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Aquifer Storage and Recovery (ASR) Pilot Test Results – Stone Ranch Well LR-19

Prepared for

South Fork Kings Groundwater Sustainability Agency
Lemoore, California

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October 2022

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ACRONYMS AND ABBREVIATIONS

$/af	dollars per acre-foot
µg/L	micrograms per liter
µS/cm	microsiemens per centimeter
AF	acre-feet
AF/yr	acre-feet per year
ASR	Aquifer Storage and Recovery
bgs	below ground surface
DDW	State Water Resources Control Board-Division of Drinking Water
DO	dissolved oxygen
DWR	California Department of Water Resources
E. Coli	Escherichia Coli
ft	feet
gpm	gallons per minute
GSA	Groundwater Sustainability Agency
GSP	Groundwater Sustainability Plan
KRCD	Kings River Conservation District
MAR	Managed Aquifer Recharge
mg/L	milligrams per liter
ml	milliliters
ORP	oxidation-reduction potential
pCi/L	picocuries per liter
PVC	Polyvinyl Chloride
PWS	Public Water Supply
RWQCB	Regional Water Quality Control Board
SI	Saturation Index
SFKGSA	South Fork Kings Groundwater Sustainability Agency
SGMA	Sustainable Groundwater Management Act
TDS	Total Dissolved Solids
TLSB	Tulare Lake Subbasin

1. INTRODUCTION

This Aquifer Storage and Recovery (ASR) Pilot Test Results (ASR Pilot Test Results) report has been prepared by Geosyntec Consultants on behalf of the South Fork Kings Groundwater Sustainability Agency (SFKGSA).

SFKGSA, as part of the Tulare Lake Subbasin, prepared a Groundwater Sustainability Plan (GSP) in 2020 (TLSB, 2020) which included projects and management actions designed to achieve sustainable groundwater conditions by the year 2040. The SFKGSA specifically identified investigation of ASR for agricultural supply that would directly recharge the aquifer and create groundwater storage that could be withdrawn to reduce pumping of native groundwater during the irrigation season.

This report describes the results of an ASR pilot test conducted in the summer of 2021. Prior to testing, a work plan was developed (Geosyntec, 2020), which was approved by the Regional Water Quality Control Board (RWQCB) and Division of Drinking Water (DDW). This report also presents an analysis of the performance of the ASR Pilot Test, water quality changes during and after injection, and an assessment of the potential for broader implementation of ASR using existing wells throughout the SFKGSA.

1.1 ASR Concept

Aquifer Storage and Recovery (ASR) is a form of Managed Aquifer Recharge (MAR), which is gaining widespread interest in California as an approach to improving the reliability of water supply by storing "excess" surface water in underground aquifers. This stored water can then be either pumped at a later time for beneficial use (potentially reducing demand on surface water) or it could remain in the aquifer and help increase or restore groundwater levels. In the context of the Sustainable Groundwater Management Act (SGMA), MAR is being considered in many different forms as an implementation component of GSPs across the state. Figure 1-1 shows the two basic forms of MAR – surface recharge and sub-surface recharge. Surface recharge is often called surface infiltration and involves spreading water on the ground surface or in a pond and allowing it to infiltrate to the underlying groundwater. This practice is common throughout California and is also referred to as "surface infiltration", "sinking basins", and "water banking". Underground recharge uses a well to convey water into the aquifer. This practice is less common in California, and more often associated with municipal drinking water systems where highly treated water is injected into the aquifer and recovered for use as a drinking water supply. The term "ASR" is most commonly associated with municipal uses. The ASR concept being evaluated in this study for SFKGSA is primarily focused on supporting agricultural water demand.

ASR has some advantages over surface infiltration basins in that: it can target specific aquifer zones, can efficiently store smaller volumes of water, requires less land area, and is not subject to evaporative losses that occur during surface recharge. In areas where the shallow subsurface contains clays or other less permeable layers, that would prevent infiltration via surface basins, ASR may be the only effective method for artificially recharging deeper aquifers. An ASR cycle has three stages:

1. Injection phase, where surface water is pumped into the aquifer. The source of injected water for ASR is typically surface water that can be conveyed to an ASR well. A different groundwater source could also be considered for ASR (i.e. transferring groundwater from one aquifer to another). The source of water for this investigation is the Kings River, which is diverted and conveyed throughout the much of the irrigation canals (the Lemoore Canal system).

2. Storage phase, where the injected water simply "resides" in the aquifer. The injected water (injectate) does not immediately mix completely with the ambient groundwater, but rather forms a "bubble" that displaces the native groundwater with the injected surface water. Mixing of the native and injected water occurs initially on the fringes of the bubble (Figure 1-2). During storage, the injectate continues to interact with the native groundwater and surrounding aquifer material and, over time, reaches a geochemical equilibrium that represents the mixed water.

3. Recovery phase, where the water is pumped for beneficial use. The recovery of injected water can occur from the same well that injected the water or can occur from a different well that is properly placed to intercept the injected water. The longer that the injected water remains in storage, the more fully mixed the recovered water will be. The term "co-mingled" is sometimes used to describe water that has been recharged and then mixed with native groundwater.

In addition to the technical concepts for ASR, the application of ASR in an agricultural setting includes a groundwater management element relevant to SGMA and the implementation of GSPs. An underlying objective of this study is also to assess whether ASR can be implemented at a meaningful scale in a "grower-initiated" fashion where individual well owners (growers) could efficiently finance, install and operate ASR systems (at their discretion), with sufficient oversight and monitoring by the GSA, RWQCB and DDW.

1.2 Pilot Test Goals and Objectives

The objective to the ASR Pilot Test was to provide an initial technical assessment of the feasibility of implementing a broad ASR program across the SFKGSA. The goal of the Pilot Test was to collect physical and geochemical data to demonstrate the suitability of the local aquifer for ASR using surface water from local irrigation canals. The test was designed using an existing irrigation well and non-specialized infrastructure (filters, valves, and pump controls) that would be locally available and familiar to contractors and growers considering ASR.

1.3 Hydrogeologic Setting

The Tulare Lake Subbasin (TLSB) (Subbasin number 5-022.12; Figure 1-3) spans an area of 837 square miles and is located in the southern region of the San Joaquin Valley, within Kings County (Figure 1-3). The southern half of the TLSB consists of the currently dry Tulare Lakebed (TLSB GSP, 2020). Land use overlying the Subbasin is largely agricultural and supports an approximate population of 126,000 (DWR, 2020). The SFKGSA is one of five

Groundwater Sustainability Agencies (GSAs) that have collectively worked to develop and implement the GSP for the TLSB. The South Fork Kings GSA covers 111 square miles and is located in the northwestern portion of the TLSB (Figure 1-3). The regional hydrology description of the Tulare Lake Subbasin (TLSB) and local aquifer conditions described below are abbreviated from the ASR Pilot Test Workplan (Workplan) and references the TLSB GSP and California Department of Water Resources (DWR) Bulletin 118 (Geosyntec, 2020a; TLSB GSP, 2020; DWR, 2006).

The TLSB is located within the south-central portion of the San Joaquin Valley. The Valley was formed as a structural trough subsiding between the uplift of the Sierra Nevada along the east and the folding and faulting of the Coast Ranges on the west. The Valley is comprised of marine and continental sedimentary rocks that overly the pre-Tertiary basement complex with a total thickness of 6,000 feet on the eastern margin, and 30,000 feet thickness on the western margin (Scheirer, 2007; TLSB GSP, 2020). Early Tertiary marine deposits within the Valley are from the Santa Margarita, Etchegoin, and San Joaquin Formations along with undifferentiated non-marine deposits overlying the basement complex. Water found in these formations are too deep and saline to be considered usable. The east-west regional geologic cross section shown on Figure 1-4 was adapted from the TLSB GSP and depicts the water bearing zones within the area as well as general lithology of the Subbasin (Geosyntec, 2020a).

The regional stratigraphy is comprised of undifferentiated continental deposits, lacustrine deposits, and older and younger alluvium (Figure 1-4). Continental deposits of poorly to moderately sorted fine to medium sand, silt, gravel, and clay from the Late Pliocene are overlain by Early Pleistocene. Early Pliestocene deposits consist of lakebed clayey or silty clay units interfingered with alluvial and continental deposits from the east to the west and have been identified as A through F clays (Croft, 1972; TLSB GSP, 2020). These clay layers are often regionally continuous and separate and isolate productive aquifer zones within the TLSB. The productive aquifer zones found between clay layers are composed of coarse to medium-grained sand to gravel with local, thin, discontinuous silt and clay interbeds. The regionally continuous clay units and aquifer zones have been named as follows:

- The “A-clay” is dark greenish gray and the most-shallow clay found approximately 60 feet below ground surface (bgs) with a thickness ranging from 10 to 60 feet.
    - The “A-zone” aquifer is the shallowest unconfined aquifer, and groundwater within this aquifer is first encountered at depths less than 15 feet bgs. The A-zone aquifer varies in thickness and is considered too saline for municipal or agricultural use. The A-zone was not a target aquifer for the ASR Pilot Test.
- The “B-“, “C-“, and “D-clay” are yellow brown to blue gray clay layers that can be warped and folded. The “C-clay” is considered regionally extensive and generally found at a depth of 230 feet (ft) bgs with a thickness of 10 feet (KDSA et al., 2015).
    - The “B-zone aquifer is the intermediate aquifer and is generally considered a semi-confined aquifer. The top of the B-zone is defined by A- or B-clay. The bottom of the B-zone aquifer is defined by the E-clay (see below). The B-zone aquifer consists of two relatively distinct sections (upper and lower) that are often

defined by the C-clay. The upper B-zone is often unconfined, while the lower B-zone is more typically semi-confined to confined. Groundwater in the upper B-zone tends also tends to be higher in salinity, while the lower B-zone has lower concentrations of total dissolved solids (TDS). The B-zone was the targeted aquifer for the ASR Pilot Test.

- The "E-clay", is also known as the "Corcoran Clay", and is composed of dark gray clay and silts. The E-clay is the most extensive regional aquitard in the San Joaquin Valley and is found at depths ranging from 400 to 800 feet bgs in the Subbasin.
    - The "C-zone" Aquifer is below the E-clay at a depth of 600 to over 1,200 feet bgs. The C-zone is fully confined, with a low storage coefficient, compared to the B-zone aquifer. Recharge to the C-zone aquifer only occurs along the eastern margin of the Subbasin where the E-clay is absent. This creates the confined pressure head that then propagates throughout this deep confined aquifer. The C-zone was not targeted for the ASR Pilot Test.

1.4 Pilot Test Work Plan

The *Aquifer Storage and Recovery (ASR) Program Pilot Test Work Plan* (ASR Work Plan) was submitted to the Central Valley Regional Water Quality Control Board (CVRWQCB) and the State Water Resources Control Board – Division of Drinking Water (DDW) in August, 2020 (Geosyntec, 2020a). The workplan described the elements of the proposed Pilot Test and was approved in Addendum on November 13, 2020 followed by a Pump Test Update submitted in June, 2021 (Geosyntec, 2020b, Geosyntec, 2021. All report documents submitted to the regulatory CVRWQCB and DDW are included in Appendix A.

2. ASR PILOT TEST SETUP AND IMPLEMENTATION

2.1 Injection and Well Network Overview

The project area encompasses about 445 acres in Kings County, California just north of the City of Lemoore (Figure 2-1). A monitoring network was established consisting of seven total wells, with five wells used for water level monitoring and seven wells for water quality sampling. Construction details for each well are presented in Table 2-1 and described below:

- Well LR-19 is an active agricultural well that used as the injection well for the Pilot Test. LR-19 is completed to a total depth of 540 ft bgs and screened from 340 to 540 ft bgs in the lower portion of the B-zone. It was monitored for water levels and water quality. Further discussion of this well is provided in Section 2.1.1.
- Well LR-4 is an active irrigation well 4,264 feet northeast of LR-19 and was used as a monitoring well. LR-4 is completed to a total depth of 390 ft bgs and screened from 210 to 390 ft bgs. LR-4 was used to monitor water levels and water quality within the B-zone.
- Well LR-18 is an active irrigation well 2,581 feet south of LR-19. LR-18 is completed to a total depth of 450 ft bgs and screened from 210 to 450 ft bgs. LR-18 was only used to monitor water levels within the B-zone.
- Well AG-1 is a shallow well 511 feet southeast of LR-19. AG-1 is completed to a total depth of 60 ft bgs. The screened interval is uncertain as a well completion report cannot be located. AG-1 was used to monitor water levels and water quality in the A-zone.
- Well “Sunset Active” is one of two D1 public water supply (PWS) wells located 5,413 feet northeast of LR-19. The second PWS well is known as the “Sunset Standby” well. Both Sunset wells are completed to a depth of 320 ft bgs and screened from 200 to 320 ft bgs and approximately 70 feet away from each other. These wells are completed in the upper portion of the B-zone. The Sunset Standby well was inaccessible at the time of the test. The “Sunset Active” well will be referenced as the “Sunset well” throughout the report. The Sunset well was used to monitor water levels and water quality in the B-zone.
- Well 18S20E29Z001M is the closest domestic well approximately 1,743 feet northwest of injection well LR-19. The well is completed to a total depth of 220 ft bgs and screened from 140 to 220 ft bgs. This well is completed in the upper portion of the B-zone aquifer and is shallower than the Sunset well. This well was added as a water quality observation well for the B-zone as mentioned in the Addendum (Geosyntec, 2020b). Well 18S20E29Z001M will be referenced as well ‘Z001M’ throughout the report.
- Well W1606-006 is approximately 3,087 feet northwest of injection well LR-19. The well is completed to a depth of 400 ft bgs and screened from 300 to 400 ft bgs. This well has a similar completion interval and radial distance from injection well LR-19 as observation well LR-4. This well was added as a water quality observation well for the B-zone as mentioned in the Addendum (Geosyntec, 2020b).

2.1.1 LR-19 Well Construction

The State of California DWR Well Completion Report states that the LR-19 Pilot well was constructed on October 24, 2013 by the Schrack Drilling Company of Selma California. The well was constructed with a 36-inch boring diameter to 76 feet bgs followed by a 28-inch boring diameter to total depth of 555 feet bgs. A 30-inch diameter steel conductor was installed from 0 to 76 feet bgs. A 16-inch diameter SDR 17 polyvinyl chloride (PVC) well casing was installed with a slotted interval from 340 to 540 feet bgs. A gravel filter pack extends from 76 feet to 555 ft bgs. The cement surface seal is installed from ground surface to 76 feet bgs. A photo of the well is included in Figure 2-3. A sketch of the well's construction features and dimensions is available in Figure 2-4.

2.1.2 Site Stratigraphy

As described in Section 1.3, the regional hydrogeology discussed in the Tulare Lake Subbasin GSP recognizes three aquifer zones, designated the A-zone, B-zone and C-zone. The target aquifer ASR is the B-zone. However, the B-zone consists of multiple layers of sand, gravel, and clay, ranging in thickness from a few feet to tens of feet. This finer scale stratigraphy is an important element of understanding the response of the aquifer to ASR. The detailed site stratigraphy is shown on Figure 2-2. The blue, green, yellow and orange layers represent sand and gravel layers documented on the well logs for wells LR-19, LR-18, LR-4 and the Sunset well. The brown shading represents clay. The sand and gravel layers range in thickness from 1 to 75 feet and there appears to be general continuity of these layers across the site. The blue and green layers on the cross-section represent layers that intersect the well screen for LR-19 and would receive injection from ASR. The blue layers are shown to be coarse sand and gravels on the well logs, while the green layers are indicated as more of a medium sand, which would have lower permeability. The green layers appear to be continuous and are intersected by wells LR-18 and LR-4. It is likely that a higher proportion of injected water would enter the blue layers as compared to the green layers. The yellow and orange layers are above the screen interval for well LR-19 and therefore do not directly receive injection water. The orange layer is labeled as the "Upper Aquifer" and corresponds to the A-zone in the regional hydrostratigraphy. A thick clay layer is present between the orange and yellow layers, and the yellow layer is therefore interpreted to be the upper portion of the B-zone. The yellow layer is labeled "Overlying Sand" since it did not receive direct injection from LR-19, though it is still considered part of the B-zone aquifer. Note that a geologic log for the Sunset well is not available, but it likely intersects the same stratigraphy as LR-4.

2.1.3 Well Construction Effects on Water Levels

As shown on Figure 2-2, the injection zone for well LR-19 is associated with the blue and green layers, with the majority of injection likely occurring in the blue zone. However, Well LR-19 also has a gravel pack extending across the entire length of the 16-inch casing. Therefore, there is some hydraulic continuity along the well casing that connects the screen interval to the shallower layers of both the B-zone and the upper aquifer (A-zone). Similarly, wells LR-18, LR-4, intersect the both the injection zone of LR-19 and layers above the injection zone. The volume of water that could move upward through the gravel pack of LR-19 into the upper aquifer is small and the vast majority of water injected is entering horizontally into the lower B-zone, particularly the blue layers.

2.2 Surface Water Delivery and Injection Infrastructure

2.2.1 Surface Water Delivery

The summer of 2021 was one of the driest on record in the area and delivery of irrigation water from the Kings River to the Lemoore Canal was severely curtailed. Surface water from Lateral 4 of the Lemoore Canal became available for injection on June 19, 2021. Water was conveyed from Lateral 4 through a PVC pipe via gravity to the wellhead. A 10” tee with butterfly valve in the conveyance lateral was used to connect the lateral to the inlet of the injection pump (described below). The pipe from Lateral 4 also conveyed water to an adjacent delivery canal and storage area. Surface water flow rates entering the injection infrastructure were monitored by a totalizing flow meter. This meter was also used by the Lemoore Canal Company to calculate charges for the surface water used for injection.

2.2.2 Injection Infrastructure

A schematic of the injection infrastructure used at LR-19 for the pilot test is shown on Figure 2-5a through 2-5c. All temporary aboveground infrastructure for the test was provided and installed by Rain for Rent, Westside Pump of San Joaquin, CA. A 50-horsepower electrical pump rated for up to 2,100 gallons per minute (gpm) and 135 feet of head was used to pump water from the 10” gravity feed. The pump motor was equipped with a variable frequency drive (VFD) to allow variable flow rates to the well. The VFD was powered by a portable diesel generator. Water was then delivered to a filtration system. The filter system consisted of four, 48-inch diameter sand filters with 75% #20 mesh crushed silica sand and 25% #3 mesh gravel, designed to operate at a maximum injection flow rate of 1,000 gpm (approximately 20 gpm per square foot of filter media). The filtration system included an automated backwash system that backwashed each filter based on a differential pressure set point across the filter or a set time interval. During each backwash cycle, a portion of the supplied water was used to backwash one of the four vessels, which temporarily reduced the flow rate available for injection into the well. Each backwash cycle lasted a total of approximately 2 minutes per vessel on average. Backwash cycles typically were initiated approximately every 3 hours on average. Two air-release valves were installed in the injection piping with two additional air release valves in the filtration system to reduce air entrainment in the water injected into the well. A pressure regulating valve located at the filtration system outlet pipe was installed to help regulate the water supply pressure during backwash cycles.

Filtered water was then directed to the LR-19 well casing via a 8” aluminum pipe with a pressure regulating valve and injected into the well through the pump column. Injection tubes were originally proposed to be used for injection, but the pump column was used instead to reduce the amount of modification necessary for the well and better accommodate the water-level sounding tubes. The impellers on the pump were “released” so that they would rotate backwards during injection. Irrigation pump impellers are typically “locked” so they only rotate during pumping. However, many turbine pumps are designed so that they can be released and rotate backwards.

2.3 ASR Pilot Test Procedures

2.3.1 Start-up Operations

Start-up operations for the ASR test were initiated on June 21, 2021 and transitioned to normal test operations by July 6, 2021. Operations were determined based on aquifer hydraulic properties determined during the baseline pump tests that occurred in March 2021. Properties are listed on Table 2-2.

During initial start-up of the system, injection flow rates ranged between 450 and 650 gpm. Initially, positive pressure could not be maintained at the well head causing "suction breaks" and "cascading water" (i.e. high air entrainment) in the pump column. This was caused by difficulties equalizing the pressures from the gravity-fed inflow, through the variable speed pump to the filtration system, and then down the borehole via the pressure regulating value. Specific issues during the initial start-up included: (1) insufficient backpressure in the well and pump column initially resulting from the relatively deep static water level; and (2) a large pressure drop across the filtration system combined with temporary pressure drop during backwash cycles. One of the causes for these pressure problems was a combination air valve was used at the well head which allowed atmospheric air to be pulled into the column pipe to prevent a vacuum condition. This valve was later replaced with a continuous air vent without vacuum relief, so air was only permitted to be vented from the column pipe and not allowed to enter. These problems should be recognized for future applications.

Once the system was stabilized, it operated relatively smoothly for the duration of the test. The automated filter backwash was typically triggered every 2-3 hours and there was minimal air-entrainment in the pump column. The well was fully backwashed every 3-4 days using the well pump.

2.3.2 Testing Sequence

After the initial start-up described above, the overall testing sequence consisted of 7 "cycles" of injection, followed by a 37-day storage period and 16 days of recovery (pumping). Each injection cycle lasted between 3 and 5 days and concluded with a full backflush of the well. Throughout each injection cycle, periodic backflushing of the filter system occurred.

A total of 80 acre-feet (AF) of water was injected into the aquifer. During the storage phase, pumping continued at adjacent irrigation wells. Initial recovery involved recovery of 87 AF from the injection well with routine water quality sampling during. A step test was then conducted to evaluate well efficiency. The injection well was then put back into service for irrigation. After irrigation ceased (in November), the well was inspected with a video log and conditioned using an acid wash, followed by another step test to evaluate well efficiency. A timeline showcasing the ASR Pilot Test is provided on Figure 2-6.

2.4 Water Level Responses

Water level measurements at the pilot test well and observation wells (AG-1, LR-4, LR-18, Sunset) were monitored throughout phases of the ASR Pilot test using pressure transducers, supplemented by manual measurements using an electric tape sounder. A summary of water level monitoring locations and frequencies are provided in Table 2-3.

Transducers were deployed into wells LR-19, Sunset, and LR-18 before the start of the injection phase to monitor water levels every five to fifteen minutes. Transducers were not deployed in AG-1 and LR-4 before the injection phase began due to well accessibility issues. There were also intermittent problems with transducers during the test.

For example, Wells LR-4 and LR-18 were inadvertently pumped for irrigation supply during the test and when those wells were pumping, the water levels dropped below the transducer. However, sufficient water-level data was collected to observe water level response (or lack of response) during the test. Recorded transducer water levels throughout the phases of the test are available in Appendix B.

2.5 Water Quality Monitoring

Water quality monitoring occurred before and during the ASR pilot test in the injection/extraction well LR-19, observation wells LR-4, AG-1, W1601-006, Z001M, and Sunset Vista Estates PWS (Sunset Active). A summary of water quality monitoring locations and frequency are presented in Table 2-4.

Baseline water quality samples were collected from the pilot and observation wells in late March 2021. Additionally, a sample from the Kings River immediately downstream of Pine Flat Dam was collected several days before the injection phase began. Surface water quality was consistent with water quality results from 2019 presented in the Work Plan (Geosyntec, 2020a). A variety of water quality parameters were analyzed during the course of testing, including general chemistry, base metals, isotopes, and microcystins. A summary of water quality parameters and all water quality data is provided in Appendix C.

During the injection phase of the ASR pilot test, samples were collected from the source water once every week; from LR-19 during each backflush cycle of the well; and from the observation wells after 4 weeks of injection.

During the storage phase of the ASR pilot test, samples were collected from LR-19 every two weeks and from observation wells every 4 weeks.

During the extraction phase of the ASR pilot test, field parameters from LR-19 (pH, DO, conductivity, and Redox potential) were collected every 15 minutes and samples were collected for laboratory analysis every 3 to 5 days, depending on the field parameter results. The sampling during recovery was intended to observe water chemistry changes as the ASR “bubble” was withdrawn and native groundwater passed back through the injection well.

For groundwater samples, low-flow sampling protocols were used at the five observation wells during the three phases of the pilot test as well as at LR-19 during the storage phase. During the injection and extraction phases, grab samples were collected from LR-19 while the well was being pumped. Samples were collected in laboratory-provided certified clean containers, with preservative as needed, and were submitted to BC Laboratories, Inc. of Bakersfield, California, for analysis. Samples collected for metals analysis were filtered by the laboratory prior to analysis.

3. ASR PILOT TEST RESULTS

This section presents the results of the ASR pilot test, including injection volumes and water levels (Section 3.1), water quality during each phase of the pilot test (Section 3.2), and performance of the injection well (Section 3.3). Hydrographs of the injection phase for LR-19 are summarized on Figures 3-1a through 3-1g and Figures 3-2a through 3-2d for observation wells Sunset, LR-18, LR-4, and AG-1. Water quality results are summarized on Appendix C and discussed in further detail in Section 3.2.

A total of 80 AF of water was injected over 7 cycles of injection, followed by 37 days of storage. A total of 87 AF of water was then recovered, and the well was put back into service for irrigation and was not monitored further. In general, results can be summarized as follows:

- Water level build-up in the injection well increased continuously during each injection cycle and a steady state water level was not achieved for any injection cycle.
- Peak build-up of 200 to 250 feet was achieved after 3-4 days of injection at injection rates of between 500 and 600 gpm.
- Water quality during injection was consistent in the injection well and no changes were observed in the observation wells. This is consistent with the “bubble” concept, where in injected surface water displaced native groundwater with a relatively small radius of influence.
- Field water quality (pH, temperature, specific conductance, dissolved oxygen, and oxidation-reduction [redox] potential) of recovered water showed now water quality changed at the edge of the bubble, represents a mixing zone between surface water and native groundwater .
- The differences in water quality between injected surface water and native groundwater caused chemical reactions at the edge of the bubble that resulted in increases in metals, including arsenic and uranium.
- Geochemical chemical equilibrium between the injected surface water and native groundwater was not achieved after 37 days of storage, as indicated by the water quality changes at the edge of the bubble.

3.1 ASR Phases and Water Levels

The injection phase began on July 6, 2021. Figures 3-1 through 3-2 show the water-level hydrographs in each well for all injection cycles. Figures 3-3a through 3-3c show the water-level responses for each injection cycle. A summary of each injection Phase is provided below:

Injection Phase

- **Injection Cycle 1** began on July 6 and a total of 15.5 AF of water was injected over a 3-day period. Maximum head build-up in LR-19 was about 240 feet. Well LR-4 showed no response to injection. Water levels in well LR-18 rose about 4.5 feet in response to injection.

- **Injection Cycle 2** began on July 9 and an additional 17.1 AF of water was injected over a 6-day period for a total injection volume of 32.4 AF. There were several minor shut-downs during this cycle caused by generator issues and filter maintenance. The short-frequency water-level fluctuations in well LR-19 are caused by the automated filter backwash system. Maximum head build-up in LR-19 was about 184 feet. Well LR-4 showed no response to injection. Water levels in well LR-18 continued to increase and then dropped about 4.5 feet likely in response to pumping at a neighbor's well. Water-levels then rose again at LR-18 before the end of Cycle 2.

- **Injection Cycle 3** began on July 16 and an additional 13.9 AF of water was injected over a 4-day period for a total injection volume of 46.2 AF. Maximum head build-up in LR-19 was about 187 feet. Well LR-4 showed no response to injection. Water levels in well LR-18 rose about 3.8 feet in response to injection.

- **Injection Cycle 4** began on July 20 and an additional 10.3 AF of water was injected over a 3-day period for a total injection volume of 56.4 AF. Maximum head build-up in LR-19 was about 200 feet. Water levels in well LR-4 dropped below the bottom of the transducer for a short time when the well pump was inadvertently turned on to sample the well. It then recovered and continued to show no response to injection. Water levels in well LR-18 were stable during this injection cycle, unlike the response during Cycle 1 and 3.

- **Injection Cycle 5** began on July 23 and an additional 12.6 AF of water was injected over a 4-day period for a total injection volume of 68.8 AF. The short-frequency water-level fluctuations in well LR-19 caused by the automated filter backwash system became more pronounced during this cycle. Maximum head build-up in LR-19 was about 185 feet. Well LR-4 showed no response to injection. Water levels in well LR-18 declined 5.2 feet during this injection cycle, again in response to pumping at a nearby neighbor's well. Water levels increased slightly toward the end of the Cycle.

- **Injection Cycle 6** began on July 27 and an additional 4.9 AF of water was injected over a 2-day period for a total injection volume of 73.6 AF. The short-frequency water-level fluctuations in well LR-19 caused by the automated filter backwash system was less pronounced during this cycle. Maximum head build-up in LR-19 was about 240 feet. Well LR-4 showed no response to injection. Water levels in well LR-18 were fairly stable, and declined about 1-foot the end of the Cycle.

- **Injection Cycle 7** began on July 29 and an additional 6.4 AF of water was injected over a 3-day period for a total injection volume of 80.03 AF. During this cycle, maximum head build up in the well was over 250 feet and reached the top of the well casing. The Cycle was interrupted and restarted, but the injection system began having problems maintaining well pressure and the Cycle was stopped. Well LR-4 showed no response to injection. The pump in well LR-18 was turned on at the end of this cycle and water levels dropped below the bottom of the transducer.

Storage phase

- Storage began on August 1 and lasted until September 6. Except for well LR-19, irrigation operations in surrounding wells resumed as normal. Water-levels in well LR-19 declined slowly over the first 15 days, reaching an elevation of about -80 feet. This water level is 10 feet below the original static water level prior to the test. Water levels increased slowly to about -65 feet at the end of the storage phase.
- Well LR-18 began pumping at the end of the injection phase. Water levels were at or below the pump bowls and could not be measured manually with the electric sounder or transducer. Water levels for Well-LR-18 were captured when the well was turned off on August 29-30 and then again September 2-6.
- Water levels in LR-4 initially showed a slight decline in water levels during the storage phase and then showed four distinct recovery responses from pumping. In each of the four responses, the water levels dropped below the pressure transducer, so the maximum drawdown from the pumping was not measured and the observations are limited to the recovery of water levels. On August 15-16, Well LR-4 was turned on twice and water levels dropped below the transducer twice and then recovered slowly over a period of about 10 days. On August 27-30 well LR-18 was operating and water levels dropped below the transducer twice. The shape of the recovery response for the first two pumping events in LR-4 is different than the response to the last two pumping cycles in LR-18.
- The Sunset well showed no response to pumping.

