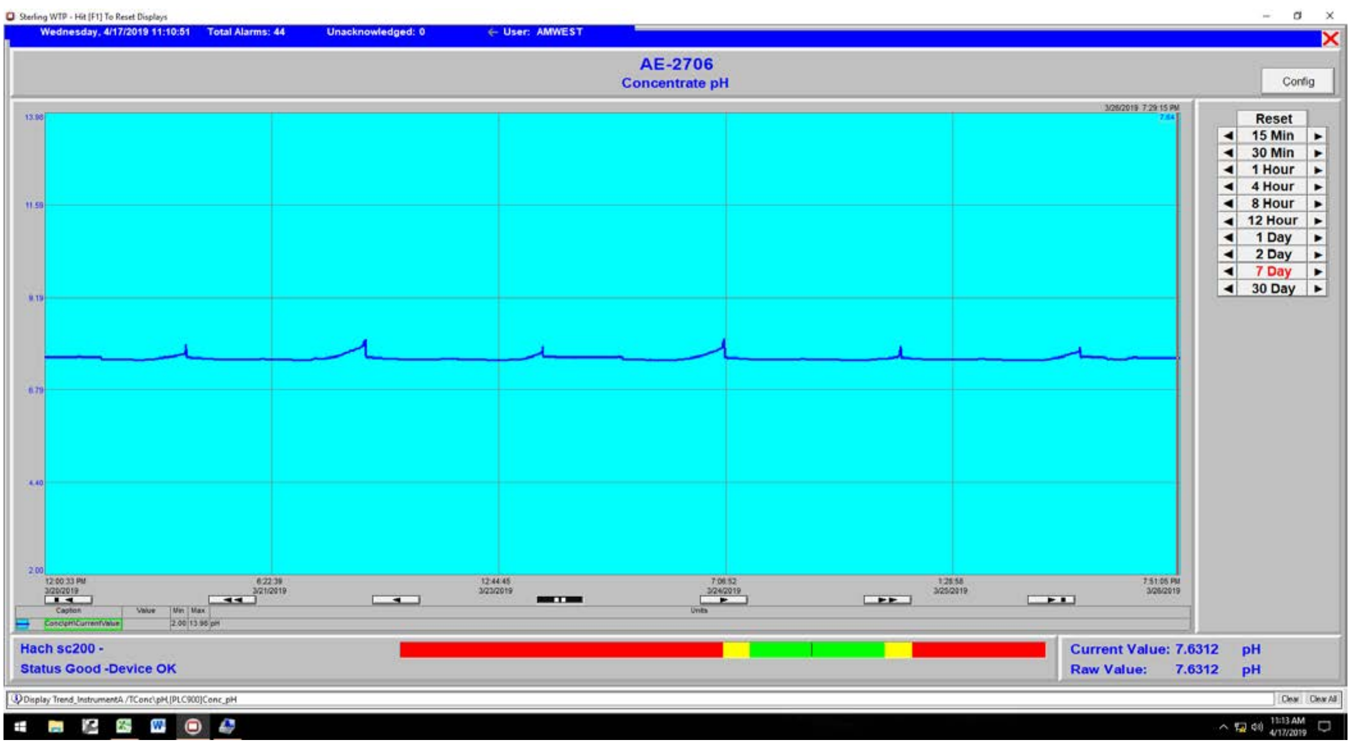

Figure 20: Sterling Concentrate Tank pH spikes during a week of overnight shutdowns.

III. UPCOMING OPPORTUNITIES – WHAT'S NEXT

Long-term monitoring shows improved brine transport and disposal control for these facilities, and the move forward is to apply a broader vision to the treatment of brine through chemistry. As these facilities and others continue to optimize their processes for more efficient operation with less waste, requirements of the brine treatment and/or disposal process are expected to evolve. As such, reliable and standardized data collection and proactive planning will be critical.

The study at the drinking water facility discharging brine into the IEBL for downstream treatment is not an isolated challenge. Studies have already begun to expand the current successes of chemistry for brine transport control to additional IEBL discharging water treatment facilities. From one facility to another, the pretreatment and maintenance chemistry varies, and concentrate recovery processes are growing and evolving. In addition, a wide variety of industries discharge into the IEBL, including biotech, pharma, laundries, and food processing. These dynamics increase the complexity of improving and maintaining the health of this discharge line. They add challenges to the screening methods used to make recommendations and the tests necessary to validate that the results are long-term improvements. Work toward increased improvements will continue, as SAWPA continually works with dischargers to encourage accountability and establishes reliable monitoring methods that allow them to be stay ahead of the coming challenges.

The Sterling Water Treatment Plant is a case for improvement opportunities in the steady operation of deep well injection systems. The incorporation of Nutreat™ 1700 into deep well discharge has expanded from RO brine to mining waste and, as a result, it has opened doors to a collective conversation about the measuring sticks for a healthy deep well injection system. Sterling has been tackling the optimization of this process since 2013 and has no shortage of monitored data to verify their success. As a result, they have developed a multi-level evaluation of a healthy deep well operation that can benefit other facilities working toward the same.

IV. CONCLUSIONS

The introduction of brine-targeted chemistry was initiated as an attempt to reduce interruptions to operation and to reduce costs associated with operational downtime and maintenance required due to the scaling of high TDS brine during transport and disposal. In the case of IEBL pipeline transport of RO brine, test pipe inspections have been used to visually confirm reduced scale accumulation in the pipeline, and flow tests have verified that flow capacity is being maintained since the facility studied began injecting supplemental antiscalant prior to brine discharge. For deep well injection operations in Sterling, Colorado, the year-over-year and long-term trend monitoring of multiple process parameters has been used to confirm improvements in the strains on use of the deep wells. As applications are expanded, the value of these pre-established approaches for validation will continue to grow.

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VI. ACKNOWLEDGEMENT

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