Recovery Phase

- The LR-19 injection well was pumped from September 6 until September 22nd. A total of 87.1 AF was pumped during the recovery phase.
- Well LR-4 showed no response to pumping, consistent with the response during injection.
- Well LR-18 showed some response to pumping, but, unfortunately the well also operated during the recovery phase and water levels dropped below the transducer.
- The Sunset well showed no response to pumping.
- After recovery, an 8-hour step pumping test was conducted on September 23 and followed by a 24-hour constant rate test on well LR-19. Higher drawdowns were observed during the post-recovery testing, indicating a loss of well efficiency. This is discussed further in Section 3.3. Well LR-19 was then put back in service for the remainder of the irrigation season.
- On January 18, 2022, well LR-19 was video inspected. On February 18, 2022, samples were collected to capture water and precipitates found within the well screen. This was followed by rehabilitation using an acid wash. A 4-hour step pumping test was then conducted on March 1, 2022 to evaluate well efficiency.

Hydrographs for the Pilot Well (LR-19) during the Storage and Recovery phase are presented in Figures 3-4a and 3-4b. Hydrographs for Observation Wells during the Storage phase are presented in Figures 3-5a through 3-5d and Recovery phase hydrographs are provided in Figures 3-6a through 3-6d.

3.2 ASR Water Quality

This section summarizes the water quality conditions observed before the pilot test (baseline) and during the injection, storage, and recovery phases of the pilot test. Field parameters and analytical results from groundwater and surface water samples collected during the pilot test are presented in Appendix C.

3.2.1 Baseline Water Quality

Baseline water quality samples were collected in March 2021 from the ASR pilot well (LR-19), the observation wells (LR-4, Sunset, AG-1, Z001M, and W1601), and surface water according to the frequency and sample methods shown in Table 2-4 (Appendix C). Time series of groundwater composition at pilot well LR-19 during the pilot test are shown in Figure 3-7a through 3-7c. Baseline water quality results are summarized below:

- Baseline groundwater at pilot well LR-19 and the observation wells is generally characterized by circumneutral pH (approximately 7 to 8.5), low conductivity (<700 microsiemens per centimeter (µS/cm)), and low total dissolved solids (TDS) (<400 milligrams per liter (mg/L)), except for well AG-1, where groundwater conductivity was 2,226 µS/cm, and TDS was 1,400 mg/L. Well AG-1 is screened in the shallower A-zone, whereas the other observation wells and LR-19 are screened in the B-zone (Section 2.1).
- Baseline groundwater oxidation-reduction potential (ORP) values were generally <100 millivolts (mV), and dissolved oxygen (DO) values were variable. Nitrate was not detected (<0.10 mg/L) in baseline groundwater samples. Dissolved iron and manganese were detected up to concentration of 0.61 and 1.4 mg/L. Taken together, these results are consistent with moderately reducing conditions.
- Baseline groundwater in ASR pilot well LR-19 is characterized as a sodium-bicarbonate ($Na\text{-}HCO_3$) water type, with low levels (<10 mg/L) of calcium, magnesium, and sulfate (Figure 3-8). Baseline groundwater in observation wells LR-4, Sunset, W1601, and Z001M is also characterized as a $Na\text{-}HCO_3$ water type, with similar groundwater composition to LR-19 (Figure 3-9). Baseline groundwater in observation well AG-1 is a sodium-sulfate ($Na\text{-}SO_4$) water type, with sulfate concentrations exceeding 700 mg/L (Figure 3-9).
- Baseline metals concentrations in the ASR pilot well and observation wells were generally low and below the California primary and secondary drinking water standards, with a few exceptions (Appendix C) (22 California Code of Regulations [CCR] § 64431; 22 CCR § 64449). Primary drinking water standards for aluminum and lead and secondary drinking water standards for iron were exceeded at LR-19.

Primary drinking water standards for aluminum and secondary drinking water standards for iron and manganese were exceeded at one or more observation wells.

- Baseline microbiological results indicated total coliform was present in pilot well LR-19 and observation well LR-4 at levels greater than 4 most probably number (MPN)/100 milliliters (ml). Total coliform was not detected at the other observation wells. Escherichia Coli (E. coli) was only detected in observation well LR-4.
- Baseline stable water isotope results at pilot well LR-19 (-85.8% δD, -11.39% $\delta^{18}O$) were isotopically heavier than baseline surface water (-96.1% δD, -12.79% $\delta^{18}O$) (Figure 3-10). Baseline stable water isotope results at the observation wells were similar to baseline surface water.

Baseline surface water quality samples were collected from Lateral 3 of the Lemoore Canal System (Cement Box) in September 2019 and downstream of the Pine Flat Dam (KRIV1) in June 2021 (Appendix C). Baseline surface water quality results are summarized below:

- Baseline surface water is generally a calcium-bicarbonate (Ca-HCO_3) water type with TDS concentrations of approximately 35 mg/L, much lower than baseline groundwater (Figure 3-8).
- Baseline metals concentrations in surface water met all California primary and secondary drinking water standards.
- Baseline microbiological results for surface water indicated total coliform was present in Lemoore Canal and in the Kings River below Pine Flat Dam. E. coli was only detected in the Kings River below Pine Flat Dam.

3.2.2 Water Quality During Injection

Groundwater quality during injection was monitored at well LR-19 during backflushing events and at the observation wells midway through the injection phase (Appendix C). Time series of groundwater composition at pilot well LR-19 during the pilot test are shown in Figure 3-7a through 3-7c. Water quality results during injection are summarized below:

- Water quality at well LR-19 was similar to surface water during in injection, characterized as a calcium-bicarbonate (Ca-HCO_3) water type with low TDS, bicarbonate, chloride, and sulfate concentrations (Figure 3-8). Field parameters from well LR-19 during backflush events included lower pH and conductivity and higher dissolved oxygen and ORP compared to baseline measurements (Figure 3-7a).
- Groundwater at well LR-19 was more oxidizing than baseline conditions during injection (consistent with the injectate). Dissolved oxygen (DO) concentrations generally exceeded 10 mg/L, which represents saturation at ambient temperature and pressure at ground surface. (This is consistent with the challenges reported in delivering the injected water without entraining air, described in Section 2.3.1.) ORP values were generally greater than 0 mV, and dissolved iron concentrations were around 0.05 mg/L, an order of magnitude lower than baseline concentrations (Figure 3-7a, 3-7c).

- Water quality at the observation wells was nearly identical to baseline water quality, as shown on a Piper diagram (Figure 3-9). This is consistent with the preliminary modeling analysis (particle tracking) that indicated that the radius of influence during injection would not reach the surrounding domestic wells (Geosyntec, 2020a). Minor changes in individual constituents in groundwater at the observation wells over the course of the pilot test can be attributed to natural fluctuations.

- Metals concentrations at well LR-19 and the observation wells generally remained at baseline levels or decreased during injection, with the exception of manganese, which increased (Figure 3-7c). During injection, the secondary drinking water standard for manganese was exceeded at well LR-19 and the observation wells.

- Microbiological results for groundwater indicated an increase in total coliform and E. coli concentrations at pilot well LR-19 compared to baseline results. Microcystin concentrations never exceeded the threshold concentration for stopping injection (1.0 micrograms per liter (µg/L)) (Geosyntec, 2020b). Microbiological results at observation wells were generally similar to baseline; total coliform and E. coli were only identified at observation well LR-4.

- Stable water isotope results at pilot well LR-19 (-96.7% δD, -12.92% $\delta^{18}O$) were similar to baseline surface water (-96.1% δD, -12.79% $\delta^{18}O$) (Figure 3-10). Stable water isotope results at the observation wells remained stable at baseline levels.

3.2.3 Water Quality During Storage

One groundwater sample was collected from pilot well LR-19 during the storage phase of the pilot test (after injection and prior to recovery) (Appendix C). Water quality at well LR-19 during storage was similar to baseline groundwater, characterized as a sodium-bicarbonate (Na-HCO_3) water type (Figure 3-8). Field parameter measurements of groundwater at LR-19 were also similar to baseline groundwater, with circumneutral pH (approximately 7 to 8.5), moderately reducing ORP (around -120 mV), low conductivity (<700 µS/cm), and low total dissolved solids (TDS) (<400 mg/L) (Figure 3-7a). Bicarbonate alkalinity (190 mg/L as $CaCO_3$), chloride (14 mg/L), and potassium (0.21 mg/L) approached their respective baseline concentrations, but sulfate (41 mg/L), calcium (4.1 mg/L), magnesium (0.85 mg/L), and sodium (150 mg/L) were elevated well above baseline concentrations (Figure 3-7b). Metals concentrations at LR-19 during storage were below California primary and secondary drinking water standards (Appendix C, Figure 3-7c). These results suggest that the injected water was equilibrating with the aquifer matrix, at least within the immediate vicinity of the injection well LR-19. No observation wells were identified to be within the "bubble", so the radial extent of equilibration is unconfirmed in this pilot test. Elevated concentrations of sulfate, calcium, magnesium, and sodium likely reflect mobilization from the solid phase during storage.

3.2.4 Water Quality During Recovery

Groundwater sampling during recovery focused on the water recovered from LR-19. During recovery, five samples were collected from ASR pilot well LR-19, and one sample was collected from each of the observation wells (Appendix C). Time series of groundwater composition at pilot well LR-19 during the pilot test are shown in Figure 3-7a through 3-7c. Water quality results during recovery are summarized below:

- Water quality at pilot well LR-19 was generally similar to baseline water quality as plotted in a Piper diagram (Figure 3-8). Compared to baseline conditions, concentrations of calcium, magnesium, and potassium at LR-19 during recovery increased by more than 20% as an overall result of the Pilot Test (Figure 3-7b). Concentrations of sodium, chloride, sulfate, and bicarbonate alkalinity at the end of the recovery phase were more than 20% lower than baseline conditions (Figure 3-7b).

- Water quality at the observation wells remained nearly identical to baseline and injection results, as shown in a Piper diagram (Figure 3-9). These results are consistent with a lack of influence of injection on water quality at the observation wells.

- Field parameters at well LR-19 generally trended towards conditions observed during baseline monitoring (Figure 3-7a). Field parameter values at the beginning of the recovery phase were similar to values measured during the injection phase of the pilot test (more oxidizing, lower pH, lower conductivity), and as the injected water was recovered, field parameter values eventually evolved to reflect native groundwater (more reducing, higher pH, higher conductivity). This pattern is indicative of the hydrogeochemical structure of the bubble, where the center of the bubble, which is removed at the beginning of recovery, evolves to a mixed water quality and then transitions to a water quality representative of native groundwater.

- Concentrations of metals at well LR-19 were below the primary and secondary drinking water standards, with some exceptions (Figure 3-7c). Iron and aluminum each exceeded a drinking water standard in one sample collected during the recovery phase. Arsenic exceeded the primary drinking water standard in all samples collected during the recovery phase.

- The arsenic concentration at the end of the recovery phase (0.026 mg/L) was higher than baseline concentrations (around 0.007 mg/L) and exceeded the drinking water standard of 0.01 mg/L (Figure 3-7c). The arsenic concentration of a sample collected in November 2021 was similar to the concentration measured at the end of the recovery phase.

- The uranium concentrations at the end of the recovery phase (11 picocuries per liter (pCi/L)) was higher than baseline concentrations (around 4 pCi/L) but did not exceed the drinking water standard of 20 pCi/L (Figure 3-7c). The uranium concentration of a sample collected in November 2021 (19 pCi/L) was greater than the concentration measured at the end of the recovery phase.

- Microbiological results for groundwater indicated a decrease in total coliform and E. coli concentrations at pilot well LR-19 and observation well LR-4 compared to baseline conditions.

- Stable water isotope results at pilot well LR-19 were initially isotopically lighter than in the injection phase, then gradually increased throughout the recovery phase, but did not return to baseline levels (Figure 3-10). Stable water isotope results at the observation wells were similar to results measured during the baseline and injection phases of the pilot test, consistent with no meaningful influence from the pilot test.

Analysis and discussion of these geochemical trends observed in the pilot test phases are provided in Section 4.2 below.

3.3 ASR Well Performance

An important element of the ASR test was to determine whether the injection well could maintain adequate injection and withdrawal capacity during the test; determine whether the well experienced losses in capacity as a result of injection (and if so whether capacity could be restored through redevelopment). This was evaluated using a series of step drawdown tests in the irrigation well. Well LR-19 was pumped at successively higher pumping rates for a period of 2-4 hours at each step. Drawdown in the well was measured and plotted as a function of elapsed time. Three specific capacity tests were conducted: one prior to injection in June 2021; a second after full recovery in September 2021; and a third after video inspection and redevelopment in February 2022. The step drawdown tests were evaluated in terms of specific capacity, which is simply the pumping rate divided by the drawdown in the pumping well. More complicated calculations of well efficiency were not undertaken. The results are summarized on Figure 3-11:

- Prior to injection, Well LR-19 had a specific capacity of around 34 gpm/foot at each of the pumping steps. This indicates a high well efficiency that is well matched to the pump capacity. An inefficient well typically shows lower specific capacity at higher pumping rates and/or a decrease in specific capacity within any given pumping step.

- After injection, Well LR-19 had an average specific capacity of 24 gpm/foot at each of the pumping steps. This is about 30% lower than the pre-test specific capacity. However, the specific capacity was generally consistent at 25 gpm/ft at each pumping step.

- Video inspection of the well after recovery showed abundant black precipitates in the well that were not present during the pre-test video inspection. While no encrustation onto the well screen was observed, these precipitates were the likely cause of the reduced well capacity and were fouling the gravel pack and perhaps the formation. The geochemistry associated with the fouling of LR-19 is discussed further in Sections 4.2.4 and 4.4.3. The well was then rehabilitated using hydrochloric acid wash.

- After the well video inspection and well redevelopment, Well LR-19 had a specific capacity of around 26 gpm/foot at each of the pumping steps. This is about 24% lower than the pre-test specific capacity, and 8% higher than from the post-test specific capacity.

4. ANALYSIS AND DISCUSSION

This section presents an analysis and discussion of the ASR pilot test results. It is focused on four general topic areas:

1. Aquifer hydraulics
2. Aquifer water quality and geochemistry
3. Injection well performance
4. ASR injection system performance

4.1 Aquifer Hydraulic Response

Aquifer hydraulic properties were collected in March 2021 during an 8-hour step and 24-hour constant rate test in conjunction with a baseline sampling event. Properties found from the baseline pump tests were similar to the screening-level groundwater flow model discussed in the ASR Workplan and Pump Test Update and are listed in Table 2-2 (Geosyntec, 2020a; Geosyntec, 2021).

4.1.1 Area of Influence

Stimulations from the screening-level groundwater flow model predicted the influences of ASR activities (injection, storage, extraction) including estimated drawdown at the observation wells (Geosyntec, 2020a). The model included three simulations (base case, decreased storativity, and worse case) which forecasted water level fluctuations at LR-19 and observation wells, Sunset and LR-4. The model predicted no water level response from the Sunset well and up to 1.4 feet of head variance from LR-4.

4.1.2 Lower B-zone Response

Well LR-18 is the only observation well completed and monitored within the lower portion of the B-zone. This was also the only well with water levels that reacted to injection at LR-19 with an average rise of 4.2-feet during injection cycles 1 and 3, and an average decrease of 4.9-feet during injection cycles 2 and 5. The decreasing water-levels during cycles 2 and 5 were likely a response to pumping at a nearby well that was not monitored during the test.

Well LR-18 was pumped during the storage phase except for two short periods of time. During these periods, water levels dropped below the transducer, but, when the well was off, showed some response to pumping at LR-19.

4.1.3 Upper B-zone and A-zone Response

Two shallow aquifers were monitored during the ASR Pilot Test, the perched A-zone aquifer (AG-1), and upper portion of the B-zone (LR-4 and Sunset). Water levels were not influenced during any phase of the ASR Pilot Test. Observation wells, LR-4 and the Sunset well monitored the upper portion of the semi-confined aquifer and did not experience water level responses to any phase of the ASR Pilot Test. Wells completed in the shallow aquifer were not affected by ASR activities.

4.2 Water Quality Responses

This section discusses the water quality results of the pilot test in the context of ASR operations.

4.2.1 Water Quality in Observation Wells

The Piper diagram of groundwater composition at the pilot test observation wells indicates that water quality at the observation wells was not affected by pilot test activities (Figure 3-9). In addition, stable water isotope results at the observation wells remained stable at baseline levels throughout the pilot test. These results are consistent with the preliminary modeling analysis (particle tracking) that indicated the radius of influence during injection would not reach the surrounding wells (Geosyntec, 2020a). The lack of response in surrounding domestic wells indicates that ASR can be effectively employed at LR-19 without impacts to local drinking water quality.

4.2.2 Water Quality in Injection Well LR-19

Pilot test activities induced changes in groundwater composition at pilot well LR-19 (Figure 3-8). The LR-19 Piper diagram indicates that groundwater composition was similar to groundwater at observation wells before initiation of the pilot test. During the injection and storage phases of the test, groundwater composition at LR-19 transitioned to being similar to surface water. Finally, during the recovery phase of the pilot test, groundwater composition gradually returned to near-baseline conditions.

Comparison of groundwater composition and stable isotopes at pilot well LR-19 at baseline and at the end of the pilot test suggests that the "bubble" of injected water was not entirely extracted during the recovery phase. Concentrations of calcium, magnesium, and potassium remained greater than 25% higher than baseline concentrations at the end of the pilot test (Figure 3-7b). Concentrations of sodium, bicarbonate alkalinity, chloride, and sulfate remained at least 20% lower than baseline concentrations at the end of the pilot test (Figure 3-7b). Likewise, the isotopic composition of groundwater at LR-19 at the end of the recovery phase was approximately 10% lighter than the baseline isotopic composition (Figure 3-10). The isotopic composition at the end of the recovery phase, as well as the elevated calcium, magnesium, and potassium, may reflect mineral dissolution from the aquifer matrix during the pilot test, in addition to conservative mixing behavior between the injected water and the native groundwater. Mineral dissolution is further discussed below.

The redox potential at LR-19 changed during the course of the pilot test as well, similar to the groundwater composition. At baseline conditions, ORP values were negative and dissolved oxygen concentrations were low, indicative of reducing conditions (Figure 3-7a). During injection, the dissolved oxygen and ORP values reflected the more oxic conditions of the injected water. In the storage phase, the groundwater immediately adjacent to LR-19 transitioned towards baseline reducing conditions. Upon extraction, ORP values transitioned from the injected water quality towards that of baseline conditions. Dissolved oxygen values remained relatively low throughout the recovery phase, suggesting that the amount of dissolved oxygen introduced to the aquifer via injection was consumed in geochemical reactions in the aquifer (likely driven by microbial respiration). These trends do not indicate significant post-test redox disequilibrium, such as reductive dissolution of iron and manganese oxide minerals. The concentrations of dissolved iron and manganese during recovery were relatively low (less than 1 mg/L; Figure 3-7c and Table A, Appendix C).

In contrast with other parameters discussed above, the pH of groundwater at pilot well LR-19 changed during the pilot test and did not return to baseline conditions (Figure 3-7a). Groundwater pH, which is not conservative, reflects the interaction of the injected water with the aquifer minerals, dissolved gases, and to some extent, the native groundwater. Baseline groundwater pH at LR-19 was approximately 8.5, compared to a baseline surface water pH of approximately 7 (Table F, Appendix C). During the injection phase, the pH values of the injected water remained lower than baseline, with the largest decreases observed during the backflush operations (minimum pH of 5.2). During the recovery phase, groundwater pH at LR-19 increased to a maximum value of 9.7. Likely interactions with minerals and dissolved gases that would explain this pH response are discussed further below.

The solid-phase aquifer matrix was not specifically characterized during the pilot test, but based upon the regional geological setting, the minerals comprising the Tulare Basin sediments likely include carbonates of marine and/or lacustrine origin (TLSB, 2020). These minerals were in equilibrium with the native groundwater prior to the pilot test operations, and in particular, a significant partial pressure of CO_2 gas at the depth of the LR-19 screened interval (340 to 540 feet bgs, reflecting a saturated water column of more than 200 feet). CO_2 gas can form in an aquifer over long periods of equilibration with minerals and microbial activity. Dissolved carbonate species are monitored through analysis of bicarbonate alkalinity, but the partial pressure of CO_2 gas at depth in the aquifer is not readily measurable. Instead, the influence of carbonate chemistry on the groundwater can be assessed with the combined chemical reaction below:

$$H_2O + CO_2(g) \leftrightarrow H_2CO_3^*(aq) \leftrightarrow H^+ + HCO_3^- \leftrightarrow 2H^+ + CO_3^{2-}$$

Dissolved carbonate (CO_3^{2-}) can further react with dissolved calcium and/or magnesium in groundwater to precipitate or dissolve carbonate minerals, such as calcite in the chemical reaction below:

$$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3(s)$$

Removal of CO_2 gas from the groundwater drives this equilibrium to the left, consuming H^+ and increasing the pH, but also dissolving some of the carbonate minerals in equilibrium with the groundwater. Precipitation of carbonate minerals, in contrast, drives the equilibrium to the right, producing H^+, decreasing the pH, and decreasing dissolved calcium and magnesium concentrations. The magnitude of bicarbonate alkalinity concentration changes does not necessarily align with the significant pH shifts from these reactions.

The injected water was undersaturated (saturation index [SI] < 0) with respect to carbonate minerals (such as calcite [$CaCO_3$], SI = -2.5,[1]). Upon interaction with the injected surface water, which was in equilibrium with atmospheric levels CO_2 gas (i.e., a substantially lower partial pressure of CO_2), the carbonate equilibrium of groundwater shifted to the left: carbonate minerals dissolved, resulting in elevated calcium and magnesium (Figure 3-7b) and increasing the pH (Figure 3-7a). The trend in bicarbonate and total alkalinity also supports this hypothesis. During storage, alkalinity of the bubble increased from the low levels of the surface water to baseline levels in groundwater. During recovery, however, the alkalinity was lower, with an increasing trend towards the groundwater baseline levels as the bubble and mixing zones were extracted.

If carbonate geochemistry explains the predominant trends in major ions during the pilot test, as hypothesized here, then additional storage time should allow the mineral reactions, dissolved CO_2 gas, and injected water to reach equilibrium at pH levels closer to baseline. However, carbonate mineral kinetics are notoriously slow in the environment (Stumm and Morgan, 1996), so alternate means of reaching equilibrium in an ASR setting should be considered, such as addition of carbonate to the injection water, whether via pressurization with CO_2 gas or passing the surface water through a bed of limestone (calcium carbonate) prior to injection.

4.2.3 Trace Metal Constituents

Trace metal behavior in groundwater is expected to follow from trends in primary geochemical parameters including pH, ORP, dissolved oxygen, major cation and anions, and metals iron and manganese. As described in Section 4.2.2 above, the majority of these parameters indicated a return to near-baseline conditions after the pilot test, with the exception of pH. Although the development of reducing geochemical conditions can promote reductive dissolution of iron and manganese oxides and lead to an increase in dissolved trace metal concentrations, dissolved iron and manganese concentrations remained low (<0.5 mg/L) during the recovery phase, suggesting that reductive dissolution of iron and manganese oxides during the pilot test was not significant.

Metals concentrations at pilot well LR-19 fluctuated over the course of the pilot test (Figure 3-7c, Appendix C). Typically, redox-sensitive trace metals such as arsenic, hexavalent chromium (Cr[VI]), and uranium, are drivers for water quality concerns following redox changes that are typical in ASR operations. In the pilot test, groundwater Cr(VI) concentrations decreased below baseline levels and remained stable for the duration of the pilot test. Groundwater arsenic and uranium concentrations at pilot well LR-19 increased during the recovery phase, consistent with desorption of negatively charged arsenic and uranium species from aquifer solids as pH increased. Groundwater arsenic concentrations increased to approximately 0.04 mg/L during the recovery phase and exceeded the drinking water standard of 0.01 mg/L. Groundwater uranium concentrations approached, but did not exceed, the drinking water standard of 20 pCi/L. Arsenic and uranium are well-known to adsorb to iron and manganese oxide mineral surfaces (United States Environmental Protection Agency, 2007). Adsorption of arsenic to iron oxides is strongest below circumneutral pH due to attraction of negatively charged aqueous arsenic species to

[1] The saturation index of calcite was calculated with Geochemist's Workbench using analytical results from the sample collected downstream of the Pine Flat Dam (KRIV1) on June 15, 2021 (Appendix C).

positively charged oxide surfaces. Adsorption of uranium to iron oxides is strongest at circumneutral pH and under low carbonate concentrations; uranium adsorption is minimal under acidic and alkaline pH and is further decreased in the presence of carbonate and calcium. Thus, desorption of arsenic and uranium from aquifer solids is primarily attributed to dissolution of aquifer carbonate minerals during storage and subsequent increases in pH and concentrations of carbonate and calcium. and also lead to an increase in dissolved concentrations of arsenic and uranium; however, dissolved iron concentrations remained low (<0.4 mg/L) during the recovery phase, suggesting that reductive dissolution of iron oxides during the pilot test was not significant.

Additional storage time should allow the mineral reactions, dissolved CO_2 gas, and injected water to reach equilibrium at pH levels closer to baseline. Sorption equilibria typically reflect a strong sensitivity to pH fluctuations (Stumm and Morgan, 1996), such that a return to baseline groundwater pH of ~8.5 would likely resorb much of the dissolved arsenic liberated during the pilot test.

4.2.4 Microbiological Constituents

Results of groundwater sampling during the pilot test indicate that pilot test activities did not impact the water quality of the injection well or observation wells with respect to microbiological constituents. Microcystin concentrations during injection never exceeded the threshold concentration for stopping injection (1.0 µg/L) (Geosyntec, 2020b) (Appendix C). However, an increase in total coliform and E. coli concentrations were observed in groundwater at injection well LR-19, reflecting the presence of coliform and E. coli in the injected surface water. Total coliform and E. coli were not detected in groundwater at LR-19 during the recovery phase, indicating attenuation of coliform and E. coli in groundwater during storage.

Total coliform and E. coli were not detected in groundwater at observation wells, except for well LR-4. Total coliform was detected in groundwater at LR-4 during baseline, indicating that total coliform detected during injection and recovery was independent of pilot study activities. This is consistent with the LR-4 Piper diagram that indicated water quality was not impacted by pilot study activities (Figure 3-9, Section 3.2). Additionally, observation well LR-4 was sampled from a spigot during baseline and from either a standpipe or discharge pipe during the other phases of the pilot test. Therefore, baseline results at LR-4 may not be comparable to results collected from this well during other phases of the pilot test.

4.2.5 Fouling of Injection Well LR-19

The specific capacity of injection well LR-19 after the pilot test was approximately 30% lower than the specific capacity measured at baseline, and video inspection of the well after recovery showed abundant black precipitates that were not present during the pre-test inspection (discussed in Section 4.3.2). Taken together, these results suggest mineral fouling of the injection well screen and/or filter pack.

To test the hypothesis that mineral precipitation during the pilot test caused fouling of injection well LR-19, groundwater from LR-19 was sampled with the objective of collecting sufficient suspended precipitates in the casing of the well for solid-phase analysis. Solid-phase analysis was not able to be performed on the collected precipitates due to insufficient amount of sample. Therefore, one unfiltered and one field-filtered groundwater sample were collected from well LR-19 and analyzed for iron, manganese, calcium, magnesium, sodium, potassium, chloride, sulfate, and alkalinity. Results of the unfiltered and field-filtered samples represent total and dissolved fractions of each analyte, respectively, and the composition of the suspended precipitates was determined by difference.

Groundwater sample results collected to evaluate the composition of the chemical precipitate in well LR-19 are presented in Table G, Appendix C. Concentrations of total and dissolved constituents in groundwater samples were similar, except for iron. The total iron concentration in the unfiltered sample (1.4 mg/L) was an order of magnitude larger than the concentration of dissolved iron measured in the field-filtered sample (0.11 mg/L). The manganese concentration in the unfiltered sample (0.069 mg/L) was also in excess of the dissolved concentration measured in the field-filtered sample (0.050 mg/L), but to a much lesser degree. These results suggest that an iron-bearing precipitate is primarily responsible for fouling of well LR-19 and a subsequent decrease in specific capacity. Although the exact composition of the iron precipitate was unable to be identified, it must form under conditions of elevated pH and carbonate concentration, as discussed in Section 4.2.2. Therefore, the precipitate is likely a ferrous carbonate mineral (such as siderite, $Fe(II)CO_3$), or incorporation of reduced iron and manganese into another carbonate mineral (e.g., calcite, $CaCO_3$). Acidification of the unfiltered groundwater sample to dissolve the suspended particulates likely resulted in degassing of carbonate from the groundwater sample prior to analysis, which explains why the bicarbonate alkalinity concentrations of the unfiltered and field-filtered groundwater samples are similar. In particular, the incorporation of manganese into the iron carbonate mineral could explain the black color of the precipitate observed in well LR-19.

4.3 Injection Well Performance

This section discusses how the injecting well (LR-19) performed throughout the phases of the pilot test.

4.3.1 Specific Injectivity During Injection

Specific injectivity is the ratio of an injection rate per unit of water level rise, or build up. Similar to specific capacity, specific injectivity is used to determine if the injection well maintained adequate injection throughout the testing phase. Figure 4-1 shows how specific injectivity reacted throughout the seven injecting cycles.

At the beginning of each injection cycle, specific injectivity rates were at it’s highest and decrease as time passed and injection continued. Cycle one had the highest initial injectivity rate starting at 20 gpm/ft which resembled rates on the first day of injection at the beginning of air entrainment issues. As each cycle progressed, initial specific injectivity would generally lower for the following cycle with specific injectivity reaching a minimum of 10 gpm/ft per injection cycle. Spikes in cycles two and seven were caused by shutdowns and start-ups within the cycle.

4.3.2 Pre- and Post-Test Specific Capacity

Specific capacity trends are presented in Figure 3-11 and briefly discussed in Section 3.3. Prior to ASR activities, specific capacity ranged from 31.67 gpm/ft to 34.65 gpm/ft and was capable of injecting surface water with a relatively high well efficiency of 79% (Geosyntec, 2021). ASR activities decreased LR-19's specific capacity to a range of 23.7 gpm/ft to 30.4 gpm/ft as air was introduced into the aquifer along with mineral fouling of the injection well screen and/or filter pack. After the pilot test, LR-19 was unable to pump above a rate of 1,300 gpm sparking the need for well rehabilitation. Five months after completing the pilot test, LR-19 was rehabilitated with a hydrochloric acid wash followed by a shortened step-test days after. Specific capacity showed minimal improvement with post rehabilitation ranging from 23.8 gpm/ft to 30.7 gpm/ft. Specific capacity rates were unable to return to baseline, however, post rehabilitation returned LR-19's pumping rates to pre-injection capabilities of above 1,600 gpm.

4.4 Injection System Operations

As described above, the performance of the injection system overall was variable during the pilot test and required a number of adjustments. In addition, the performance of the injection well itself declined during the course of the test and ultimately resulted in a loss of well capacity because of precipitation of iron/manganese in the gravel pack. While capacity was restored through well redevelopment, fine tuning of the operational framework for ASR is warranted to better define ways to reduce operating costs and provide design options for a more broadly implemented program.

4.4.1 Filter System Design

- The filter media for this pilot test was 20 gpm per square foot of media, using four 48-inch diameter sand filters with 75% #20 mesh crushed silica sand and 25% #3 mesh gravel. During injection operations, the sand filter media was frequently backwashed to remove filtered solids and reduce pressure drop in the injection system. The effectiveness of backwash was assessed by observing the color/clarity of the backwash water in the sight glass for the filter system. The PRV was installed at the effluent of the sand filter system to ensure suitable backpressure was maintained in the filter system during backwash cycles to achieve optimum backwash. The filters were determined to be sufficiently clean when no observable sediment and brown color was observed in the sight glass.

- In general, the filter system design, combined with down-column injection without a foot valve contributed to several problems. First, the sand filter system was likely slightly undersized, leading to excessive pressure drop at the higher flows used during down-column injection. This was further complicated during automatic backwash cycles, which caused a decrease in pressure downstream of the PRV, leading to cascading and air entrainment in the well during injection. Secondly, the visual inspection using the sight glass may have been insufficient to indicate clogging of the filters with suspended sediment in the source water.

- Most of the filter system problems can be avoided by using a downhole control valve to regulate flow rates in the pump column. This will eliminate the need for a PRV and reduce the backpressure issues that affected the filter system. In addition, a more robust study of suspended solids content and organic carbon content in the source water should be performed during future tests to evaluate clogging mechanisms. It would be advisable to periodically inspect the sand media itself in the vessels for evidence of a significant clogging layer in the upper portion of the media. If a significant clogging layer is observed after several backwash cycles, it could be removed and replaced with new sand.

4.4.2 Pump Column Injection and Air Entrainment

Down-column injection of water in larger diameter column pipe led to difficulties in maintaining well head pressure due to cascading down the column at lower flow rates (less than about 800 gpm). Cascading leads to a vacuum/siphon condition in the column pipe that can draw in ambient air from leaky air valves or joints in the column pipe. This air was carried down into the formation and became lodged in the pore spaces causing immediate decrease in injection efficiency and rapid water level rise. In addition, the pressure fluctuations may have reduced the effectiveness of the filter system. Therefore, an adjustable downhole hydraulic flow control valve and foot/check valve installed at the end of the column pipe (below the pump) is recommended as a design standard to keep the column pipe full of water prior to and during injection. Though it bears higher cost, use of an adjustable downhole hydraulic flow control valve with control system would significantly reduce or eliminate problems with cascading and air entrainment. It will also allow for a broader range of injection flow rates that can be matched to specific well conditions and available volumes of surface water for injection.

Down-column injection or injection tubes are still be considered a viable option for future applications but may require higher flow rates, additional well modifications, more complicated air release/vacuum valve configurations, and more operational adjustments to maintain a minimum level of backpressure and full column of water.

4.4.3 Chemical Additives and Backflushing

As described above, equilibration of injected surface water with aquifer solids likely caused the dissolution of carbonate minerals and elevation of pH above background during the storage phase. Upon extraction, the dissolved carbon dioxide gas off-gasses in the extraction well, leading to elevated dissolved carbonate concentrations. Consequently, iron carbonate, which is less soluble than calcium carbonate,[2] appears to have precipitated in the filter pack. Iron and possibly manganese are incorporated into the solid, giving the black color to the precipitate. These mixed solid phase precipitates are suspected to have caused fouling of the filter pack, contributed to a decrease in injection efficiency and post-injection pumping efficiency. Chemical additives to the injection system can prevent this problem and should be investigated further. Specifically, pressurization of the injected water with CO_2 gas or flowing the source water over a limestone bed prior to injection should be evaluated to control both the precipitation of solid phase precipitates in the well and improve the equilibration of the injected surface water with the native groundwater at the fringes of the injection bubble.

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[2] The solubility product (K_{sp}) of siderite ($Fe(II)CO_3$) is $10^{-10.89}$, whereas the K_{sp} of calcite ($CaCO_3$) is $10^{-8.48}$.

5. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes considerations to set up a programmatic ASR plan and what is realistically needed to achieve that plan.

5.1 Aquifer Hydraulic Response

Injection of 80 AF of surface water into the lower B-zone aquifer for 35 days caused water level changes only in the lower B-zone, with no water-level response observed in either the upper B-zone (Well LR-4 and Sunset) or the A-zone (Well AG-1). The nearest potable supply well (Sunset Well) was not affected by the pilot test. This response is consistent with the initial groundwater flow modeling conducted prior to the Pilot Test.

Water-levels changes in the upper B-zone could occur with a higher total injection volume or a longer injection period, but the modeling suggests that these water level changes are small and that “particles of water” from the injection (which would represent a potential change in water quality) do not move more that about 1,000 feet from the injection well during a given injection cycle.

5.2 Water Quality Interactions

Injection of surface water causes water quality changes in the ASR injection bubble as it expands and reacts with native groundwater in the B-zone aquifer. The geochemical disequilibrium between the injected surface water and the native groundwater caused changes in pH, which then led to an increase in dissolved arsenic and uranium. The changes were related to carbonate geochemistry in both the aquifer matrix and the groundwater. The injected water was undersaturated with respect to carbonate minerals which then interacted with native groundwater that was in equilibrium with atmospheric levels of CO_2 gas. This caused removal of CO_2 gas from the native groundwater, which then increased the pH and dissolved some of the carbonate minerals in equilibrium with the groundwater. The increase in pH had the additional effect of causing desorption of arsenic and uranium from the aquifer matrix during storage, which increased the dissolved concentrations of these metals in the samples collected during recovery. Finally, these carbonate geochemical interactions are also consistent with the precipitation of iron or manganese carbonate minerals that then caused fouling within the well bore, thus reducing the well efficiency.

These geochemical interactions reactions are complex and should be investigated further, but the conclusions are helpful for developing potential design criteria for further ASR pilot testing and planning level evaluations. In particular, the difference in CO2 partial pressure between the injection water and the native groundwater is interpreted to be a driving mechanism for most of the water quality and fouling issues observed during the test. These problems can be reduced or eliminated through a combination of additional equilibration (storage) time for the injected water (which would occur anyway in a “typical” application of ASR), combined with design modifications for the ASR injection system to increase CO2 in the injected water. However, further testing is required to confirm this and refine design parameters.

5.3 Injection Well Performance

The performance of the injection well during the Pilot test was affected by both the design of the injection system and the water quality reactions that occurred between the surface water and native groundwater. During injection, head build-up in the injection well increased over time and was not fully mitigated by the automated filter backwashing cycles and periodic full well backwashing. This was the result of air entrainment, filter backwash design, recirculation of the automated filter backwash system, and precipitation of Fe/Mn carbonate minerals in the well bore. After the Pilot Test, the well efficiency of the injection well was reduced by about 20%, even after reconditioning the well with an acid wash.

These well performance issues can be reduced or eliminated with two design changes:

1. Increasing CO2 levels in the injected water. As described above, this appears to be a driving mechanism for increased dissolved As/U concentrations in the aquifer and precipitation of Fe/Mn carbonates in the well bore. This can be accomplished through either injection of CO2 gas into the injection well or passing the water through a limestone bed prior to injection.

2. Installation of a downhole flow control device (a foot valve) at the bottom of the pump. This will eliminate air entrainment and improve the ability regulate injection rates. In combination, this should reduce total head build up for each injection cycle and improve the consistency of head build up over multiple injection cycles.

These two design changes will increase the cost of developing an ASR system and require additional testing to confirm and refine the recommended design. However, subject to additional testing results, these changes are likely to be necessary for further widespread application of ASR in the SFKGSA.

5.4 Potential Storage Volumes

On a per-well basis, a planning level volume estimate of 200 AF of storage per well is suggested. This is equivalent to an injection rate of 750 gpm for 60 days. Higher or lower per-well storage yields are possible depending on site and well-specific conditions. This planning target does not consider the availability of surface water for injection.

On a site-area basis, a planning-level well spacing of 1,500 feet is suggested. Well interference should be minimal at this radius and would provide a maximum injection well density of 10 wells per 160 acres. At this density, a grower with 1,600 acres could potentially consider a 10-well ASR program with a 1-year storage capacity of 2,000 AF. Again, higher or lower site-area storage yields could be possible depending on site and well-specific conditions. This estimate does not incorporate availability of surface water for injection.

Note that 2,000 AF is equivalent to irrigation of 1,000 acres at an irrigation demand of 2 AF/acre. Therefore, ASR could be considered as a component of a fallowing program, where storage could occur during a fallow year, and then recovered the following year to put the land into production.

On a more regional GSA-area basis, a planning-level estimate of total maximum storage capacity could be as high as 100,000 AF. This is based on an assumption of 100 ASR sites with an injection capacity of 1,000 AF per site. This estimate does not factor in the availability of surface water. At this scale of analysis, the primary constraint on the feasibility of ASR is the volume and time-window over which surface water can be made available for ASR. The ability to use ASR to store a flood event is limited by the injection capacity of individual wells. It will take at least 60 days to inject 100,000 AF of water at 100 ASR sites. So, in the event that a large volume of surface water could be made available from a flood event, some form of surface storage would be needed to hold that water over a 60-day period and then deliver/inject it into the aquifer for ASR.

5.5 Regulatory and Oversight Considerations

The objective of this Pilot Test was largely technical and experimental, but there are important regulatory and oversight considerations that will need to be addressed before more widespread use of ASR is achieved.

First, the test has demonstrated that conventional and readily available technology can be used by growers and contractors without specialized training to conduct ASR. However, the test has also demonstrated that well performance and system operational issues will likely be encountered when ASR is implemented at a larger scale. If a GSA promotes ASR as a tool for managing groundwater supply, it should clearly identify potential risks and remedies and provide minimum design standards for an ASR system. Based on this pilot test, the minimum design standards are likely to include a downhole control valve and CO2 injection, though additional testing using these two system improvements is needed.

With respect to water quality, the test has also demonstrated that measurable and potentially significant changes in groundwater quality can occur as a result of ASR, including increases in concentrations for several metals above primary or secondary drinking water criteria. Reasonable hypotheses for the cause of these changes in this pilot test have been identified (see Section 4.2) and system improvement to minimize or eliminate water quality changes are possible, but however, further follow-on testing is needed to confirm and verify them (see Section 5.6). A more robust water quality monitoring program should therefore be expected for any ASR application.

The feasibility process for identifying suitable wells for the ASR Pilot Test included a rigorous assessment of surrounding drinking water wells, and the test caused no measurable impact to water quality in surrounding drinking water wells. The water quality changes that were observed occurred within and adjacent to the bubble generated by the injection of surface water. Because the injected water was recovered and water quality then returned to its baseline condition, the test showed that water quality risks are reversible in the short term if monitoring shows unacceptable water quality conditions resulting from ASR injection. A fully developed ASR program that adequately constrains ASR well locations with respect to drinking water sources; includes adequate water quality monitoring; and requires full recovery of injected water under defined circumstances should have minimal risk to water quality. The roles of the GSA and associated state agencies, such as Regional Water Quality Control Board (RWQCB) and Division of

Drinking Water (DDW), in managing regulatory compliance issues associated with ASR still need to be determined.

5.6 Cost of ASR

This section outlines the potential costs associated with implementing an ASR program. It considers the cost of ASR at an individual well and at "full scale" implementation level. These costs are very preliminary, and there are many assumptions regarding how an ASR program would be organized that have not been described or discussed with local stakeholders or the SFKGSA.

5.6.1 Overview

Costs for ASR in an agricultural setting are best expressed as a total cost of delivering ASR water on a per-AF ($/AF) basis. Before reviewing the individual cost components of an ASR program, there are several important considerations to recognize about ASR costs:

1. The total cost of ASR is ultimately dependent on how many wells are used to develop and recover groundwater storage. Each well requires a one-time capital investment (CAPEX) and operating expenses (OPEX) when used for ASR operations. For illustration purposes, it is assumed that a single ASR well could operate at 800 gpm for 60 days, which would generate 200 AF of storage for a single ASR cycle. It is also assumed that an ASR "site" would consist of 5 ASR wells, operating in the same general area, for a site capacity of 1,000 AF. If the ASR site is operated 5 times (i.e. 5 seasons), an ASR site would develop 5,000 AF of storage.

2. The cost of injection water will be greater than zero, but could be less than the cost of access to a conventional alternative water supply during drought years. So, the total cost for ASR can be viewed as the cost of injection water plus the CAPEX + OPEX "mark-up" for storing and recovering that water via ASR operations. The financial sensibility of ASR is best evaluated by considering the cost of the injection water, the ASR mark-up, and the cost of obtaining an alternative conventional water supply during drought years. In order for ASR to make financial sense to a landowner, the cost of obtaining a conventional water source needs to be higher than the cost of the injection water plus the ASR investment (CAPEX + OPEX). This will only be true when the cost of injection water is less than the cost of a conventional water supply during the amortization period. This can be viewed as a "break-even cost" where ASR makes financial sense.

5.6.2 ASR "Per-Site" Cost and "Break-even Cost"

This section provides initial high-level evaluation of cost components for ASR. For illustration purposes, it is assumed that an ASR "site" would consist of 5 existing irrigation wells that would be converted to ASR wells. These wells would operate in the same general area as both injection and extraction wells, with a site storage capacity of 1,000 AF. It is also assumed that the amortization period for a site is long enough to allow an ASR site to be operated 5 times (i.e. 5 seasons), thus developing 5,000 AF of storage over the planning period.

The following one-time CAPEX costs are expected for a 5-well ASR site

- 5 Downhole flow control valves: $650,000
- 2 dedicated monitoring wells: $150,000
- One-time ASR feasibility/pilot testing and permitting: $350,000
- **TOTAL CAPEX : $1.15M**

The following OPEX costs are expected for each operation cycle of ASR site:

- Mobilization and set-up charges: $50,000
- Filter system + CO2 Injection : $100,000
- Operations oversight : $100,000
- Monitoring & reporting : $100,000
- **TOTAL OPEX: $1.5M (5 x $300,000)**

Combined CAPEX + OPEX is therefore estimated at about $2.6M for 5,000 AF of total storage over 5 seasons. This is equivalent to a $500 per AF ASR "mark-up" on the cost of injection water. The best way to describe the cost implications from a grower perspective is to compare the cost of ASR (including the cost of injection water) to the cost of obtaining a conventional water supply during a drought year. If the cost of injection water is $0, then ASR makes financial sense to a grower for any alternative drought-year water supply that costs more than 500 $/AF. If the cost of obtaining injection water is $500 $/AF, then ASR makes financial sense to a grower for any alternative water supply that costs more than $1,000 $/AF. Different combinations of injection water cost and the ASR mark-up would yield different break-even points between ASR and an alternative conventional water supply. Individual grower situations would also yield different break-even conditions.

In addition, the GSA could provide subsidies to landowners through State Grants or GSA fees for certain CAPEX components. This would reduce landowner costs and lower the break-even point for an individual landowner. At a "full build-out" of 100,000 AF (500 ASR wells), the total CAPEX costs subject to potential subsidy would be $500M. A 50/50 split between GSA and landowners would therefore require $250M in GSA/grant funding and would reduce the ASR "mark-up" from $500 $/AF to $250 $/AF.

6. REFERENCES

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TABLES

Table 2-1
Well Construction
South Fork Kings Groundwater Sustainability Agency ASR Pilot Test Final Report

Well ID	Distance from ASR Pilot Well (ft)	Completion Depth (ft)	Screen Interval (ft)	Well Type	Surface Elevation (NAVD88)
18S20E29Z001M*	1,743	220	140-220	Domestic	NS
W1601-006	3,087	400	300-400	Domestic	NS
LR-18	2,581	450	210-450	Agricultural	208.44
LR-19	0	540	340-540	Agricultural	207.14
AG-1	511	60	unk	Agricultural	206.83
LR-4	4,264	390	210-390	Agricultural	210.68
Sunset Active	5,413	320	200-320	Public	208.22

Notes:
*= Referenced in report as Z001M

Abbreviations:
ft = feet
Unk = Unknown. Landowner was not able to confirm information.
NAVD88 = North American Vertical Datum of 1988
NS= Not Surveyed. Wells not surveyed as they were not used to collect water level measurements. Wells were not used for measurements due to access.

Table 2-2
Aquifer Hydraulic Properties Based on Pumping Test
South Fork Kings Groundwater Sustainability Agency ASR Pilot Test Final Report

Properties (all layers)	**Step Test**	**24-hour Constant Rate Pump Test**
Specific Capacity (gpm/ft-dd) *Pumping rate: Specific Capacity*	400 gpm: 32 800 gpm: 35 1,200 gpm: 34 1,600 gpm: 35	1,400 gpm: 32
Transmissivity (ft²/day)	12,000	12,000
Storativity	0.002	0.002
Hydraulic Conductivity (ft/day)	38	--
Well Efficiency	79%	--

Notes:
dd= drawdown
ft=feet
gpm= gallons per minute
-- = no information

Aqtesolv was utilized to determine properties. Analysis methods include: Theis (1935), Cooper-Jacob (1946), and Tharakovsky-Neuman (2007).

Table 2-3
Summary of Water-Level Monitoring Locations and Frequency
South Fork Kings Groundwater Sustainability Agency ASR Pilot Test Final Report

Well ID	Stage of Test [1]	Total Number of Manual Measurements	Frequency of Manual Measurement	Recording Increments on Transducer
LR-19	PRE-TEST	5	At least 1 per day up to three days before beginning of test	Every 5 minutes
	INJECTION	1,117	Measured at least one time a day for nearly every day of the phase.	Every minute
	STORAGE	35	Measured at start, middle, and end of phase.	Every hour
	RECOVERY	111	Measured at least one time a day for nearly every day of the phase.	Every minute
	REHAB	69	Measured every few minutes during each step	Every 30 seconds
Sunset	PRE-TEST	2	Measured two weeks before and two days before start of test.	Every 15 minutes
	INJECTION	40	Measurements coordinated with Sunset Vista Estate staff. Hand measurements collected at staff member's available for well access. Measurements collected several times each week.	Every minute
	STORAGE	5	Measurements coordinated with Sunset Vista Estate staff. Hand measurements collected at staff member's available for well access. Measurement collected at start, middle, and end of phase.	Every hour
	RECOVERY	11	Measurements coordinated with Sunset Vista Estate staff. Hand measurements collected at staff member's available for well access. Measurements collected at least once every six days.	Every minute
LR-18	PRE-TEST	0 [2]	Measurement error when collected.	NA
	INJECTION	44	Measured nearly every day of phase.	Every minute
	STORAGE	1	Two unsuccessful attempts (start and mid-point in phase) to collect water levels due to pump in operation. One measurement collected at the end of the phase between well operation schedule.	Every hour
	RECOVERY	4	Water levels measured only when well is not in operation.	Every minute
LR-4	PRETEST	1 [2]	One measurement collected approximately one hour before start of test.	NA
	INJECTION	39	Measured nearly every day of phase.	Every minute
	STORAGE	4	Measured at start, middle, and end of phase.	Every hour
	RECOVERY	9	Measurements collected at least once every six days.	Every minute
AG-1	PRE-TEST	0 [2]	Obstruction in well's sounding port.	NA
	INJECTION	35	Measured nearly every day of phase.	Every minute
	STORAGE	4	Measured at start, middle, and end of phase.	Every hour
	RECOVERY	6	Measurements collected at least once every six days.	Every minute

Notes:
1. Measurements collected within the month of June 2021 before the start of the Injection Phase have been categorized as the "Pre-Test" phase. The Injection Phase began on June 21, 2021 and ended on August 1, 2021. The Storage Phase took place on August 1, 2021 and ended September 6, 2021. The Recovery Phase began September 6, 2021 and ended September 22, 2021. A pump test was performed on LR-19 after well rehabilitation (rehab) on March 1, 2022.
2. Measurement limitations for wells LR-4, LR-18, and AG-1 during the Pre-Test Phase are discussed in Section 2.4 of the report.

Abbreviations:
NA = Measurement not available

Table 2-4

Summary of Water Quality Monitoring Locations and Frequency

South Fork Kings Groundwater Sustainability Agency ASR Pilot Test Final Report

Well ID	Stage of Test	Date	Time	Field Parameters Analyzed	Analytical Analyzed
LR-19	Baseline	3/26/2021	12:10	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes
	Baseline	3/26/2021	18:50	Temp; DO; ORP; pH; EC; Turbidity	Bacterial
	Baseline	3/27/2021	9:30	Temp; DO; ORP; pH; EC; Turbidity	Bacterial
	Baseline	6/23/2021	13:49	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; T. Microcystin, Bacterial; DBP
	Injection[1]	6/28/2021	11:50	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Injection	6/30/2021	14:10	Temp; DO; ORP; pH; EC; Turbidity	T. Microcystin
	Injection	7/8/2021	12:35	Temp; DO; ORP; pH; EC; Turbidity	T. Microcystin
	Injection	7/16/2021	12:10	Temp; DO; ORP; pH; EC; Turbidity	T. Microcystin
	Injection	7/21/2021	12:56	Temp; DO; ORP; pH; EC; Turbidity	T. Microcystin; Bacterial
	Storage	8/24/2021	9:41	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry (Alkalinity only); Metals (Arsenic, Chromium, Hexavalent Chromium, Iron, Manganese, Uranium)
	Recovery	9/7/2021	11:15	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Recovery	9/12/2021	17:45	Temp; DO; ORP; pH; EC; Turbidity	Bacterial
	Recovery	9/17/2021	9:30	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry (Alkalinity only); Metals (Arsenic, Chromium, Hexavalent Chromium,Iron, Manganese, Uranium), Stable Isotopes
	Recovery	9/22/2021	15:15	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry (Alkalinity only); Metals (Arsenic, Chromium, Hexavalent Chromium,Iron, Manganese, Uranium), Stable Isotopes
	Recovery	11/11/2021	14:35	Temp; DO; ORP; pH; EC; Turbidity	Metals (Iron, Manganese, Hexavalent Chromium, Uranium, Arsenic); Total Dissolved Solids, Chlorine, Alkalinity, Stable isotopes
	Rehab	2/18/2022	11:12	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; Metals (Arsenic, Iron, Manganese)
Sunset	Baseline	3/26/2021	12:25	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
	Injection	7/21/2021	9:15	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Recovery	9/22/2021	14:05	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
LR-4	Baseline	9/4/2019	8:40	Temp; DO; ORP; pH; EC; Turbidity	Metals
	Baseline	3/26/2021	14:15	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
	Injection	7/21/2021	10:15	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Recovery	9/22/2021	13:30	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
AG-1	Baseline	3/26/2021	15:52	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
	Injection	7/21/2021	11:50	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Recovery	9/22/2021	14:40	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
W1601-006	Baseline	3/26/2021	15:20	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
	Injection	7/21/2021	8:10	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Recovery	9/22/2021	16:00	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
Z001M	Baseline	3/26/2021	15:04	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
	Injection	7/21/2021	11:10	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; DBP
	Recovery	9/22/2021	15:42	Temp; DO; ORP; pH; EC; Turbidity	Cations, Anions; General Chemistry; Metals; Stable Isotopes; Bacterial
Cement Box[2]	Baseline	9/4/2019	8:26	NA	Metals
KRIV1[2]	Baseline	6/15/2021	12:37	NA	Cations, Anions; General Chemistry; Metals; Stable Isotopes; T. Microcystin, Bacterial

Notes:

1. Sample collected during backflush
2. Surface Water baseline samples

Bacterial = Total Coliform and E. Coliform

Abbreviations:

DBP= Disinfection By-Product

Temp = temperature

DO =Dissolved Oxygen

ORP = Oxidation-Reduction Potential

EC= Specific Conductivity

T. Microcystin= Total Microcystin

Metals: Aluminum, Antomony, Arsenic, Barium, Beryllium, Boron, Cadmium, Chromium, Cobalt, Copper, Iron, Lead, Lithium, Manganese, Mercury, Molybdenum, Nickel, Selenium, Dissolved Silicon as SiO2, Silver, Strontium, Thallium, Tungsteen, Uranium, Vanadium, Zinc, Hexavalent Chromium

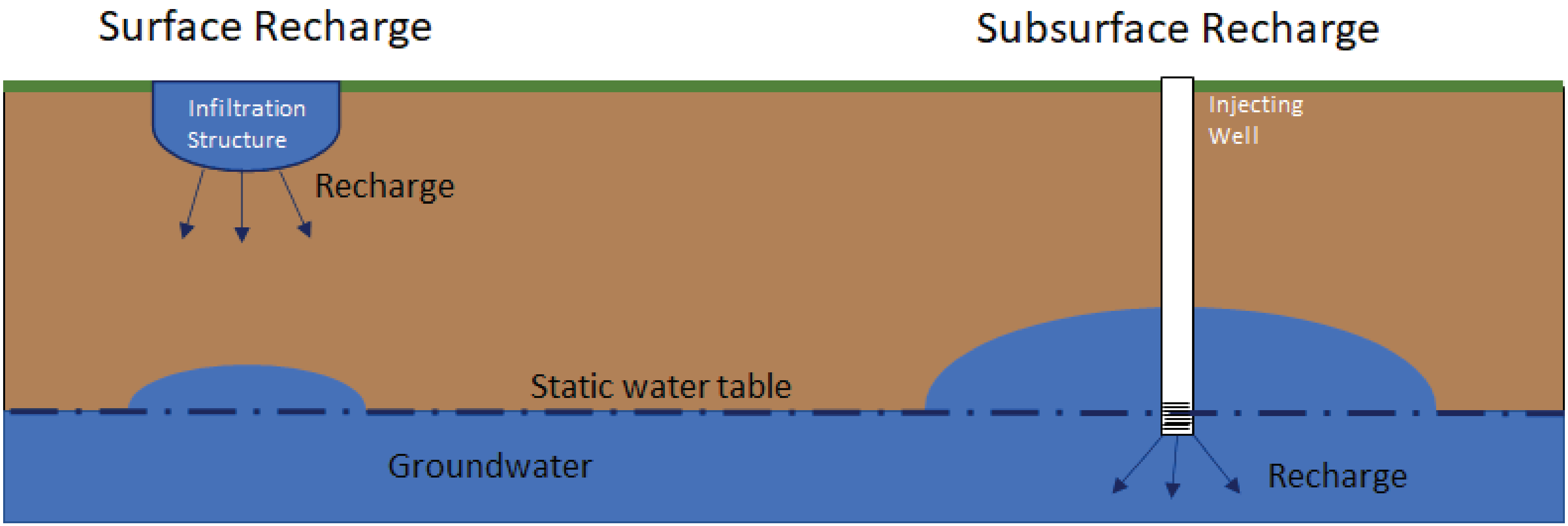
General Chemistry: Calcium, Magnesium, Sodium, Potassium, Bicarbonate Alkalinity as CaCO3, Bromide, Chloride, Fluoride, Iodide, Nitrate as N, Sulfate, Dissolved Hardness as CaCO3, Total Dissolved Solids @ 180C, Sulfide, Non-Volatile Organic Carbon

Stable Isotopes: δ Deuterium of water, δ O18 of water

DBP: Bromodichloromethane, Bromoform, Chloroform, Dibromochloromethane

Microbacterial: E. Coliform, Total Coliform, Total Microcystin

FIGURES



Explanation

Surface and Subsurface Recharge are two types of Managed Aquifer Recharge (MAR) recharge techniques. Surface recharge, or infiltration supplements natural groundwater recharge. Subsurface recharge directly recharges the aquifer using an injecting well.

Figure adapted from EarthDate, Managing Aquifer episode ED-076. *https://www.earthdate.org/node/83*

Managed Aquifer Recharge (MAR) Schematic

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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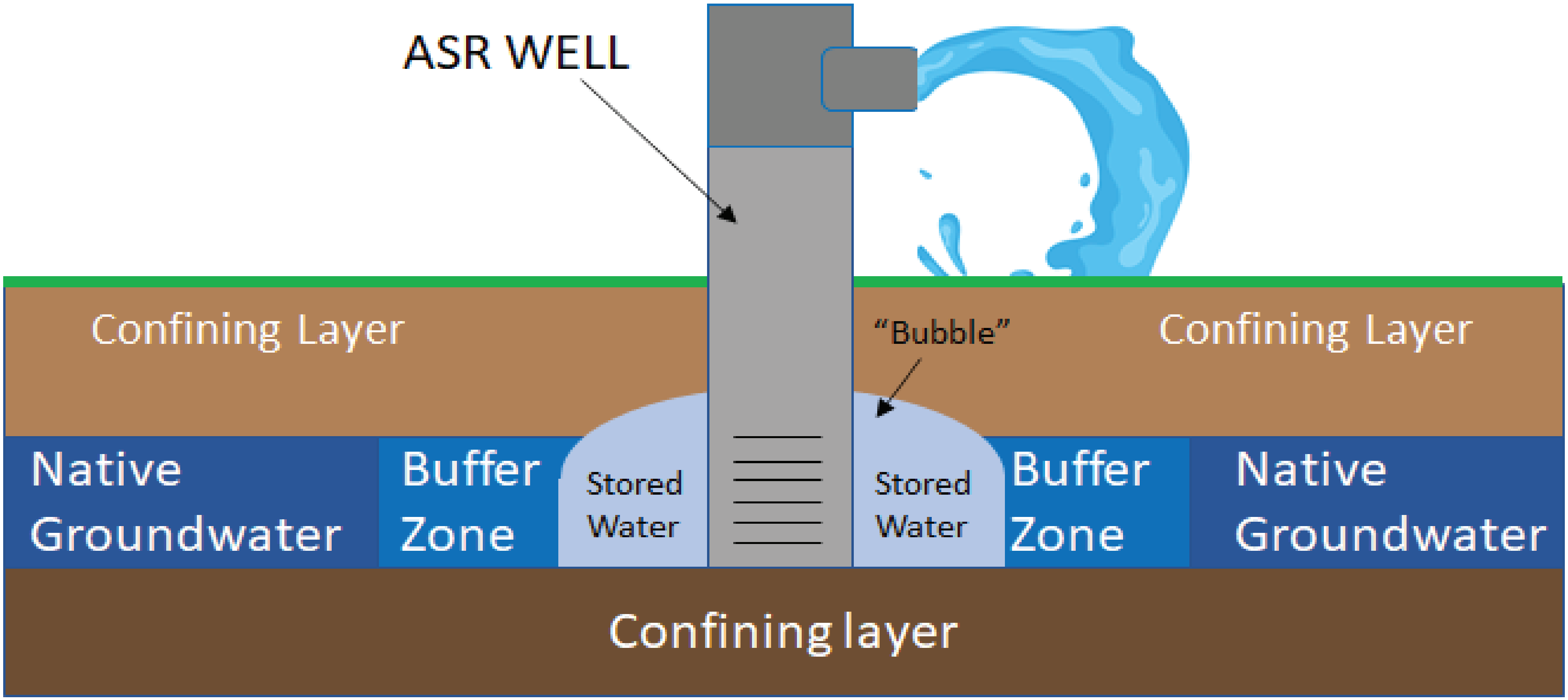
Project No.: SAC229C | May 2022

Figure **1-1**



Explanation:

Injected water does not immediately mingle with ambient, or native groundwater creating a "bubble" of stored water near the well with a buffer zone of limited mixing on the fringes of the "bubble".

Figure adapted from South Florida Water Management District and United States Army Corps of Engineers 2021 Aquifer Storage and Recovery (ASR) Science Plan.

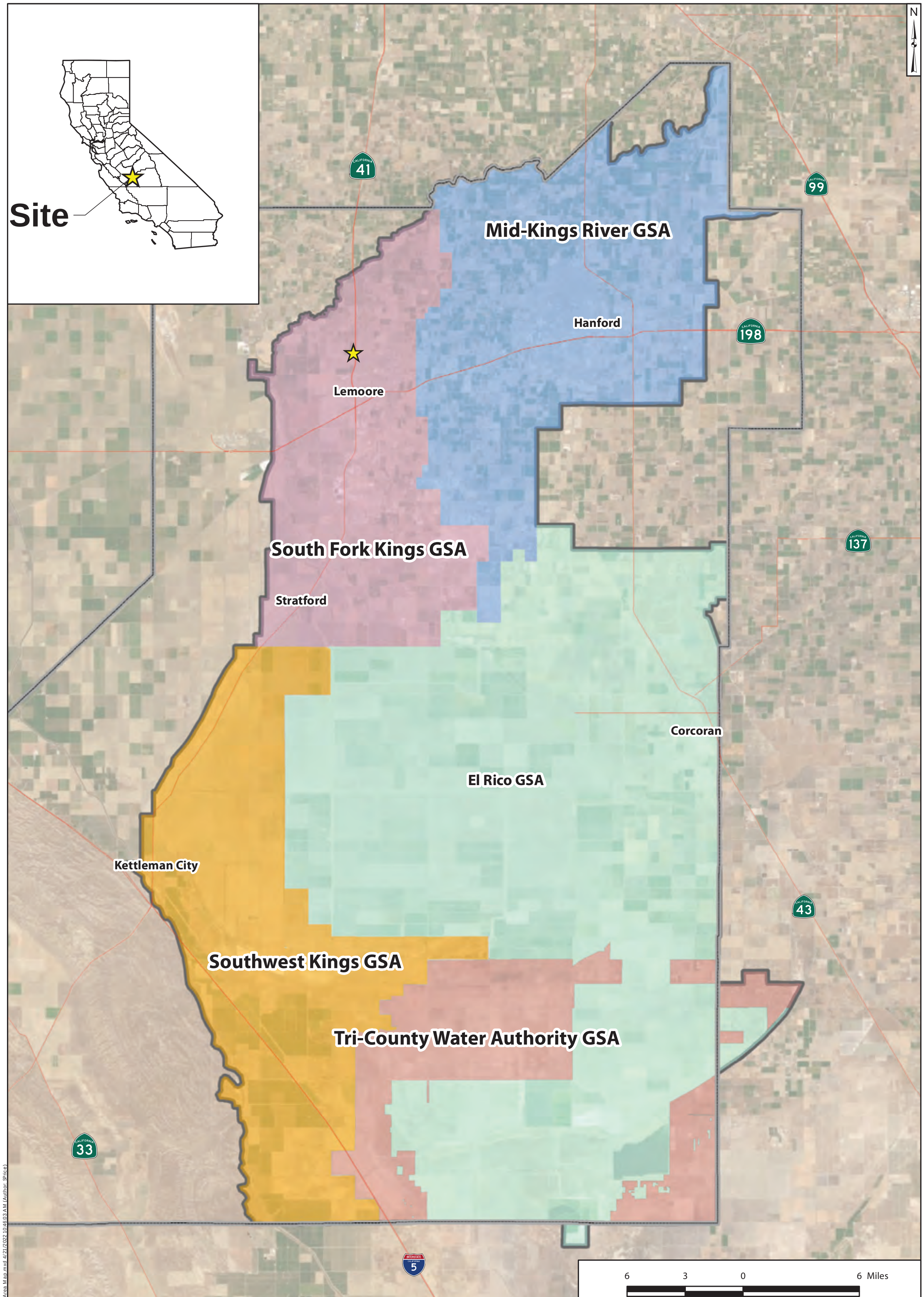
https://www.sfwmd.gov/sites/default/files/2021_draft_asr_science_report_main.pdf

ASR Concept
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

Geosyntec consultants

Figure **1-2**

Project No.: SAC229C | May 2022



Legend

- Project Area
- Roads
- Tulare Lake Subbasin Boundary
- Kings County Boundary

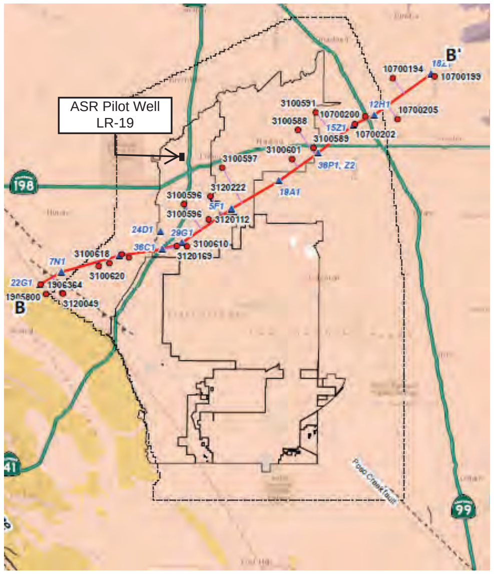
Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Project Area Map
South Fork Kings Groundwater Sustainability Agency
ASR Pilot Test Results
Tulare Lake Subbasin, Kings County, California

Geosyntec consultants

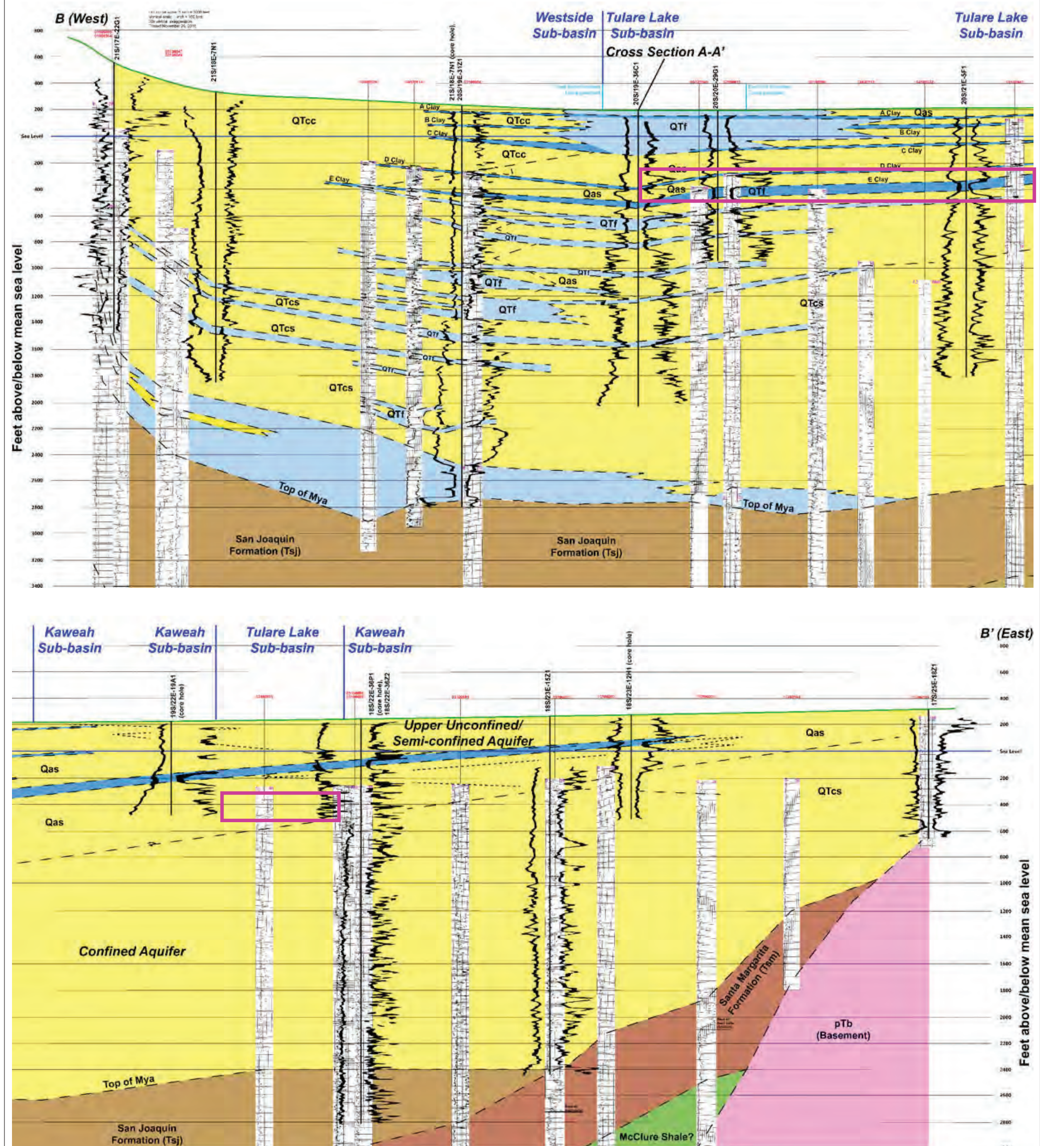
Figure 1-3

Project No.: SAC229C	April 2022



- B-B'
- Wells from original cross-sections (Croft,1972)
- Tulare Lake Subbasin
- Marine sedimentary[2]
- Continental sedimentary
- Igneous
- Cross-section lines (Croft, 1972)

Notes:
1) Well records obtained from DOGGR well search. 2018.
https://secure.conservation.ca.gov/WellSearch
2) Geologic Units derived from Geologic Map of California, 1977.



Explanation

- Coarse-grained alluvium / Tulare Formation
- San Joaquin Formation
- Etchegoin Formation
- Santa Margarita Formation
- Alluvium / Tulare Formation lacustrine sediments
- Regional clay marker beds as defined by Croft (1972)
- Crystalline basement

25S/21E-1N	CA DWR well name
03120281	CA DOGGR well APN
0 30	Electric log resistivity scale (ohmmeters)

Notes:
1) Contacts dashed where inferred.
2) CA DWR = California Department of Water Resources.
3) CA DOGGR = Division of Oil, Gas, and Geothermal Resources, California Department of Conservation.

Modified figure from the Tulare Lake Subbasin Groundwater Sustainability Plan (Figures 3-12 & 3-14b). The modified picture does not include cross sections A-A' and C-C'.

Outline indicates targeted zone for ASR activities. Outline only shown within the Tulare Lake Subbasin.

Regional Geologic Cross-Section

South Fork Kings Groundwater Sustainability Agency
ASR Pilot Test Results

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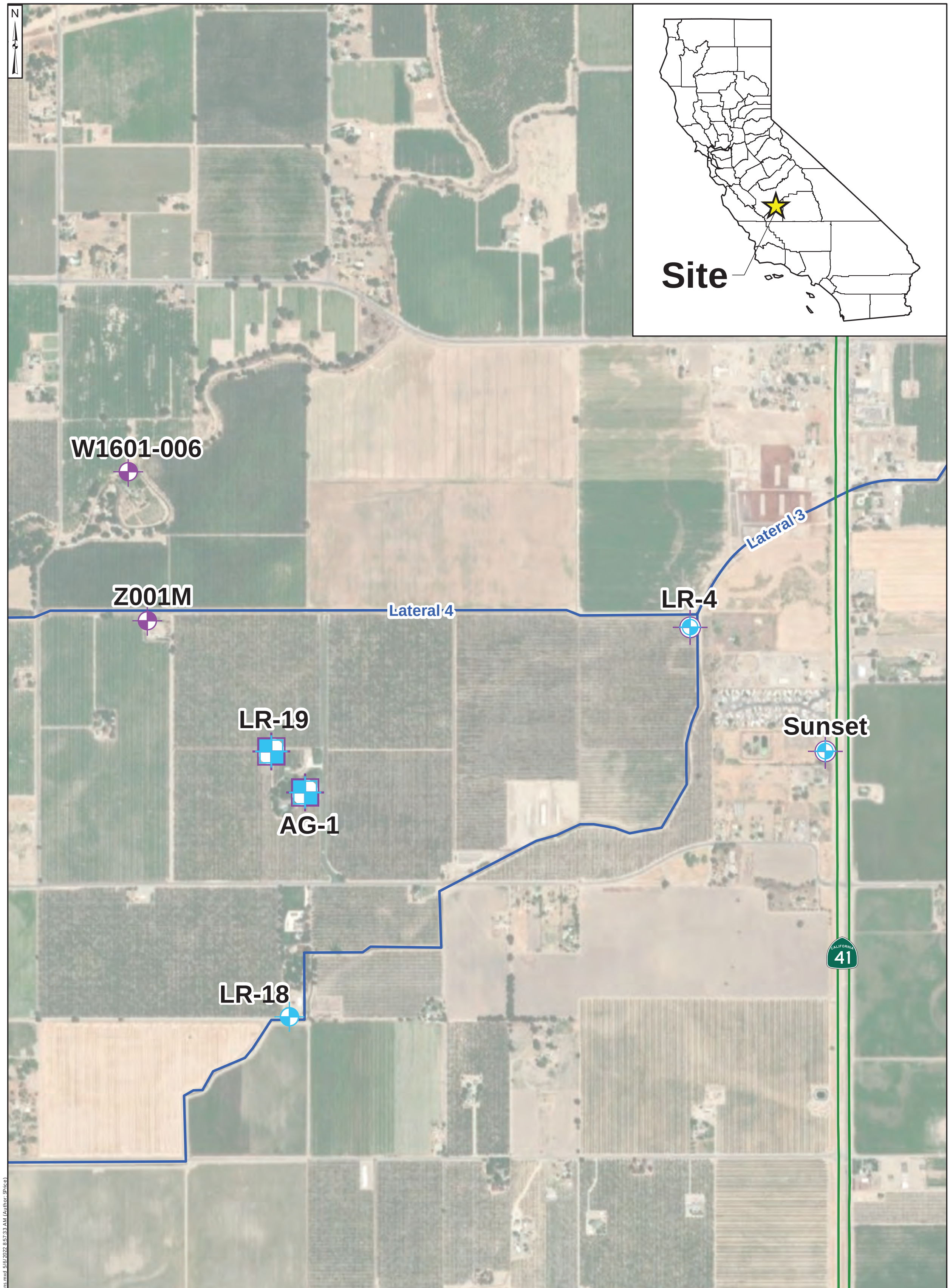
Project No.: SAC229C | December 2021

Figure 1-4



Legend

- Pilot Well Water Quality & Level Monitoring
- Water Quality & Water Level Monitoring
- Water Level Monitoring
- Water Quality Monitoring
- Roads
- Lemoore Canal

1,400 700 0 1,400 Feet

Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Site Map and Well Locations

South Fork Kings Groundwater Sustainability Agency
ASR Pilot Test Results
Tulare Lake Subbasin, Kings County, California

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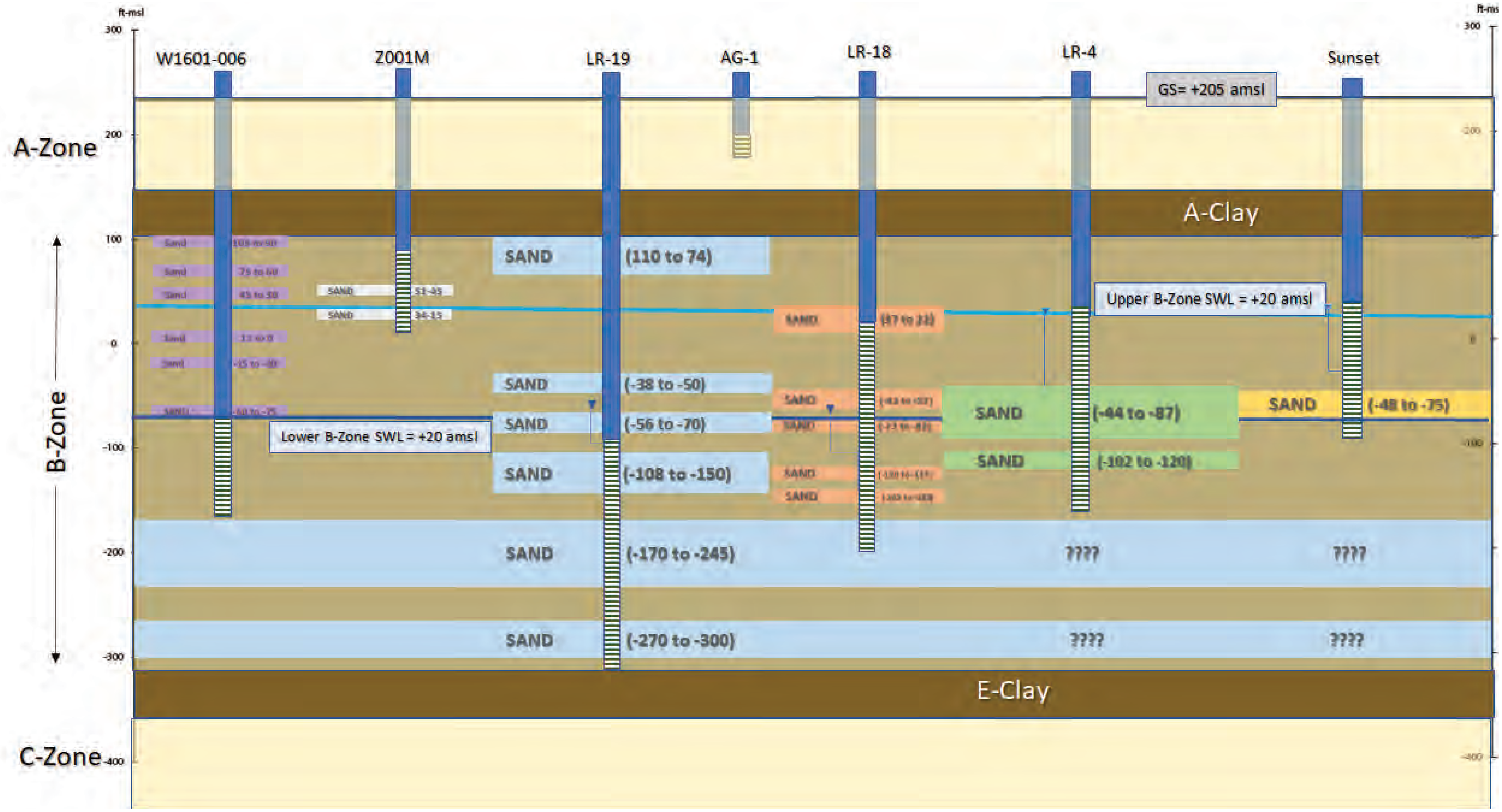
Figure 2-1

Project No.: SAC229C | May 2022

S:\GIS\SAC229_SFKings\project\ASR_FinalReport\Figure 2-1 Site Map and Well Locations.mxd 5/6/2022 8:57:33 AM (Author: SPrice)



Well ID	Distance from Pilot Well (ft)	Completion Depth (ft)	Screen Interval (ft)	Monitoring Network [1]
W1601-006	3,087	400	300-400	WQ
Z001M [2]	1,743	220	140-220	WQ
LR-19	--	350	340-540	WQ/WL
AG-1	511	60	UNK [4]	WQ/WL
LR-18	2,581	390	210-390	WL
LR-4	4,264	390	210-390	WQ/WL
Sunset [3]	5,413	320	200-320	WQ/WL

Notes:
-amsl = average mean sea level
-ASR = Aquifer Storage and Recovery
-ft bgs = feet below ground surface
-SWL = Static Water Level

Upper and Lower SWL displayed.

1 = WQ: Water Quality; WL: Water Level
2 = Shortened for 18S20E29Z001M
3 = Sunset Active well monitored.
4 = Unknown screen interval for AG-1

Site Geologic Cross-Section
ASR Pilot test
South Fork Kings GSA

Geosyntec consultants

SAC229C | December 2021

Figure 2-2

Explanation

a) View of LR-19 (Pilot Test Well) prior to well modifications. Modifications to the well prior to the injection phase include installation of a sounding tube, water spigot, magmeter to read instant and total extraction volumes, and an industrial grooved pipe off of the existing concrete pipeline which transfers water from the canal to LR-19's standpipe.

b) View of LR-19 construction setting up for injection phase. Pipeline connections are not complete in this photo. The Variable Frequency Drives (VFD) pump is shown to the right. Four filter tanks are shown behind Well LR-19.

c) View of completed Injection Phase set up at LR-19. The booster pump (left) is connected to the industrial grooved pipe and powered by the VFD. Water is lifted and transported through the pipes and filter system. Water is then injected down the column pipe through the turbine pump bowl assembly. Injected water is discharged into the well at the bottom of the pump.

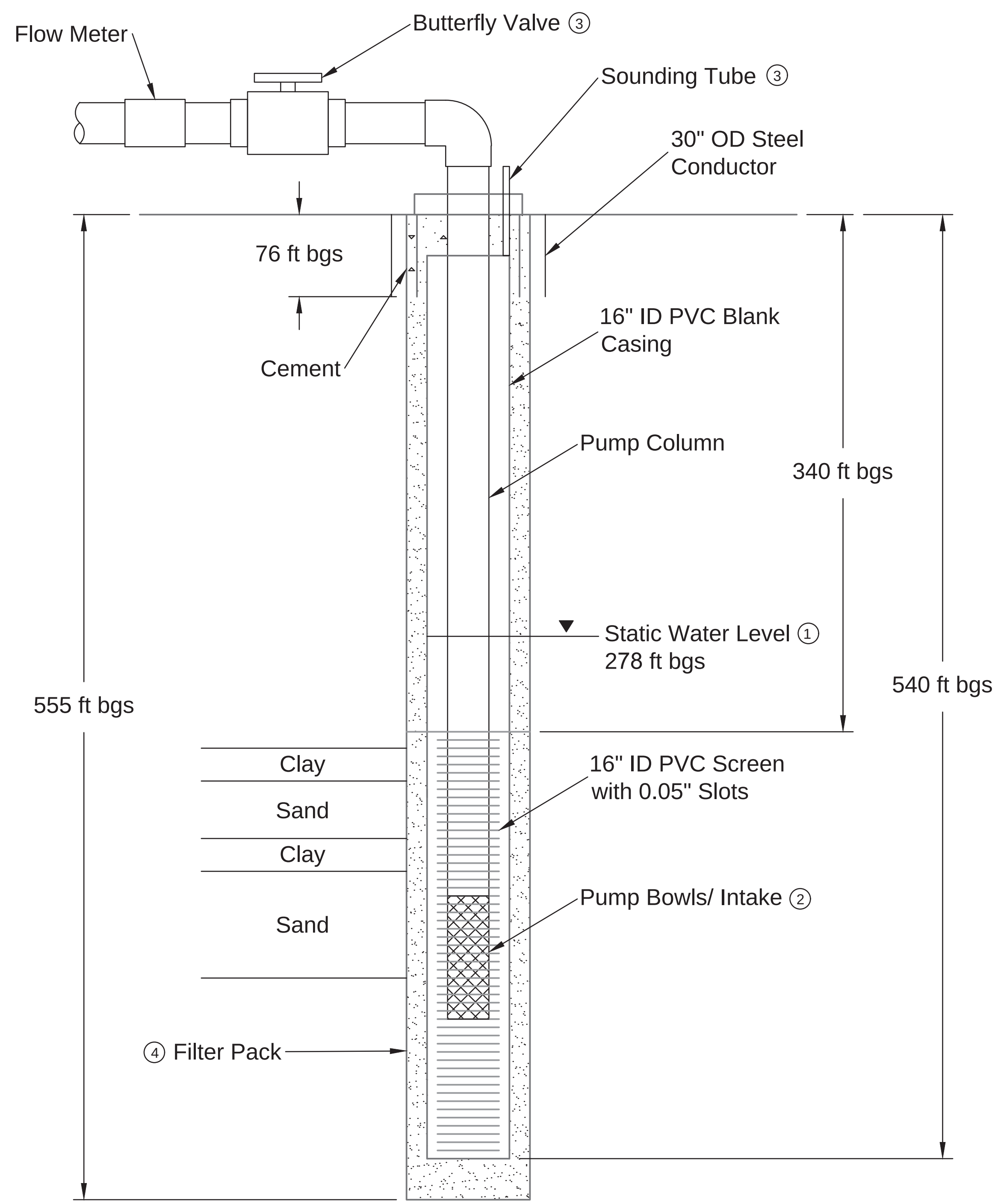
Photographs of Well LR-19

South Fork Kings GSA
ASR Pilot Test

Geosyntec consultants

Figure 2-3

Project No.: SAC229C | December 2021



Notes:

- Diagram is not drawn to scale
- bgs = below ground surface
- ASR = Aquifer Storage and Recharge
- GSA = Groundwater Sustainability Agency

① Static water level measured on 6/19/2021

② Approximate depth shown

③ Tube and valve were added to well prior to pump test and remain after completion of the pilot test.

④ Filter Pack is $\frac{1}{4}$ x 8 Well Gravel

Well LR-19 Well Construction

South Fork Kings GSA
ASR Pilot Test Results

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Figure 2-4

Project No.: SAC229C | April 2022

LEGEND

(E) SYSTEM WATER LINES

0 20' 40'
APPROXIMATE SCALE

REV	DATE	DESCRIPTION	DRN	APP

DESIGN BY:	MA/JMA
DRAWN BY:	MA/JMA
CHECKED BY:	JMA
REVIEWED BY:	JMA/AH
APPROVED BY:	JMA

TITLE: SITE PLAN

PROJECT: SOUTH FORK KINGS GSA ASR PILOT TEST

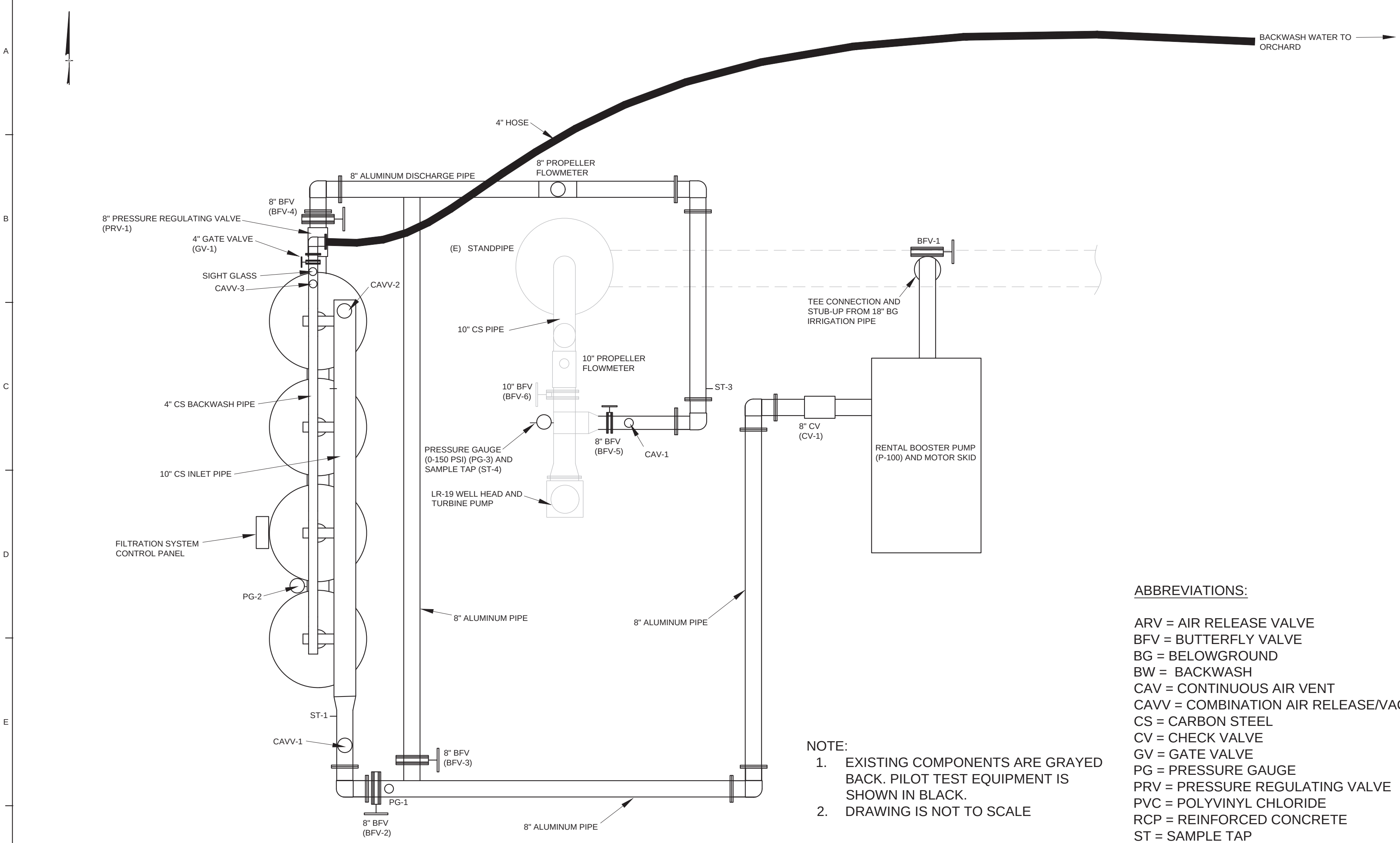
SITE: SOUTH FORK KINGS, CALIFORNIA

Figure 2-5a

Geosyntec consultants
3043 GOLD CANAL DRIVE, SUITE 100
RANCHO CORDOVA, CA 95670 USA
TELEPHONE: 916.637.8048

DATE:	DECEMBER 2021
PROJECT NO.:	SAC229B
FILE:	
DRAWING NO.:	C-1 OF 3

P:\CADD\SAC229A South Fork Kings\ASR - Site Plan-as-built.dwg



NOTE:

1. EXISTING COMPONENTS ARE GRAYED BACK. PILOT TEST EQUIPMENT IS SHOWN IN BLACK.
2. DRAWING IS NOT TO SCALE

ABBREVIATIONS:

ARV = AIR RELEASE VALVE
BFV = BUTTERFLY VALVE
BG = BELOWGROUND
BW = BACKWASH
CAV = CONTINUOUS AIR VENT
CAVV = COMBINATION AIR RELEASE/VACUUM RELIEF VALVE
CS = CARBON STEEL
CV = CHECK VALVE
GV = GATE VALVE
PG = PRESSURE GAUGE
PRV = PRESSURE REGULATING VALVE
PVC = POLYVINYL CHLORIDE
RCP = REINFORCED CONCRETE
ST = SAMPLE TAP
TYP = TYPICAL

REV	DATE	DESCRIPTION	DRN	APP

DESIGN BY:	MA/JMA
DRAWN BY:	MA/JMA
CHECKED BY:	JMA
REVIEWED BY:	JMA/AH
APPROVED BY:	JMA

TITLE: MECHANICAL LAYOUT

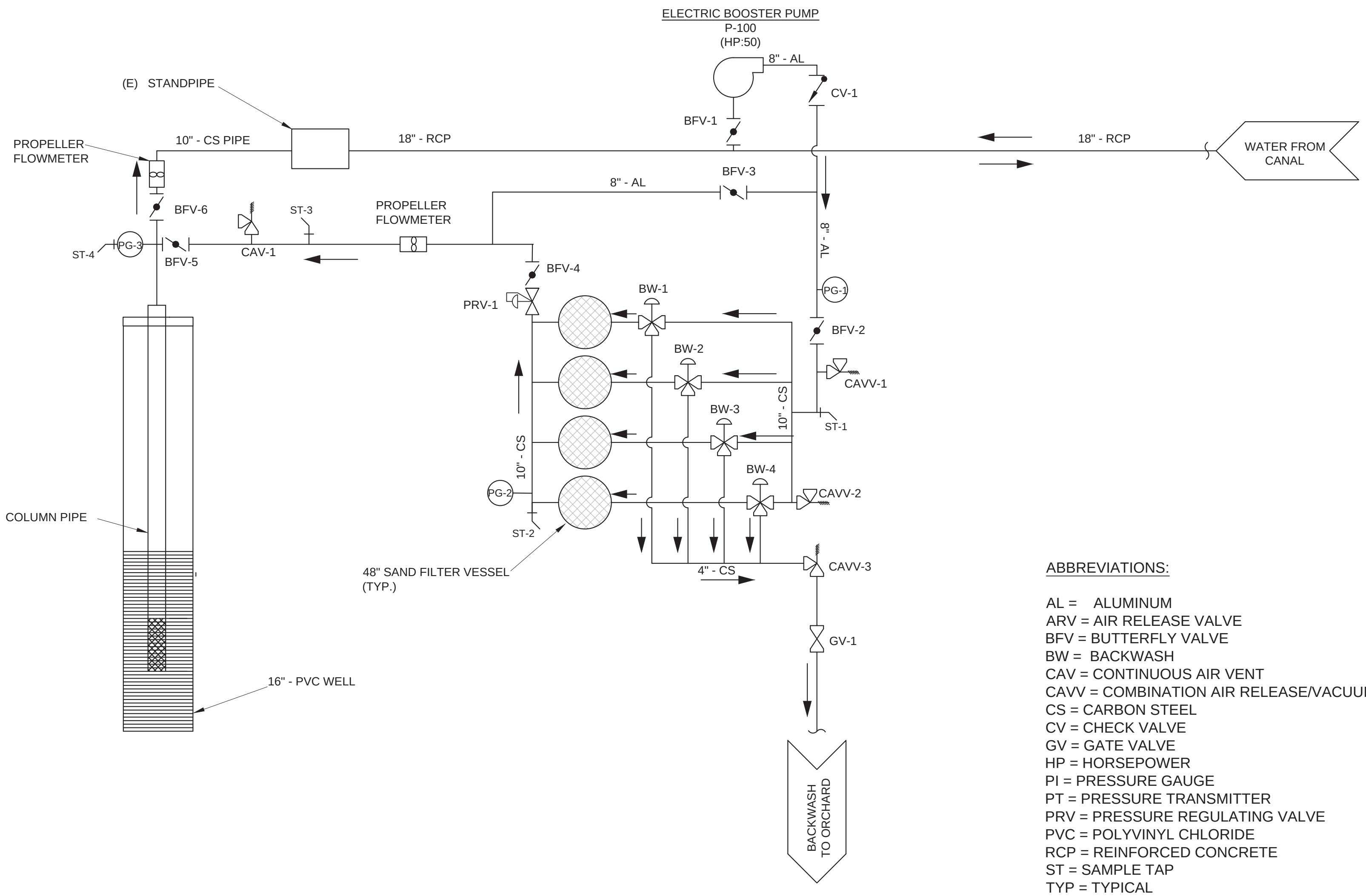
PROJECT: SOUTH FORK KINGS GSA ASR PILOT TEST

SITE: SOUTH FORK KINGS, CALIFORNIA

Figure 2-5b

Geosyntec consultants
3043 GOLD CANAL DRIVE, SUITE 100
RANCHO CORDOVA, CA 95670 USA
TELEPHONE: 916.637.8048

DATE:	DECEMBER 2021
PROJECT NO.:	SAC229B
FILE:	
DRAWING NO.:	C-2 OF 3



ABBREVIATIONS:

AL = ALUMINUM
ARV = AIR RELEASE VALVE
BFV = BUTTERFLY VALVE
BW = BACKWASH
CAV = CONTINUOUS AIR VENT
CAVV = COMBINATION AIR RELEASE/VACUUM RELIEF VALVE
CS = CARBON STEEL
CV = CHECK VALVE
GV = GATE VALVE
HP = HORSEPOWER
PI = PRESSURE GAUGE
PT = PRESSURE TRANSMITTER
PRV = PRESSURE REGULATING VALVE
PVC = POLYVINYL CHLORIDE
RCP = REINFORCED CONCRETE
ST = SAMPLE TAP
TYP = TYPICAL

REV	DATE	DESCRIPTION	DRN	APP

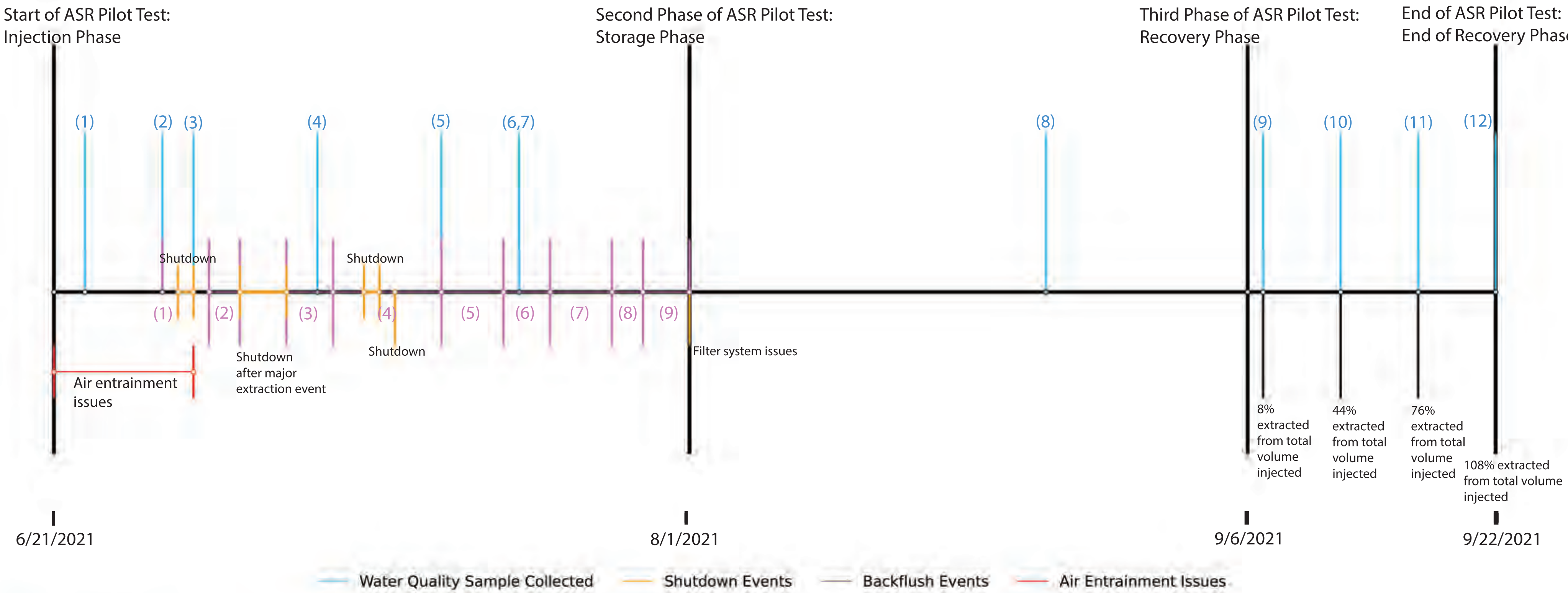
DESIGN BY: MA/JMA
DRAWN BY: MA/JMA
CHECKED BY: JMA
REVIEWED BY: JMA/AH
APPROVED BY: JMA

TITLE: PROCESS AND INSTRUMENTATION DIAGRAM
PROJECT: SOUTH FORK KINGS GSA ASR PILOT TEST
SITE: SOUTH FORK KINGS, CALIFORNIA

Figure 2-5c

Geosyntec consultants
3043 GOLD CANAL DRIVE, SUITE 100
RANCHO CORDOVA, CA 95670 USA
TELEPHONE: 916.637.8048

DATE: DECEMBER 2021
PROJECT NO.: SAC229B
FILE:
DRAWING NO.: C-3 OF 3



Note: A water quality sample (14*) was collected on 11/11/21 (LR-19_Ext05) for analysis. Approximately 263% of the injected volume was extracted at the time of sampling. LR-19_Ext05 was not included as part of the Recovery Phase as continuous extraction ceased on 9/22/21. Aquifer pumping tests immediately followed the Recovery Phase. LR-19 returned to the landowner's operational schedule at the end of the pumping tests.

Water Quality Sampling Events

#	Date	Sample Name	Description
1	6/23/2021	LR-19inj1	Injection Water Sample
2	6/28/2021	LR-19(BF1)	Sample of Backflush Water
3	6/30/2021	LR-19(Injwk2)	Total Microcystin Sample
4	7/8/2021	LR-19(Injwk3)	Total Microcystin Sample
5	7/16/2021	LR-19(Injwk4)	Total Microcystin Sample
6	7/21/2021	Observation Wells	Injection Phase Sample
7	7/21/2021	LR-19	Total Microcystin Sample
8	8/24/2021	LR19-Stor1	Storage Phase Injection Well Sample
9	9/7/2021	LR-19_Ext01	Recovery Phase Sample
10	9/12/2021	LR-19_Ext02	Recovery Phase Sample
11	9/17/2021	LR-19_Ext03	Recovery Phase Sample
12	9/22/2021	LR-19_Ext	Recovery Phase Sample
13	9/22/2021	Observation Wells	Recovery Phase Sample
14*	11/11/2021	LR-19_Ext05	Recovery Phase Sample

Backflush Events

#	Date	Description	Volume Extracted	Cumulative Injected Volume After Backwash Event
1	6/28/2021	First Event	0.09 AF	11.85 AF
2	7/1-7/3	Major Extraction Event	9.26 AF	5.44 AF
2	7/6-7/9	Cycle One: Bypass Filters	0.22 AF	15.52 AF
3	7/9-7/16	Cycle Two	0.16 AF	32.41 AF
4	7/16-7/20	Cycle Three	0.12 AF	46.19 AF
5	7/20-7/23	Cycle Four	0.1 AF	56.36 AF
6	7/23/-7/27	Cycle Five	0.09 AF	68.82 AF
7	7/27-7/29	Cycle Six	0.16 AF	73.62 AF
9	7/29-8/1	Cycle Seven	0.25 AF	80.03 AF

ASR Pilot Test Timeline

ASR Pilot Test Final Report

South Fork Kings GSA

Tulare Lake Subbasin, Kings County, California

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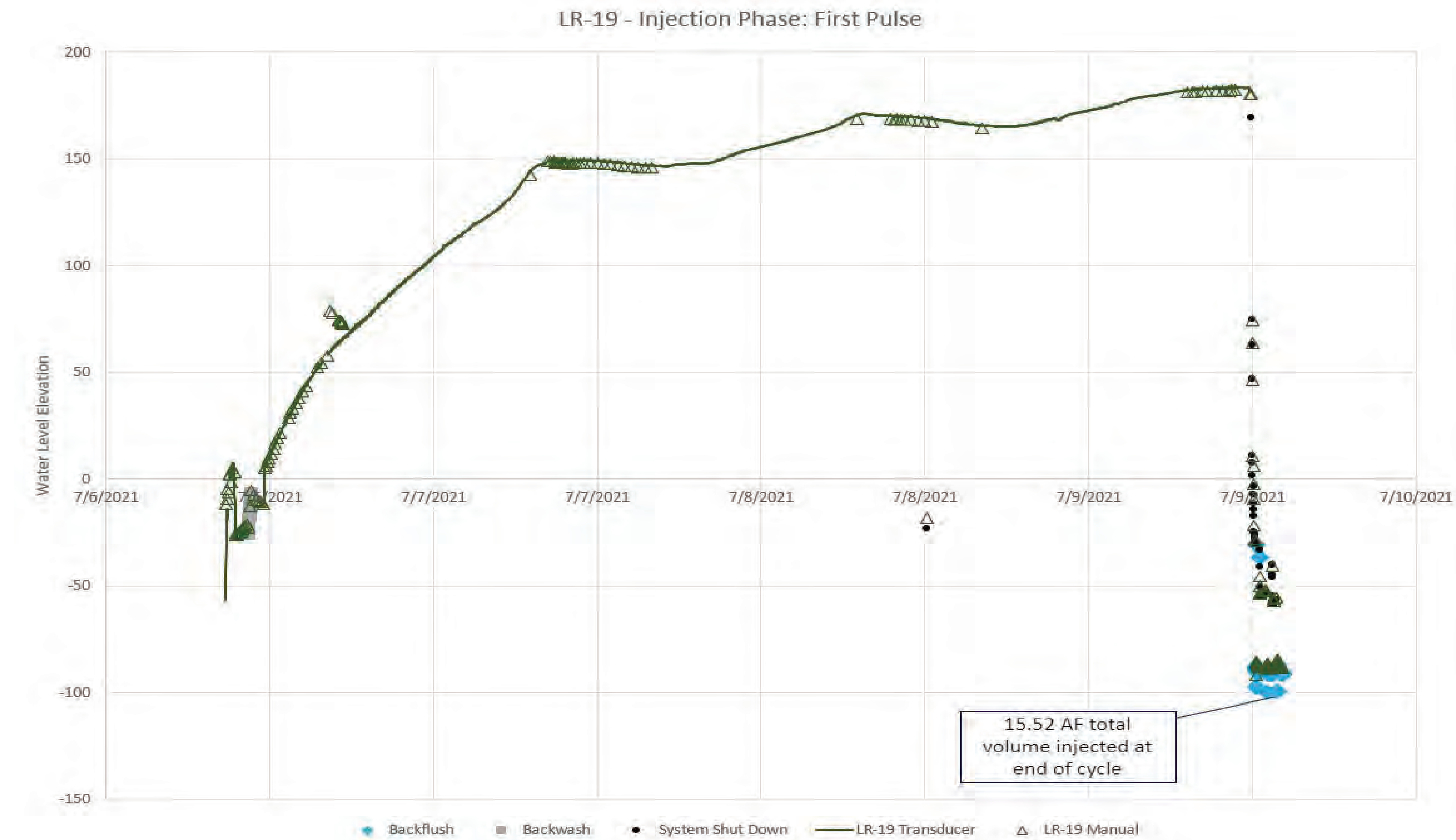
Figure 2-6

Project No. SAC299C

December 2021



Explanation

"First" pulse during injection cycle: Started after extracting 9.26 AF and ~2.5 days of system shut down. 14.70 AF of water was injected before the major backflush event. 5.44 AF remained in the aquifer before the first pulse. First pulse bypassed the filters on 7/6, 3 hours after the start of the pulse. Three days in cycle.

Water-Level Hydrographs in LR-19 During Injection Phase: First Pulse

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South Fork Kings GSA

Tulare Lake Subbasin, Kings County, California

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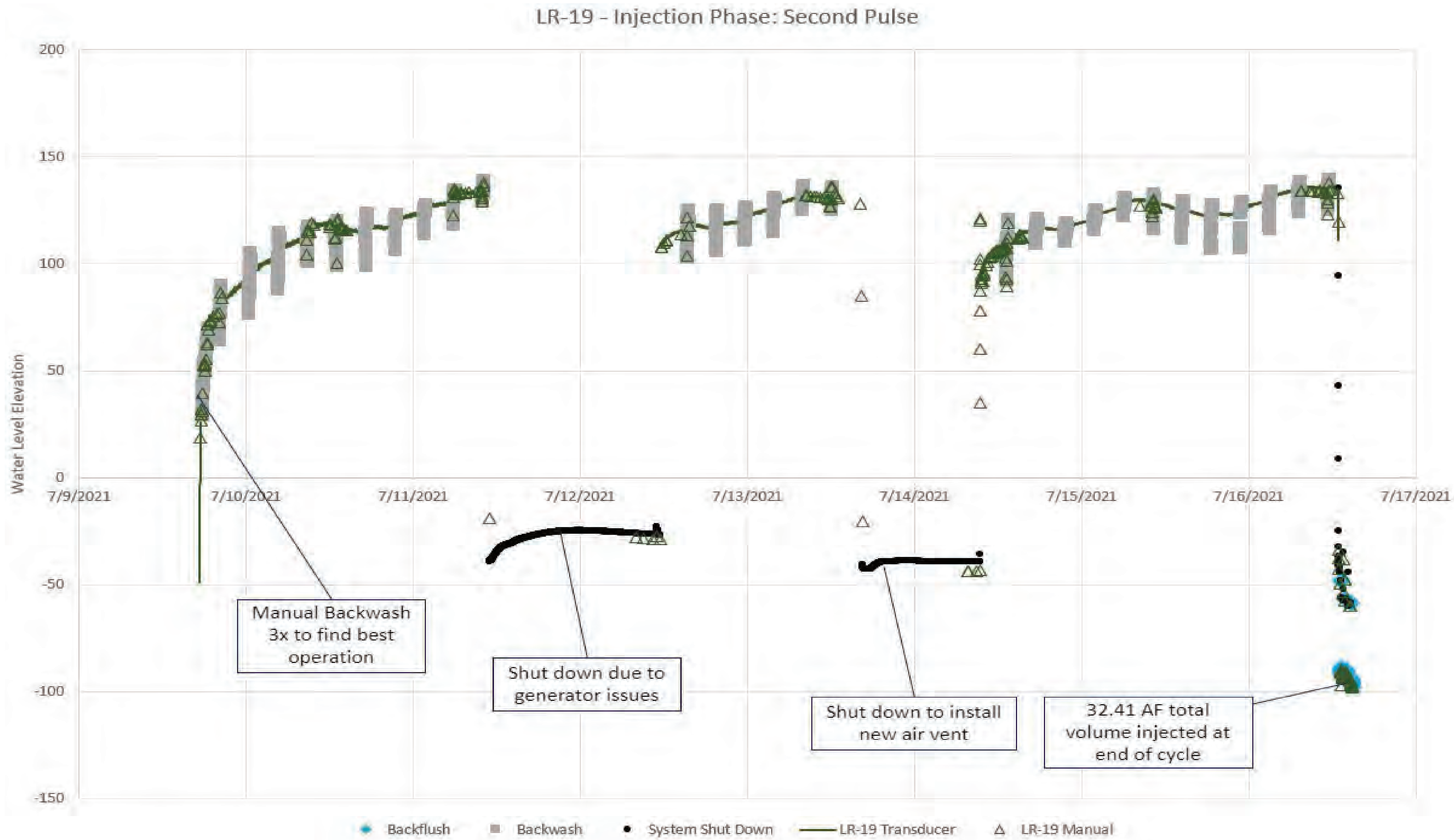
Figure **3-1a**

Project No.: SAC229C

May 2022



Explanation

"Second pulse: Injecting through filters after 7 minutes of injecting through bypass. First shut down caused by generator issues: 7/11 at 10:15 – 7/12 at 11:29; Second shut down to remove combination air vent and install continuous air vent (CAV-2): 7/13 at 16:15 – 7/14 at 9:22. Six days in cycle.

Notes:
AF= Acre Foot

Water-Level Hydrographs in LR-19 During Injection Phase: Second Pulse

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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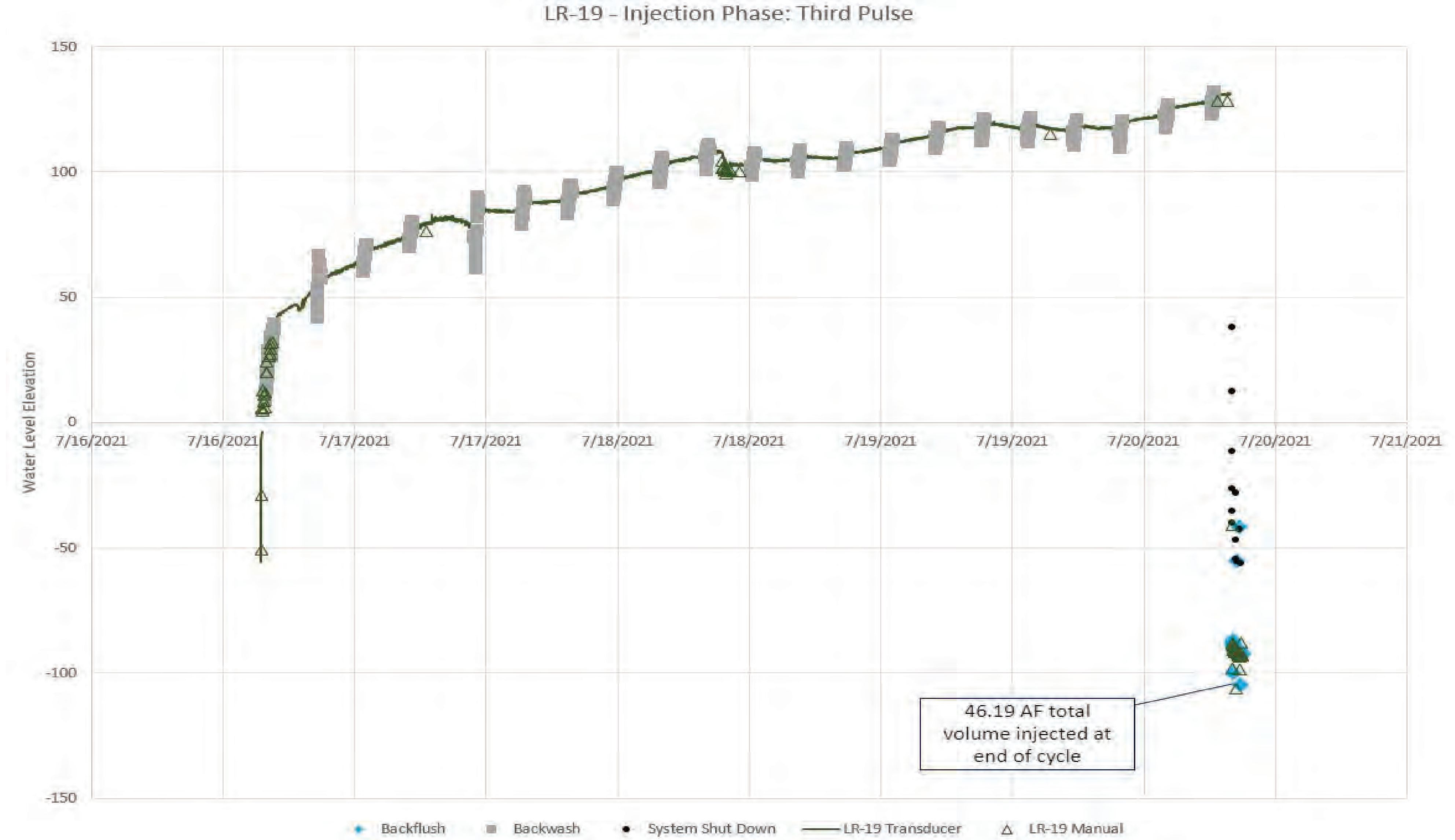
Figure **3-1b**

Project No.: SAC229C

May 2022



Explanation
Third pulse: No issues, very smooth cycle. Four days in cycle.

Notes:
AF= Acre Foot

Water-Level Hydrographs in LR-19 During Injection Phase: Third Pulse
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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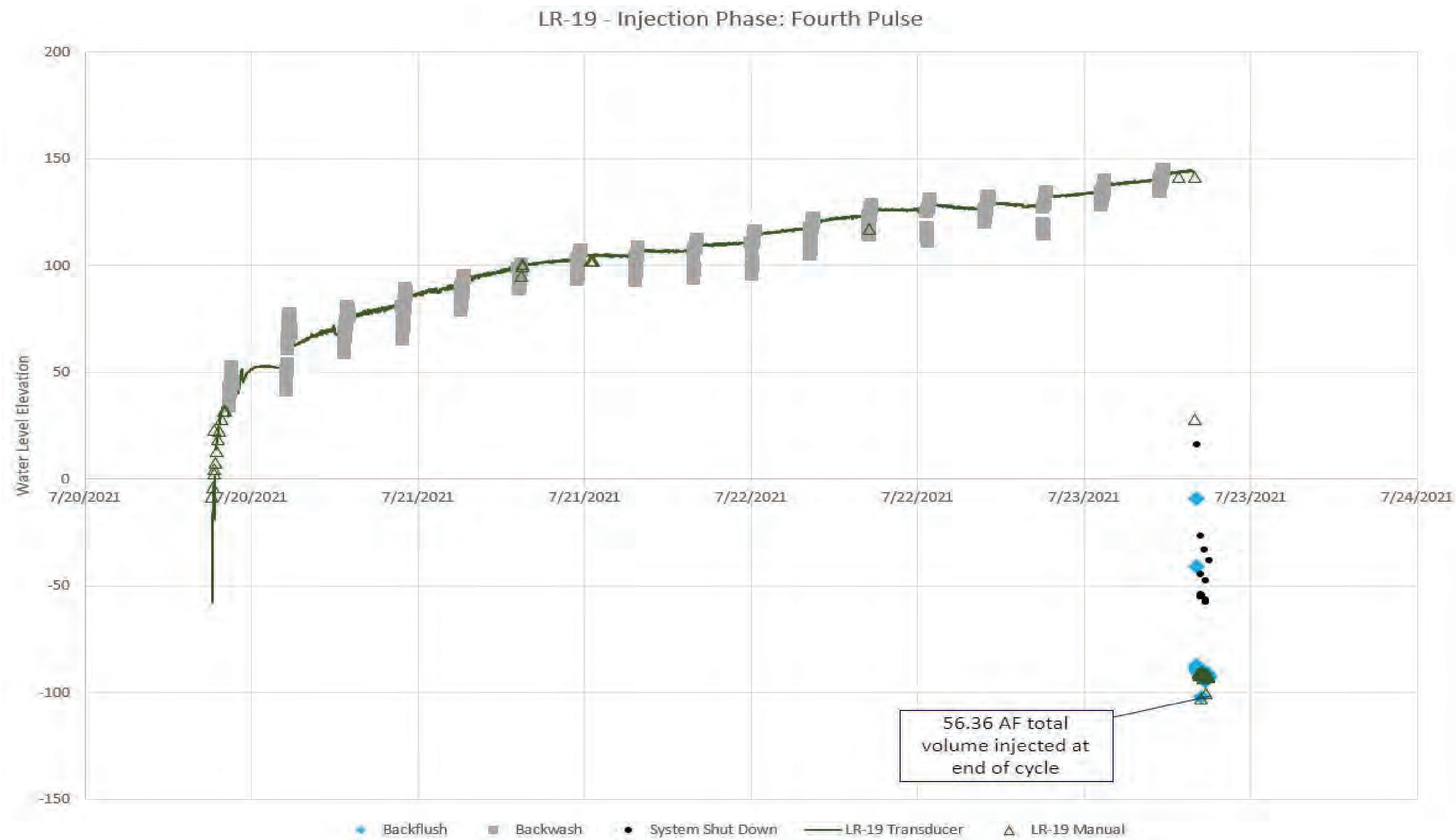
Project No.: SAC229C | May 2022

Figure **3-1c**



Explanation
Fourth pulse: No issues, very smooth cycle. Three days in cycle.

Notes:
AF= Acre Foot

Water-Level Hydrographs in LR-19 During Injection Phase: Fourth Pulse

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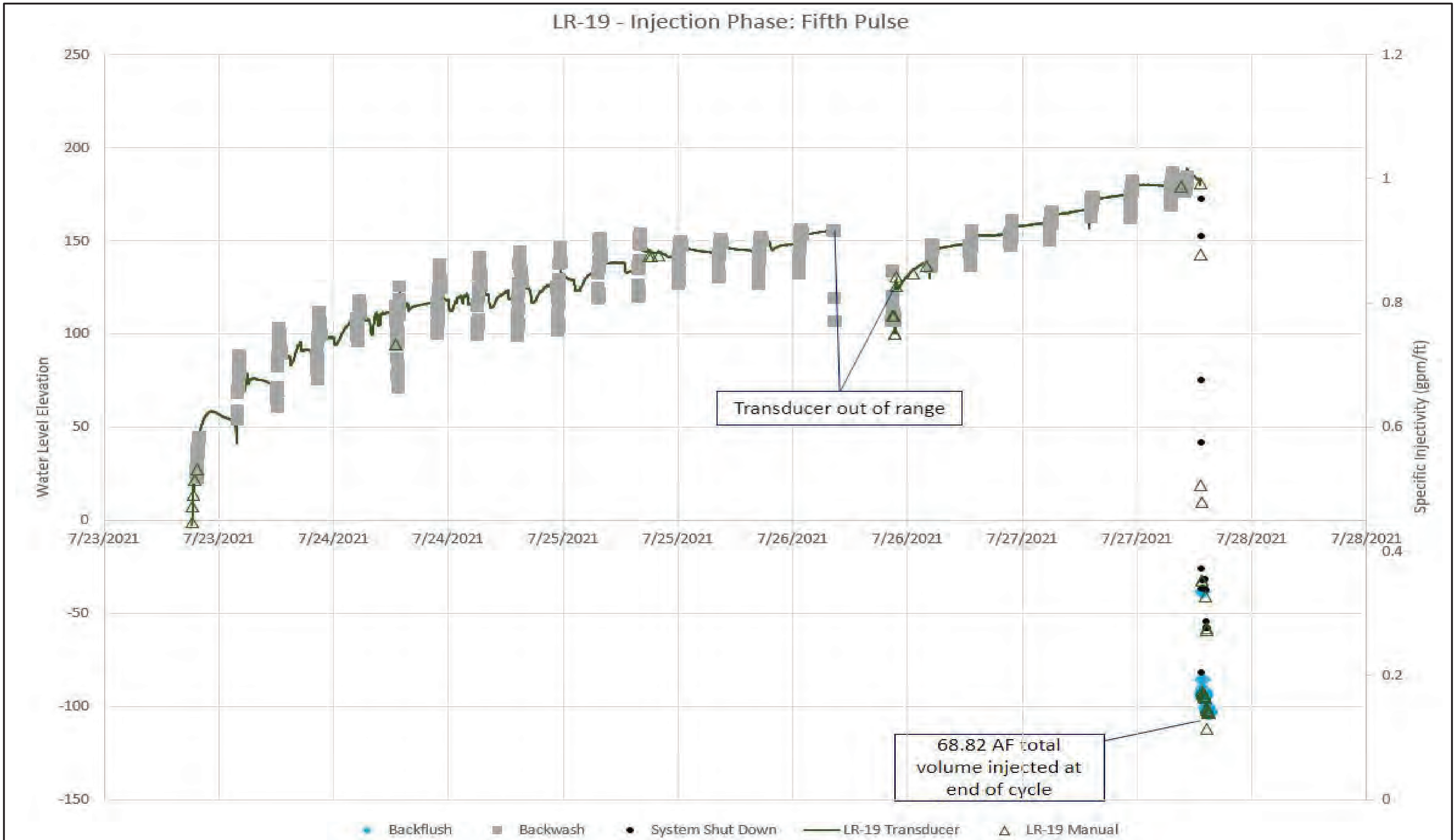
South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

Geosyntec consultants

Figure **3-1d**

Project No.: SAC229C | May 2022



Explanation

Fifth pulse: No issues during cycle. Four days of cycle. Two pulse backflushes at end of cycle due to landowner meeting staff late in the day to perform the flush. Injection started 9 minutess after Fourth pulse ended. Water level was not at static when beginning the fifth pulse. Water level rose 50 feet in 50 minutes.

Notes:
AF= Acre Foot

Water-Level Hydrographs in LR-19 During Injection Phase: Fifth Pulse

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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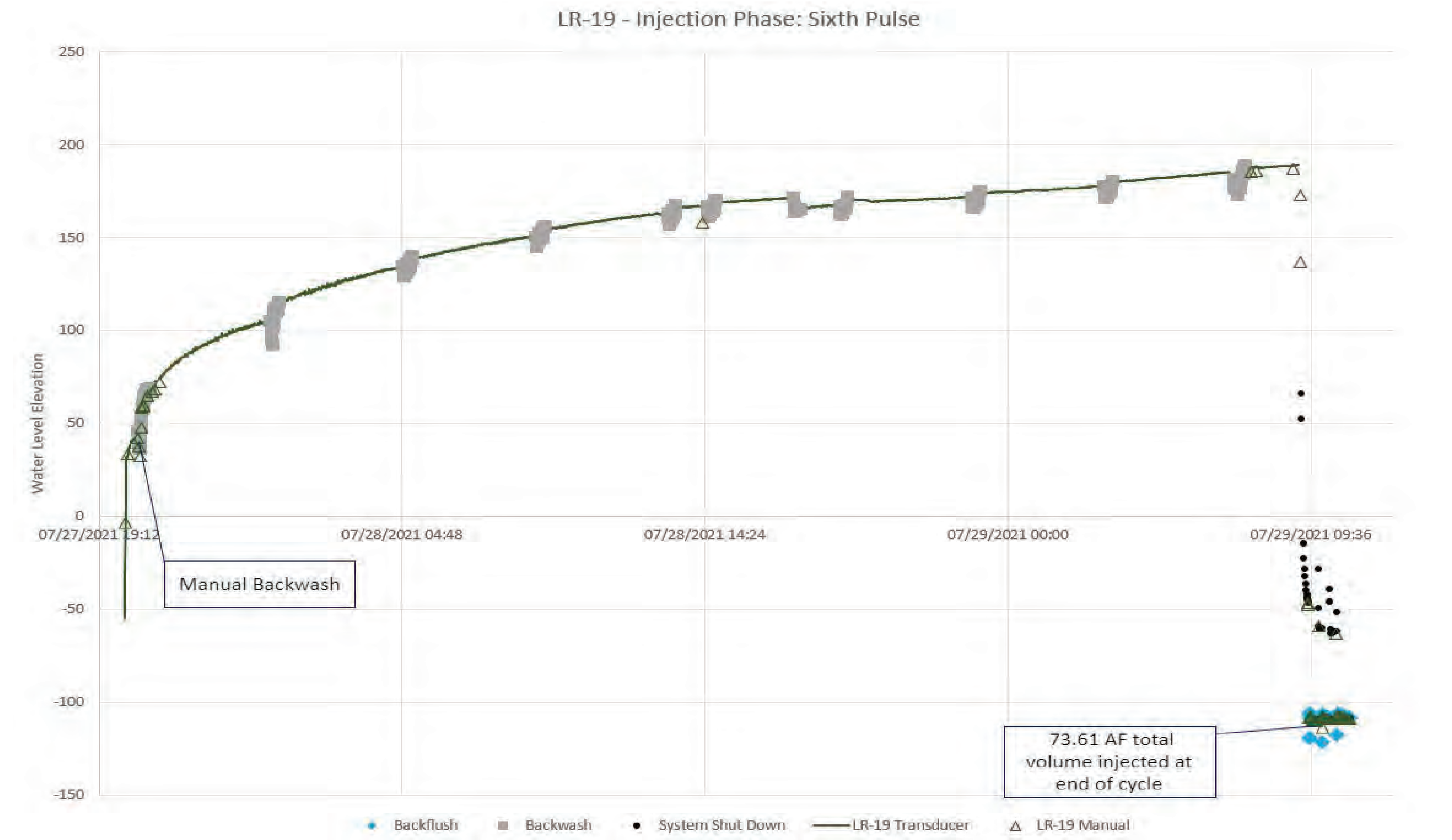
Project No.: SAC229C | May 2022

Figure **3-1e**



Explanation
Sixth pulse: Injection cycle started late evening 7/27 to prevent overflow. Two days in cycle. Water level rose 100 feet in 20 minutes.

Notes:
AF= Acre Foot

Water-Level Hydrographs in LR-19 During Injection Phase: Sixth Pulse

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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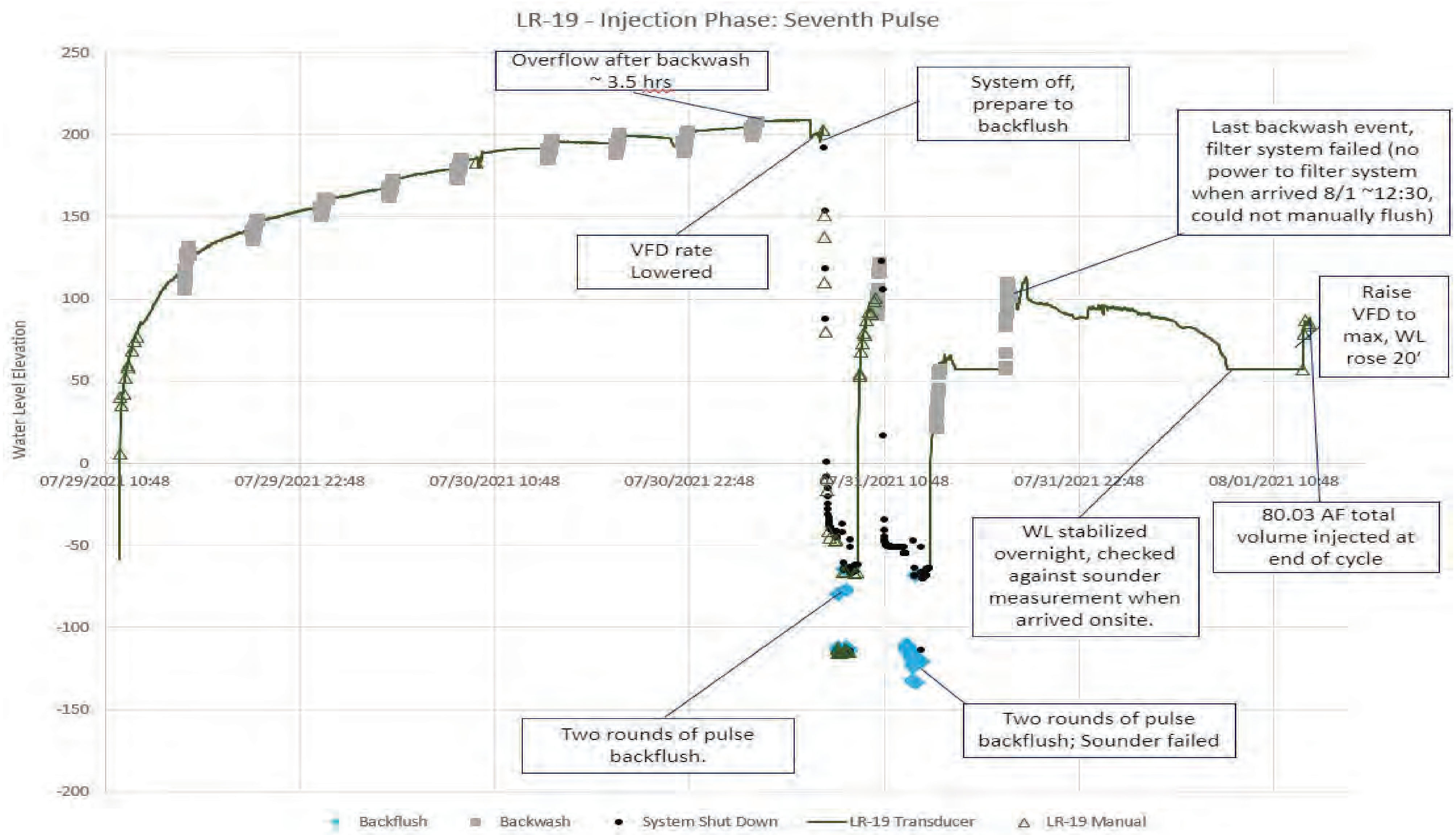
Project No.: SAC229C | May 2022

Figure **3-1f**



Explanation

Seventh pulse: Water level rose 100 feet in 13 minutes in first round of injection within cycle. Water level rose 100 feet in 5 minutes during the second round of injection within cycle. Injected for 1.5 hours between two backflush events. Two days in cycle.

Notes:
AF= Acre Foot
WL = Water level
VFD= Variable Frequency Drive

Water-Level Hydrographs in LR-19 During Injection Phase: Seventh Pulse

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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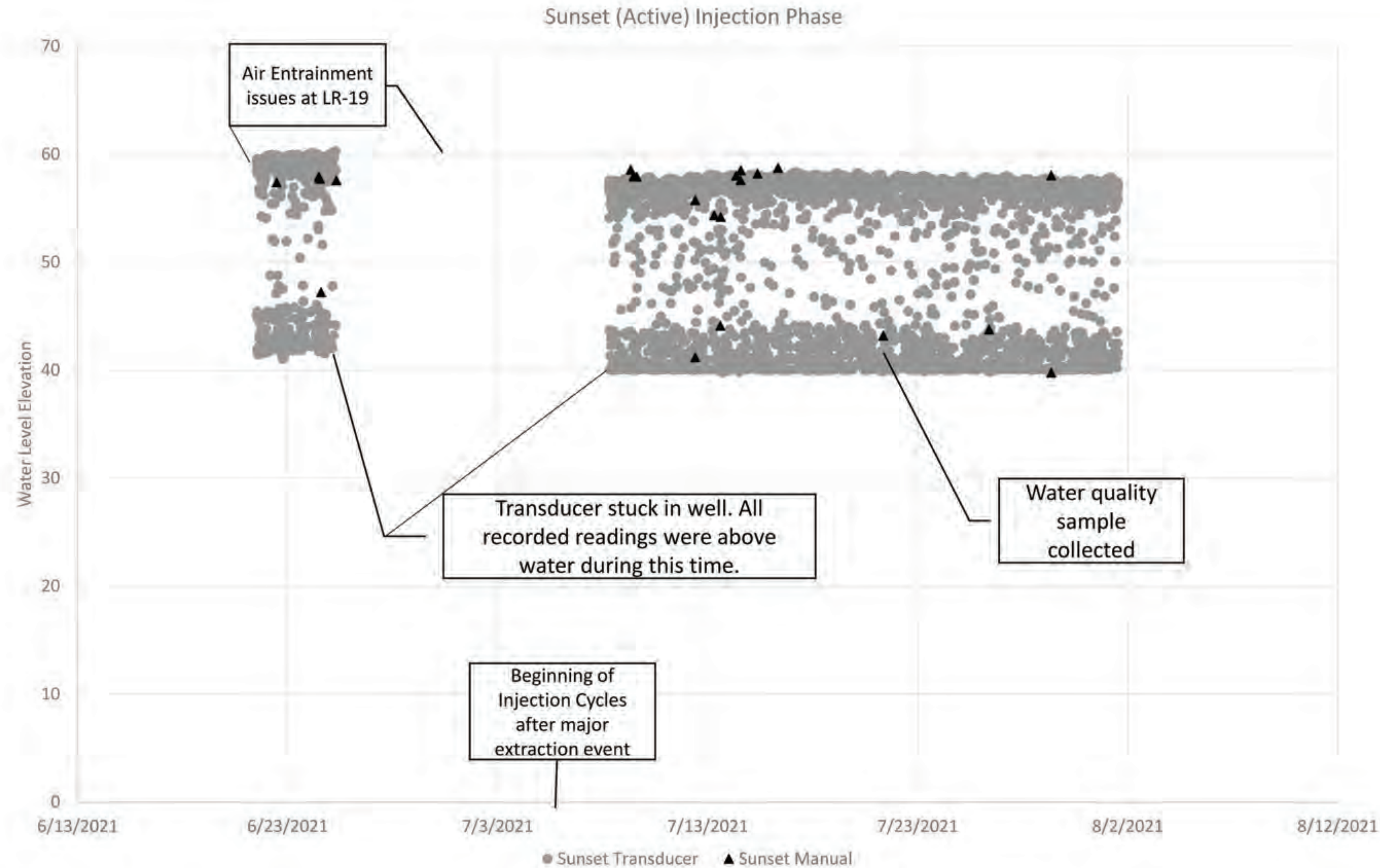
Project No.: SAC229C | May 2022

Figure **3-1g**



The ASR Pilot Test Injection Phase began on 6/21/2021 at 12:39 and ended on 8/1/2021 at 13:02. Data recorded prior to the start of the Injection Phase is not included.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in Sunset During Injection

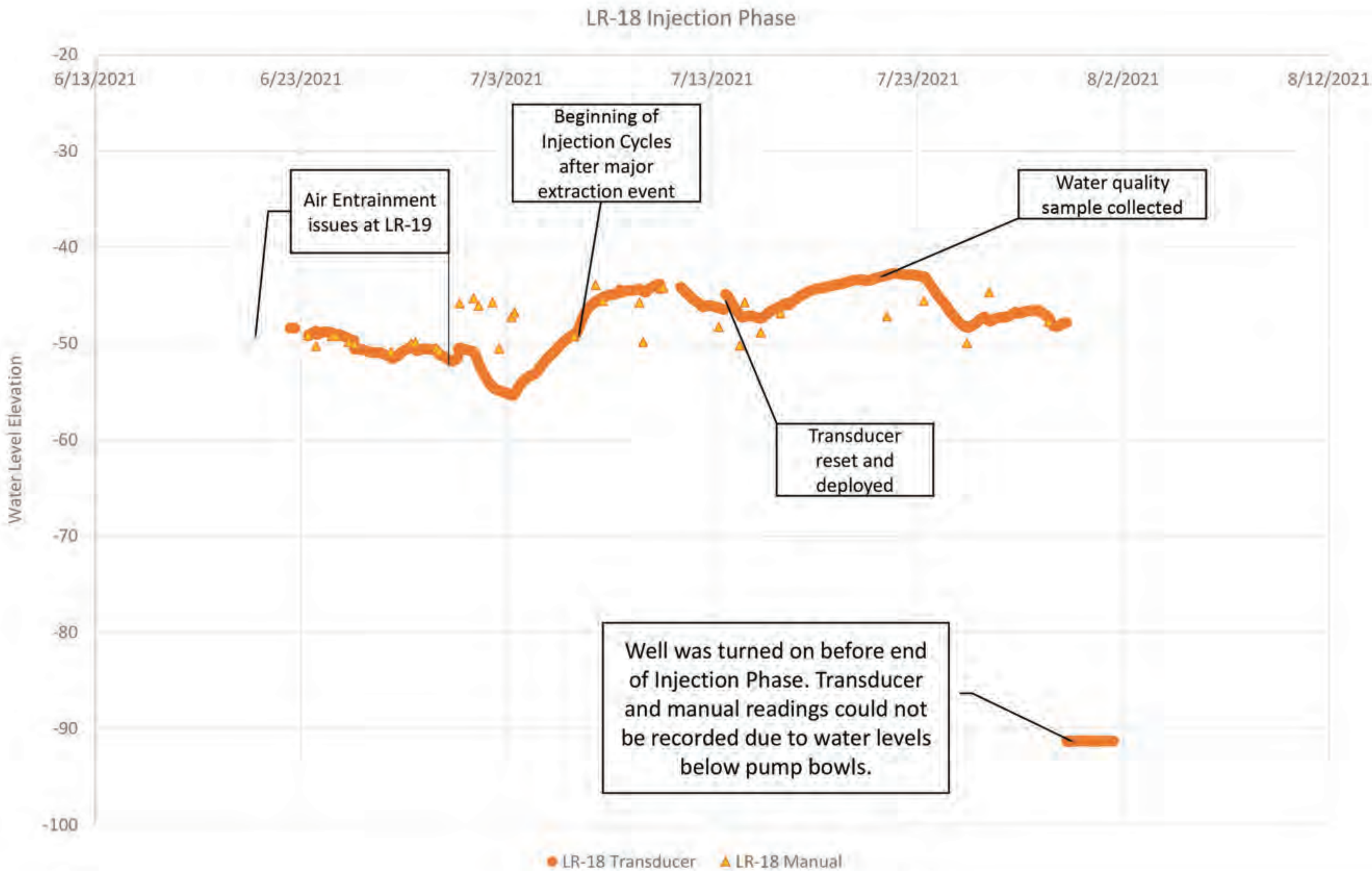
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

Geosyntec consultants

Figure 3-2a

Project No.: SAC299C

December 2021



The ASR Pilot Test Injection Phase began on 6/21/2021 at 12:39 and ended on 8/1/2021 at 13:02. Data recorded prior to the start of the Injection Phase is not included.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in LR-18 During Injection

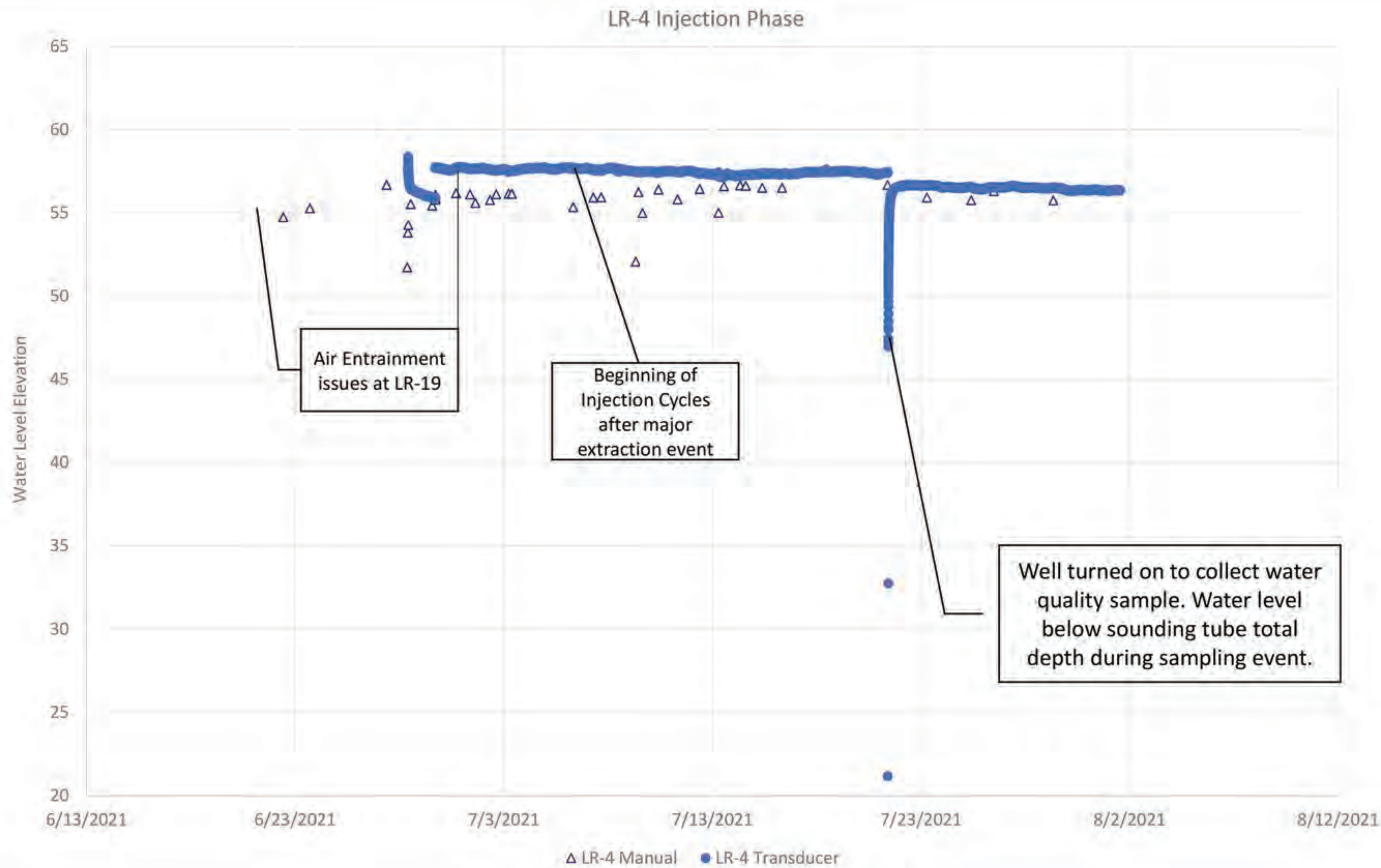
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

Geosyntec consultants

Figure 3-2b

Project No.: SAC299C

December 2021



The ASR Pilot Test Injection Phase began on 6/21/2021 at 12:39 and ended on 8/1/2021 at 13:02. Data recorded prior to the start of the Injection Phase is not included.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in LR-4 During Injection

ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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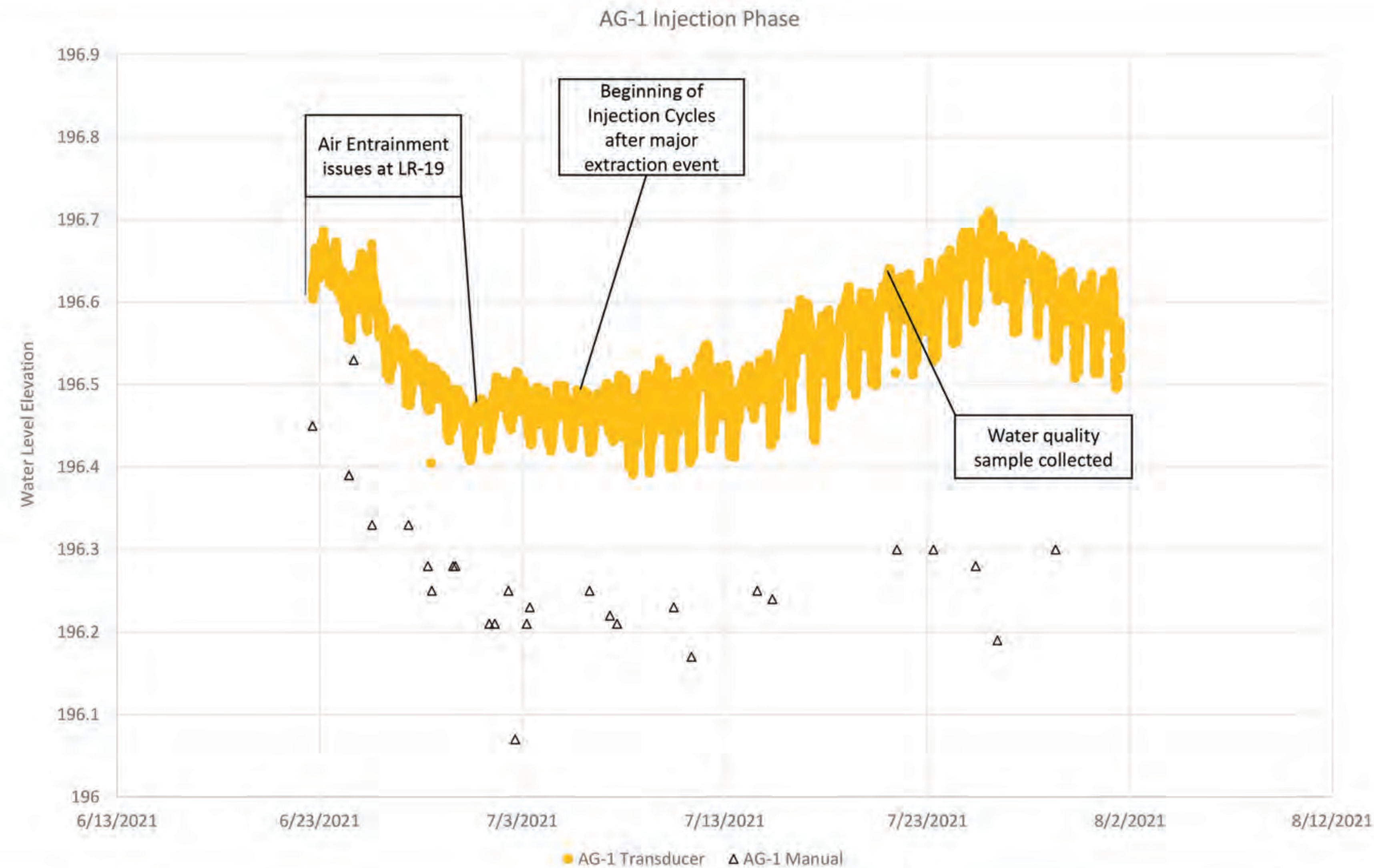
Figure 3-2c

Project No.: SAC299C | December 2021



The ASR Pilot Test Injection Phase began on 6/21/2021 at 12:39 and ended on 8/1/2021 at 13:02. Data recorded prior to the start of the Injection Phase is not included.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in AG-1 During Injection

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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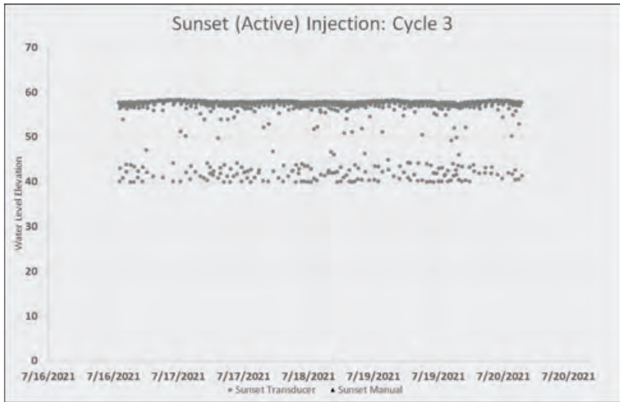
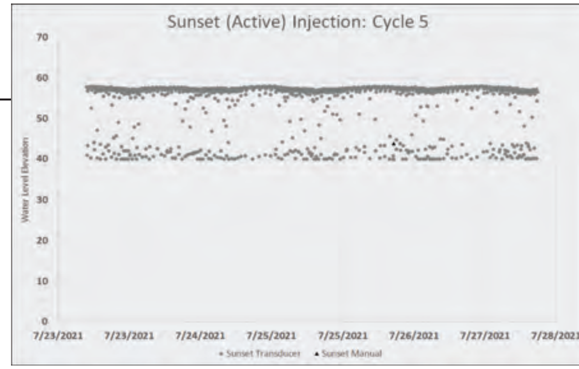
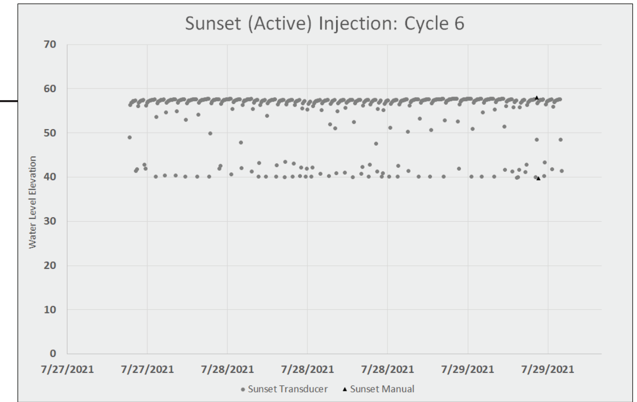
Figure 3-2d

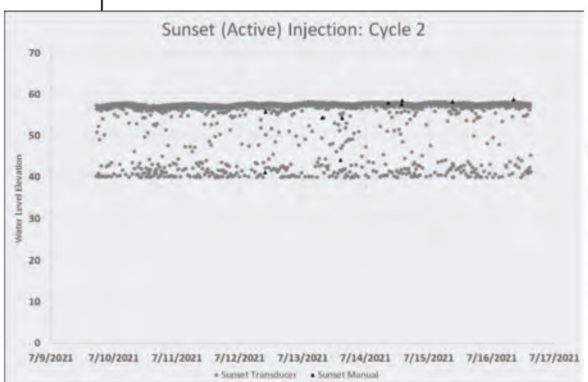
Project No.: SAC299C

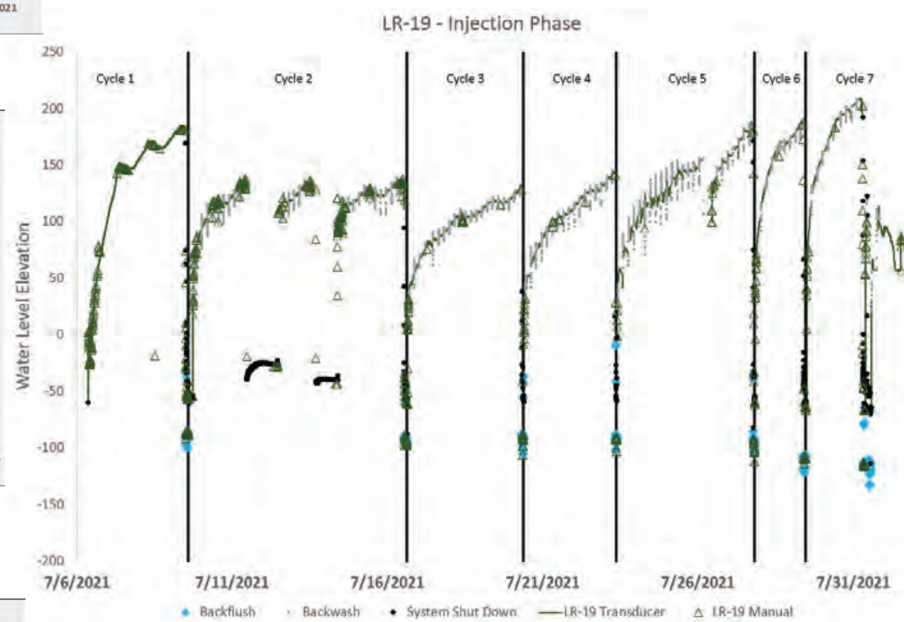
December 2021

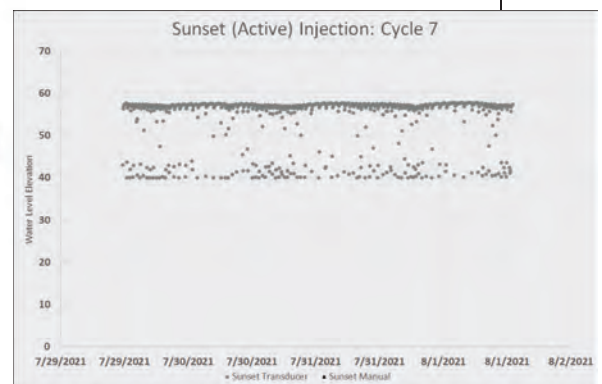


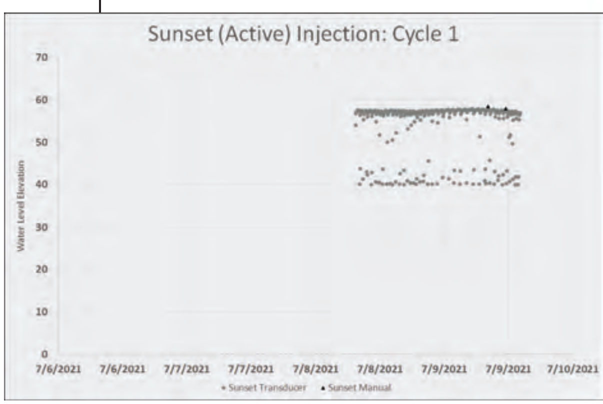


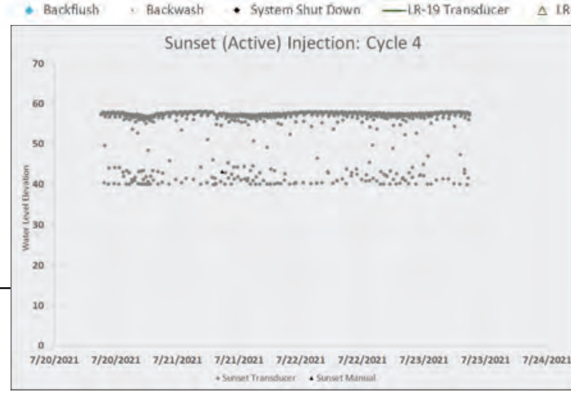












Water Level Responses in Observation Wells in Injection Cycle Sunset

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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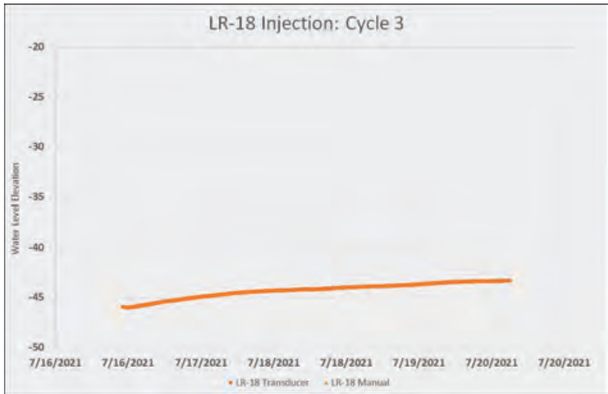
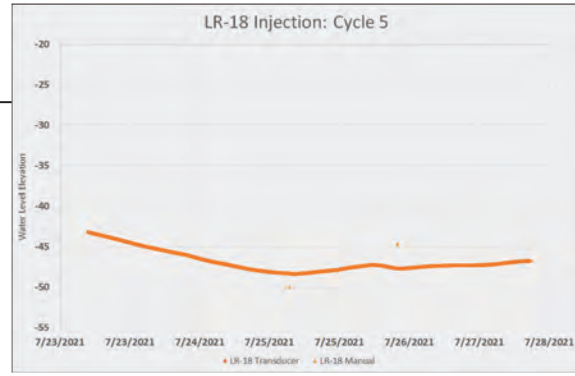
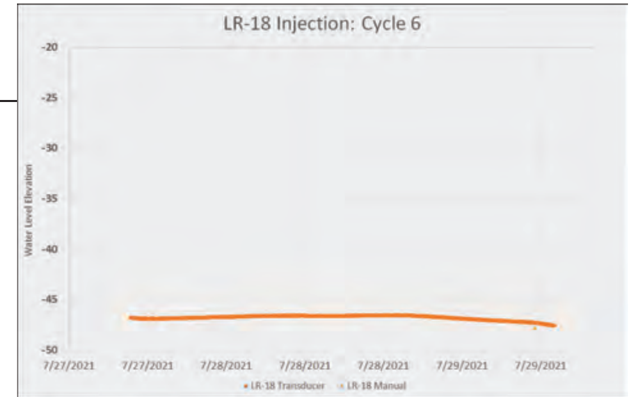
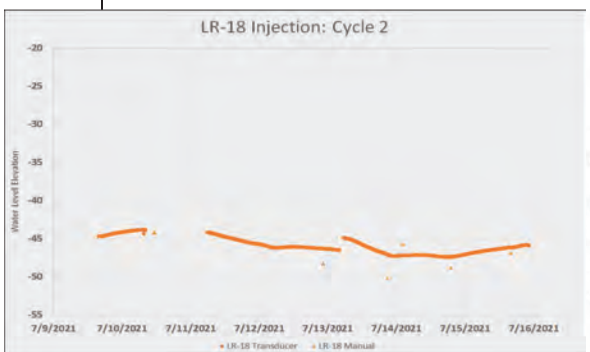
Figure **3-3a**

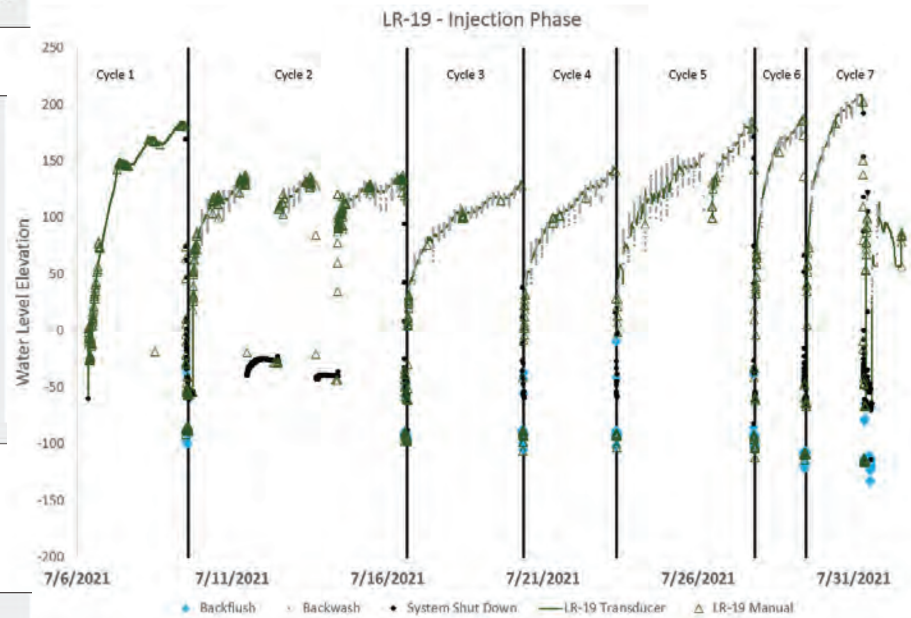
Project No.: SAC229C | May 2022

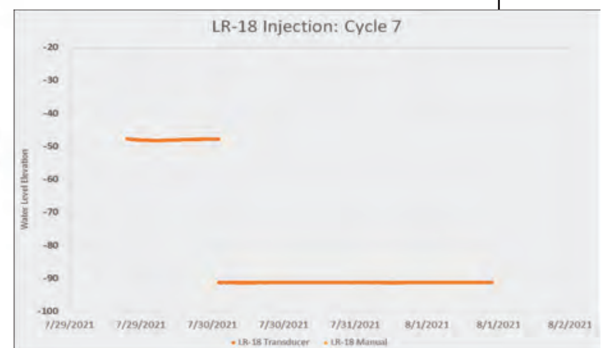


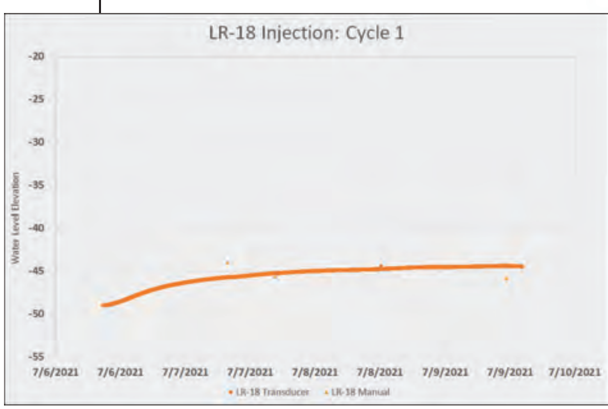


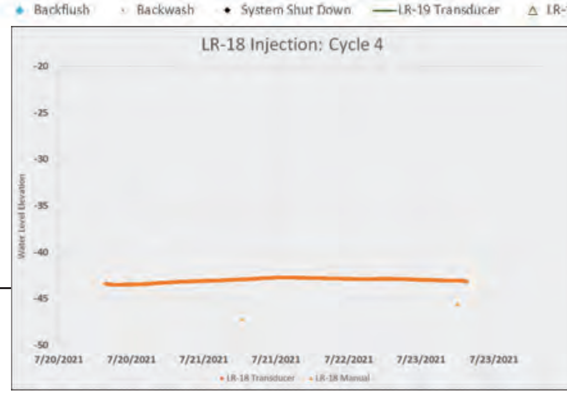












Water Level Responses in Observation Wells in Injection Cycle
LR-18

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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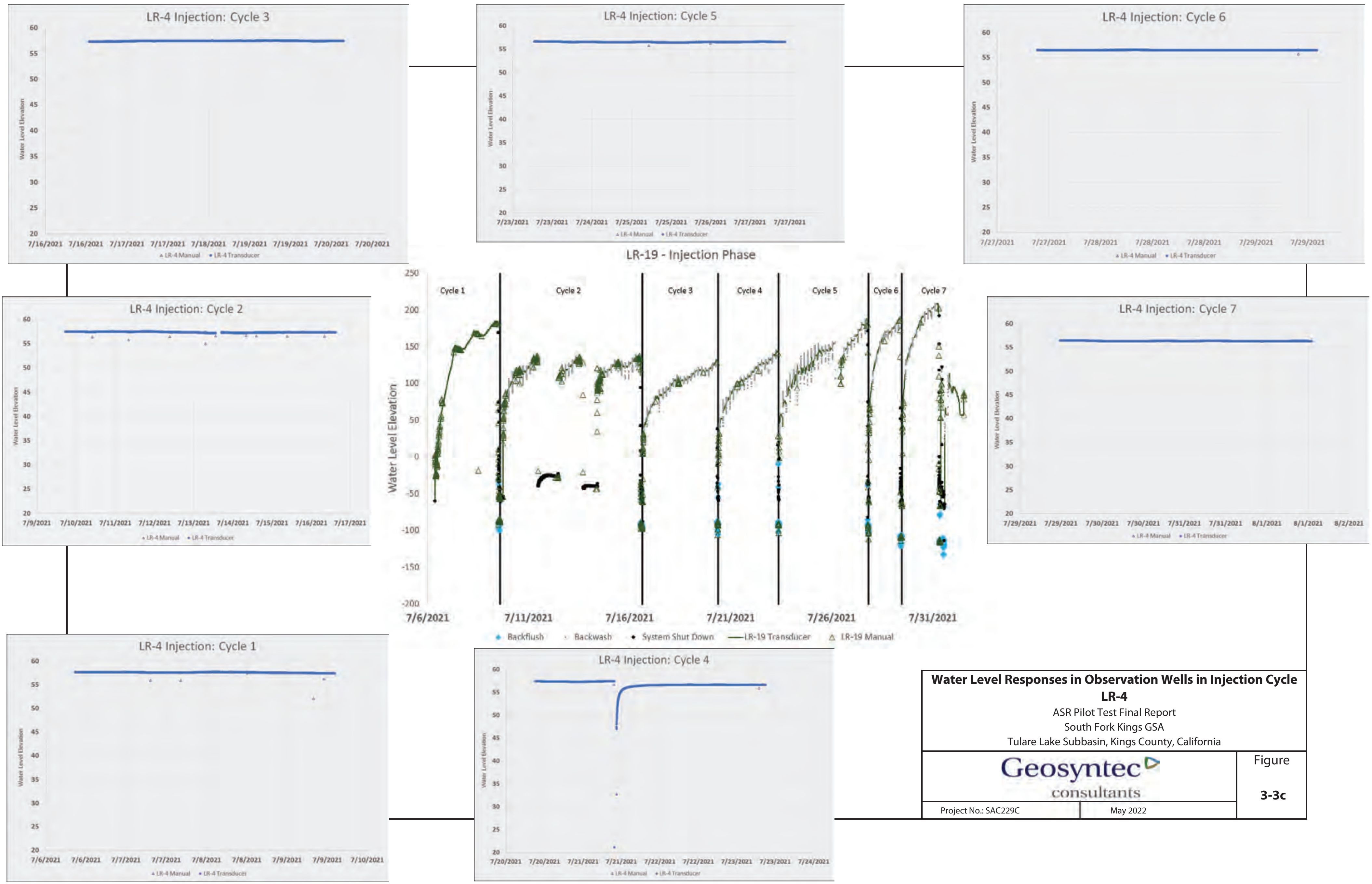
Figure **3-3b**

Project No.: SAC229C | May 2022



Water Level Responses in Observation Wells in Injection Cycle
LR-4
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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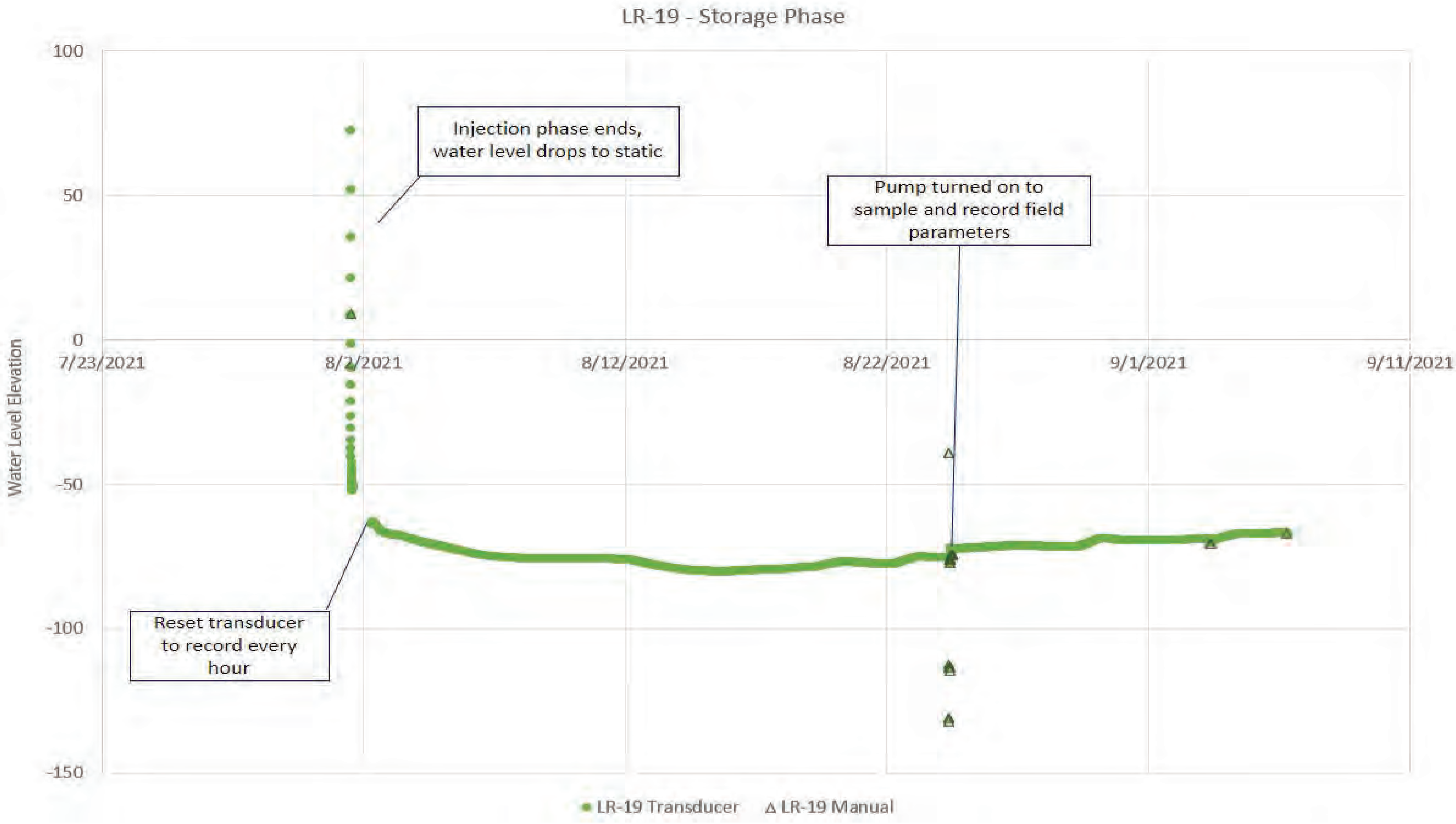
Figure **3-3c**

Project No.: SAC229C | May 2022



Explanation:

A water quality sample was collected from LR-19 during the Storage Phase on August 24, 2021. To collect the sample, the LR-19 well was turned on and purged until field parameters stabilized. An approximate 0.1 Acre-Feet of water was purged within 30 minutes.

Water-Level Hydrographs in LR-19 During Storage

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Figure **3-4a**

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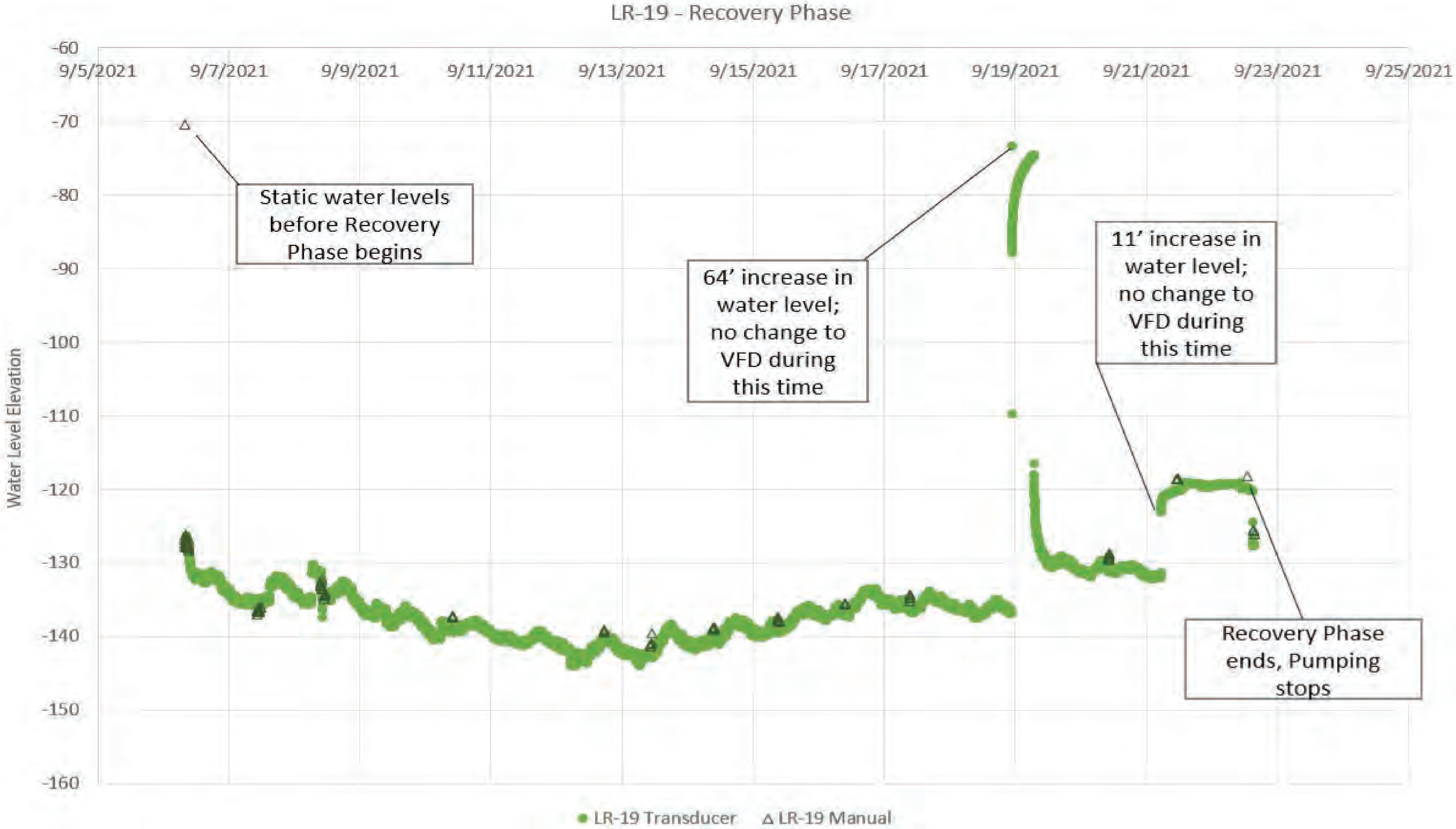

Explanation:

An electrical shortage took place on September 18, 2021 causing water levels to rise 64 feet and return to static and again on September 21st causing an 11-foot increase in water levels.

Water-Level Hydrographs in LR-19 During Recovery

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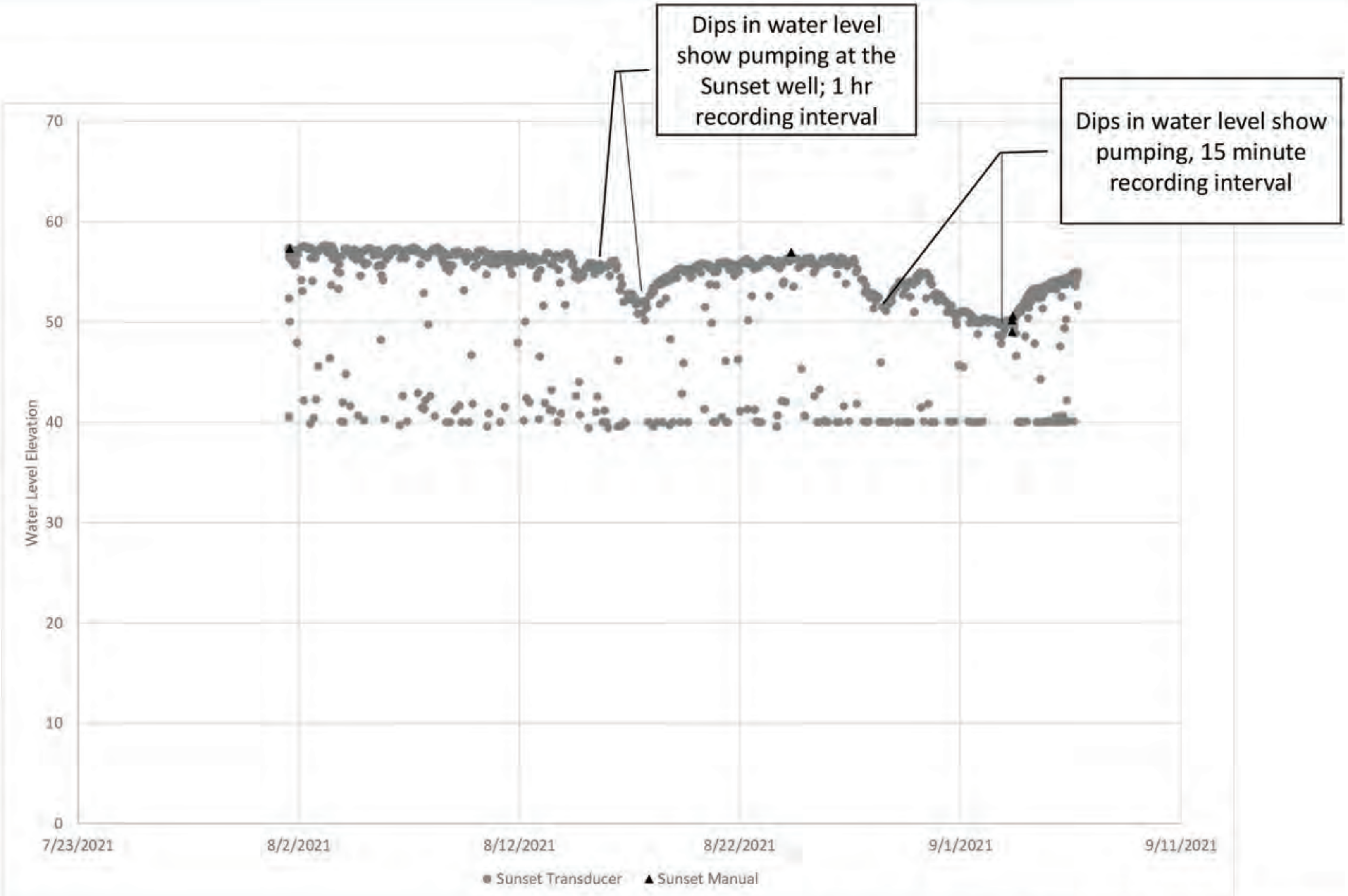
Figure **3-4b**

Project No.: SAC229C | May 2022



The ASR Pilot Test Storage Phase began on 8/1/2021 at 13:02 and ended on 9/6/2021 at 8:04. The above hydrograph only depicts data within the Storage Phase.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in Sunset During Storage

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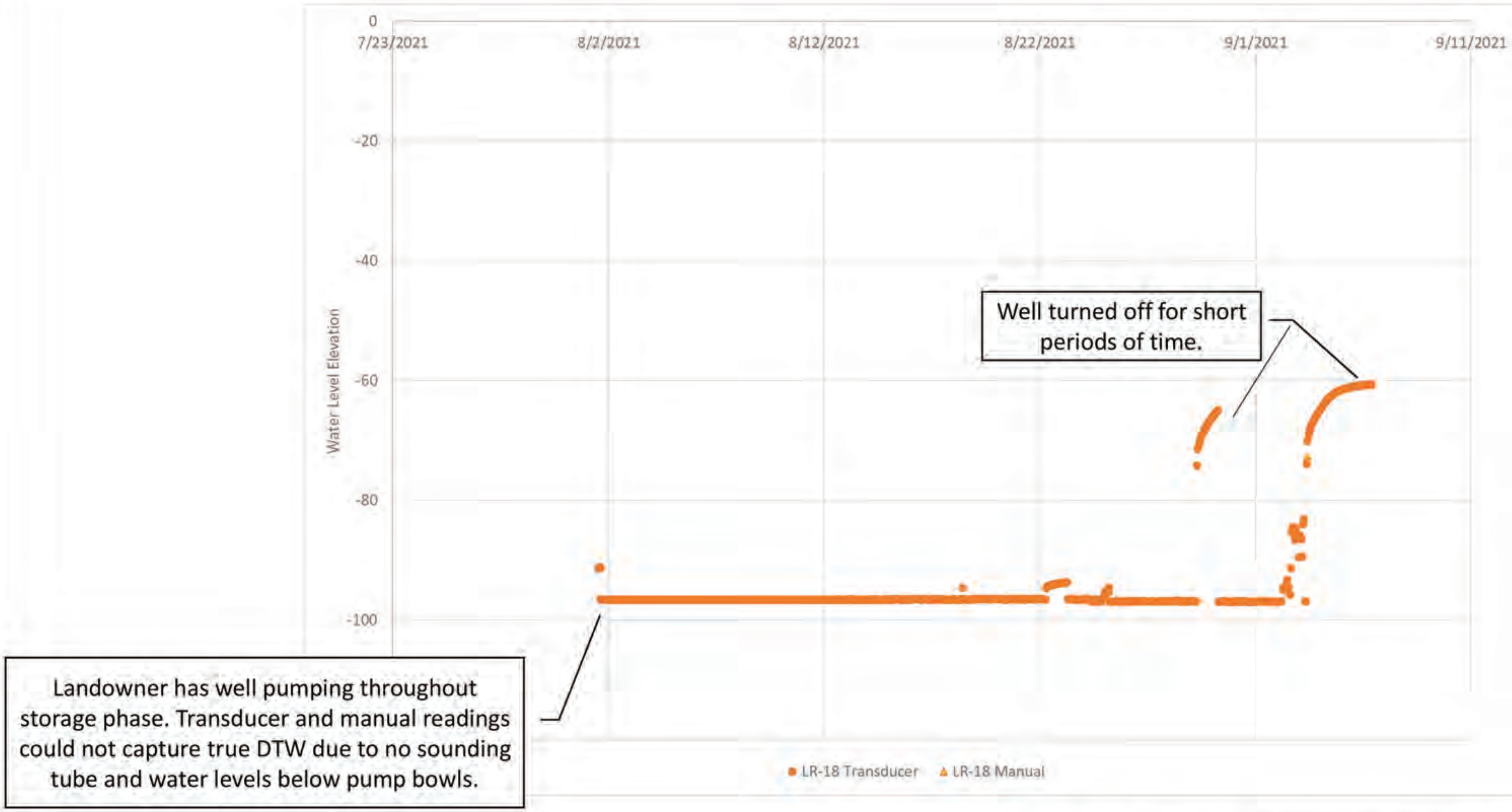
December 2021

Figure 3-5a



The ASR Pilot Test Storage Phase began on 8/1/2021 at 13:02 and ended on 9/6/2021 at 8:04. The above hydrograph only depicts data within the Storage Phase.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in LR-18 During Storage

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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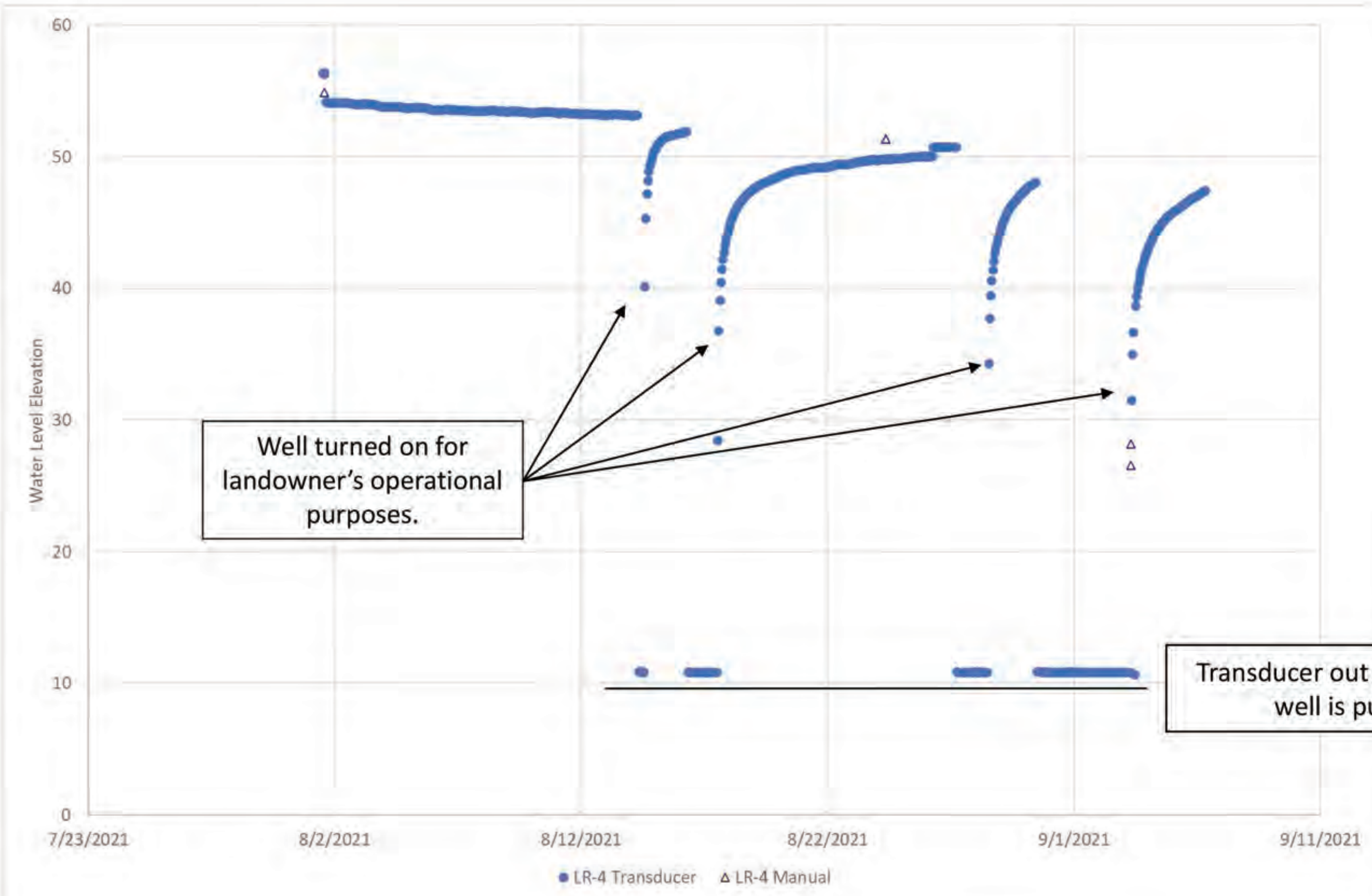
Figure 3-5b



The ASR Pilot Test Storage Phase began on 8/1/2021 at 13:02 and ended on 9/6/2021 at 8:04. The above hydrograph only depicts data within the Storage Phase.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in LR-4 During Storage

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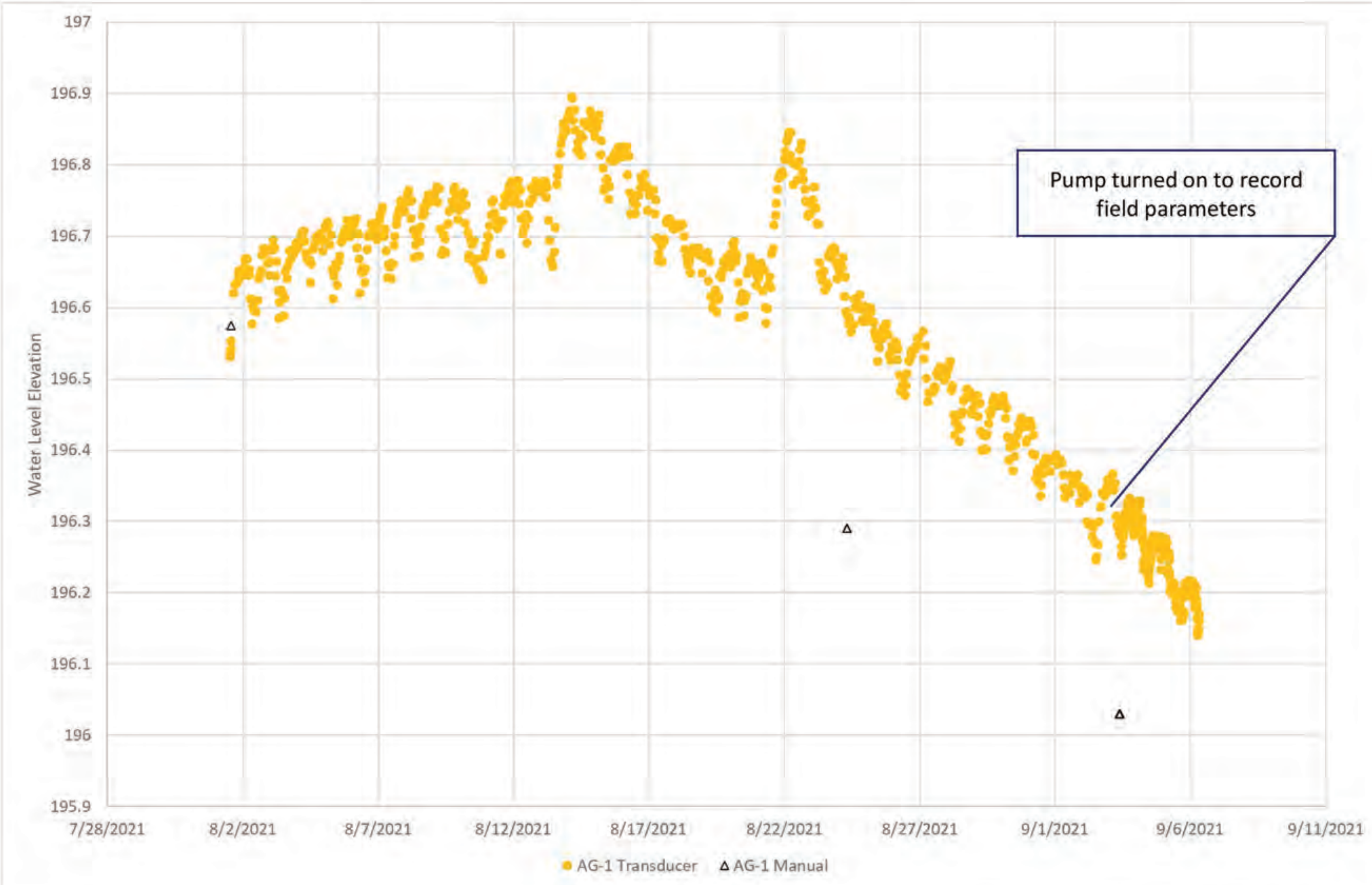
Figure 3-5c



The ASR Pilot Test Storage Phase began on 8/1/2021 at 13:02 and ended on 9/6/2021 at 8:04. The above hydrograph only depicts data within the Storage Phase.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in AG-1 During Storage

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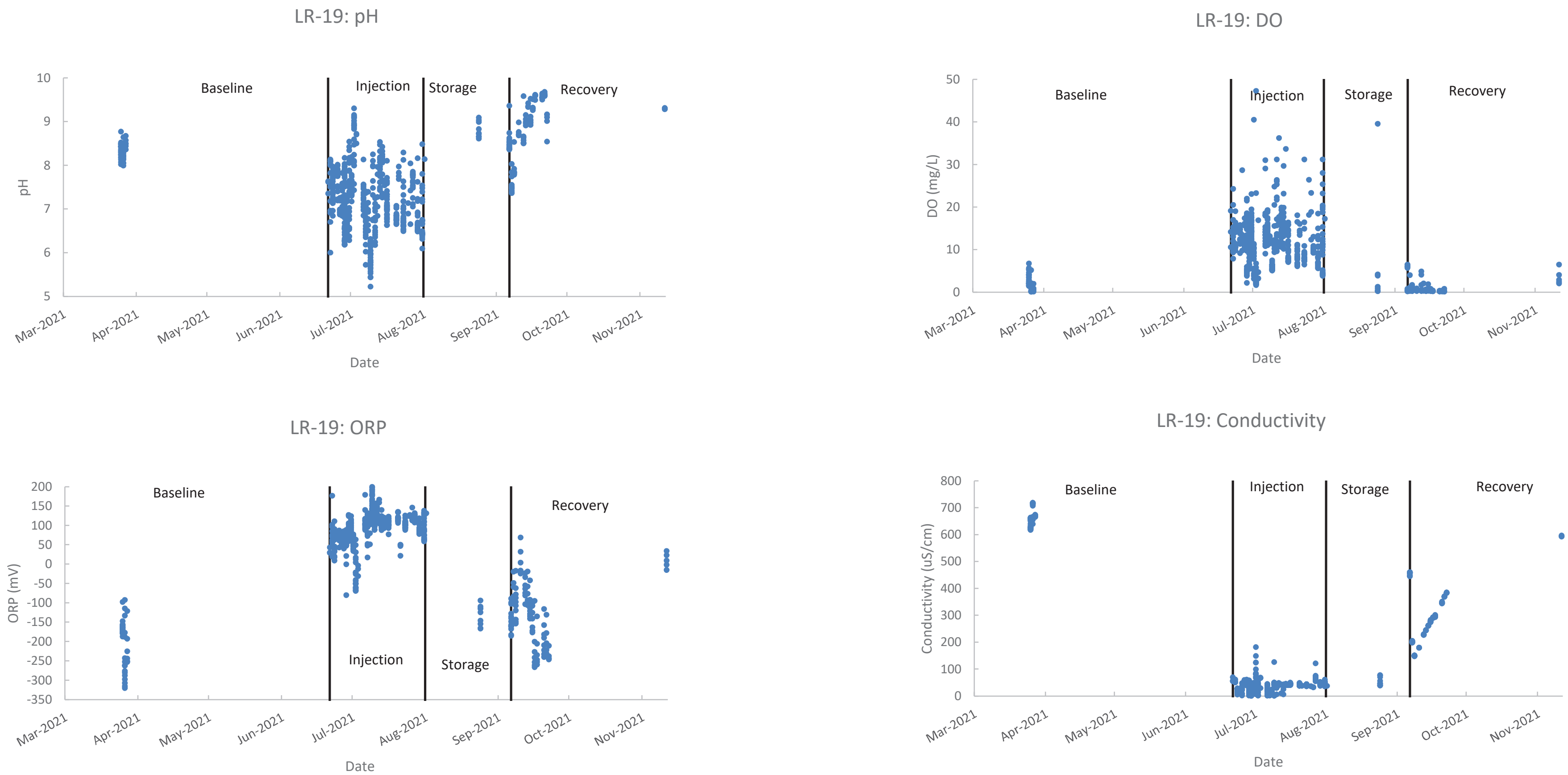
Figure 3-5d



Notes:
mg/L = milligrams per liter
mV = millivolts
uS/cm = microsiemens per centimeter
DO = dissolved oxygen
ORP = oxidation-reduction potential

Baseline = March 26 - 27, 2021
Injection = June 21- August 1, 2021
Storage = August 1 - Sept 6, 2021
Recovery = Sept 6 - 22, 2021

Time Series of LR-19 Water Quality During Pilot Test: Field Parameters
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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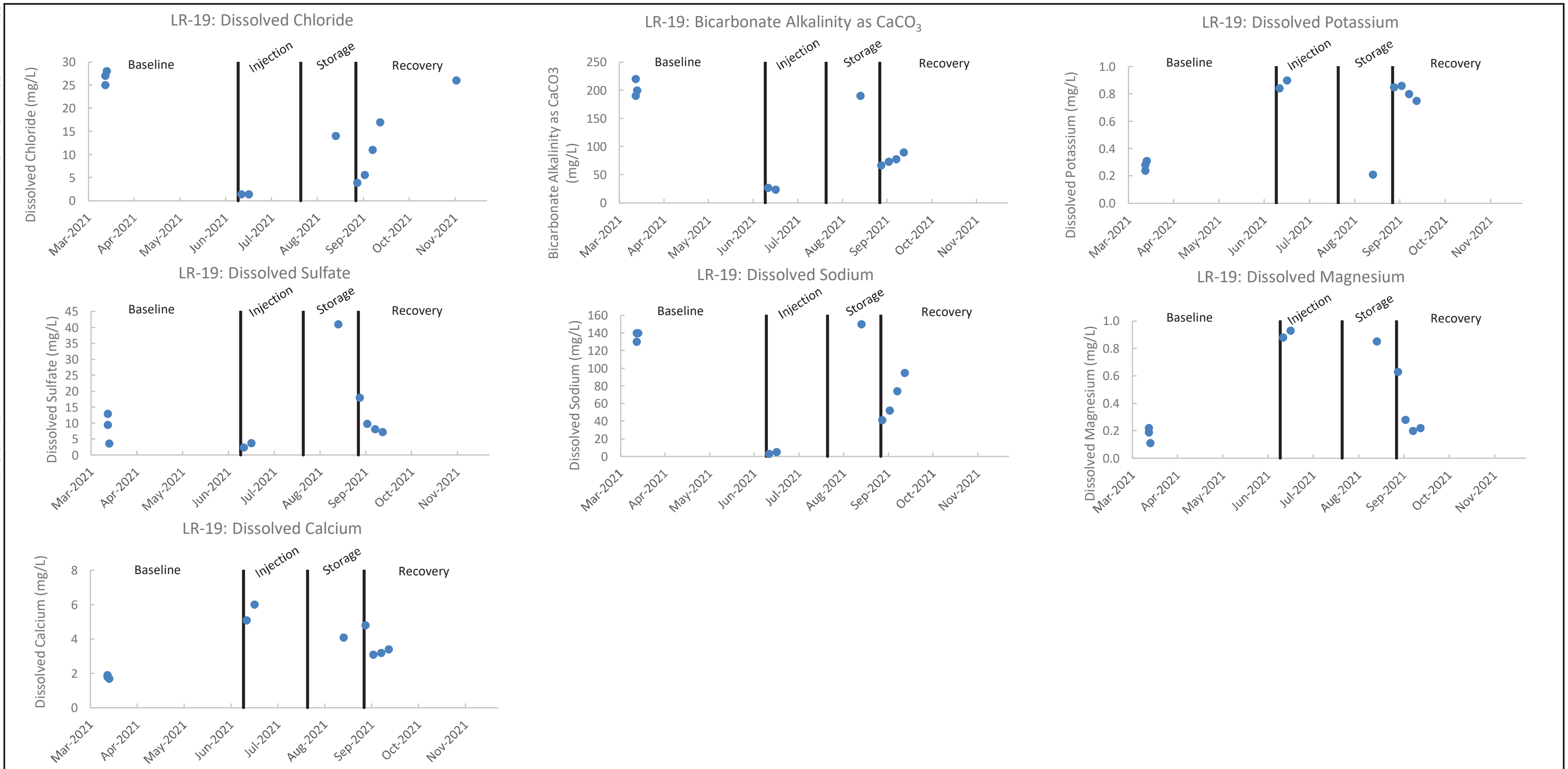
Project No.: SAC229C | May 2022

Figure 3-7a



Notes:
mg/L = milligrams per liter
Baseline = March 26 - 27, 2021
Injection = June 21- August 1, 2021
Storage = August 1 - Sept 6, 2021
Recovery = Sept 6 - 22, 2021

Time Series of LR-19 Water Quality During Pilot Test: Major Cations and Anions
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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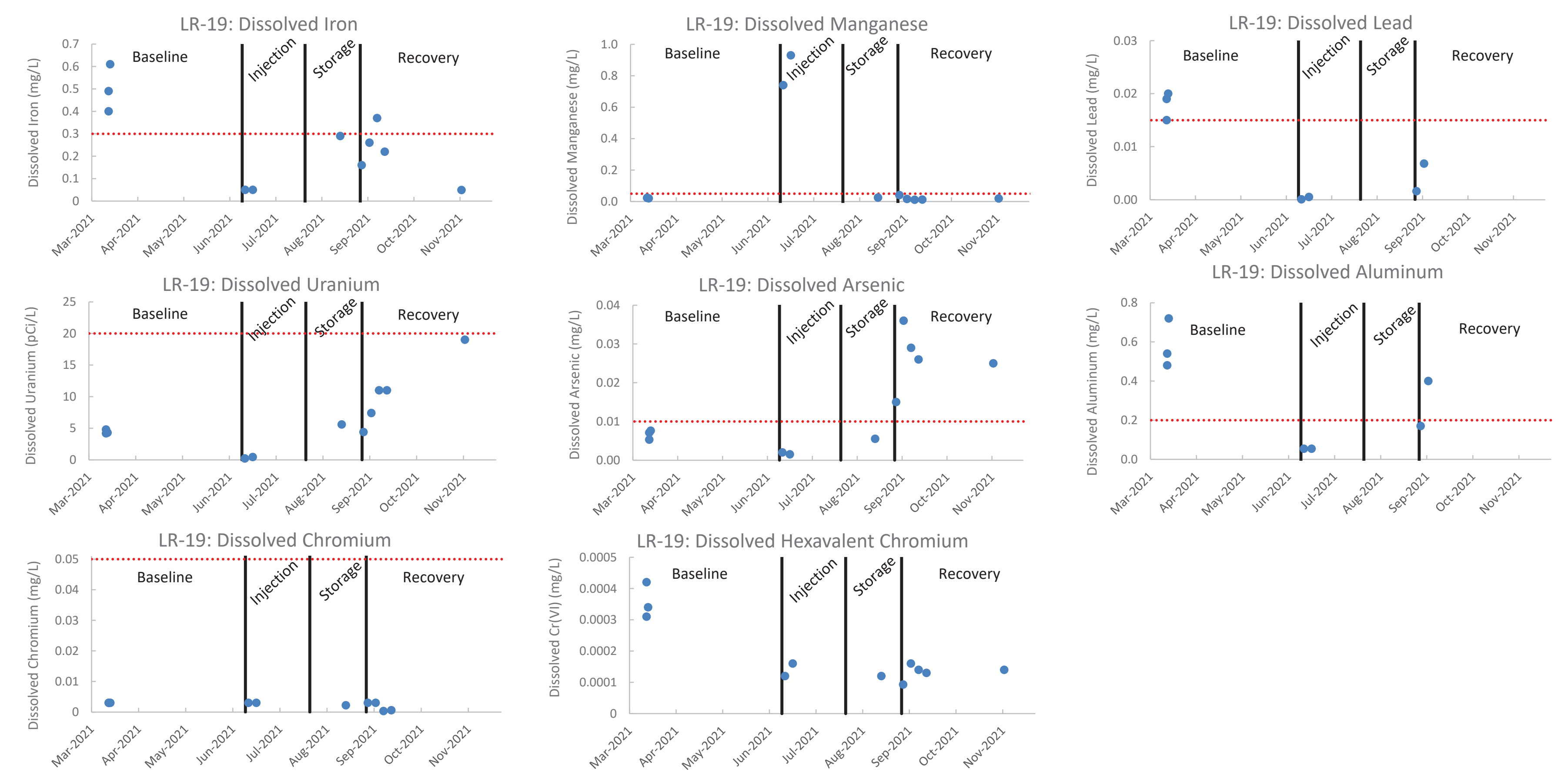
Figure 3-7b



Notes:

Aluminum and lead were not measured during the storage phase.
Cr(VI) = hexavalent chromium
mg/L = milligrams per liter
pCi/L = picocuries per liter
= California maximum contaminant limit (MCL)
Baseline = March 26 - 27, 2021
Injection = June 21- August 1, 2021
Storage = August 1 - Sept 6, 2021
Recovery = Sept 6 - 22, 2021

Time Series of LR-19 Water Quality During Pilot Test: Select Metals

ASR Pilot Test Final Report
South Fork Kings GSA
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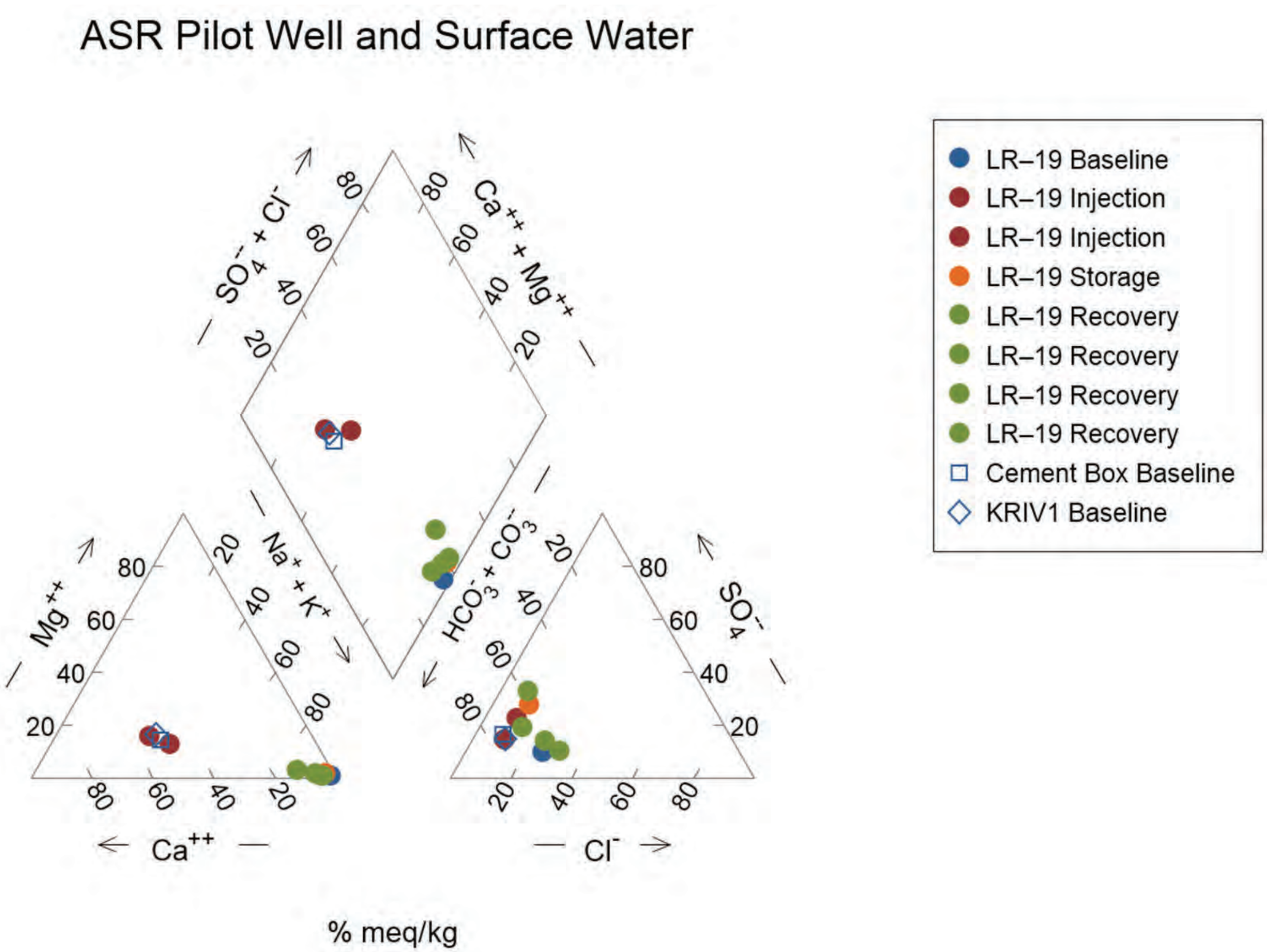
Figure 3-7c



Notes
% meq/kg = percent milliequivalents per kilogram
ASR = Aquifer Storage and Recovery
GSA = Groundwater Sustainability Agency

Piper Diagram of LR-19
Groundwater During Pilot Test
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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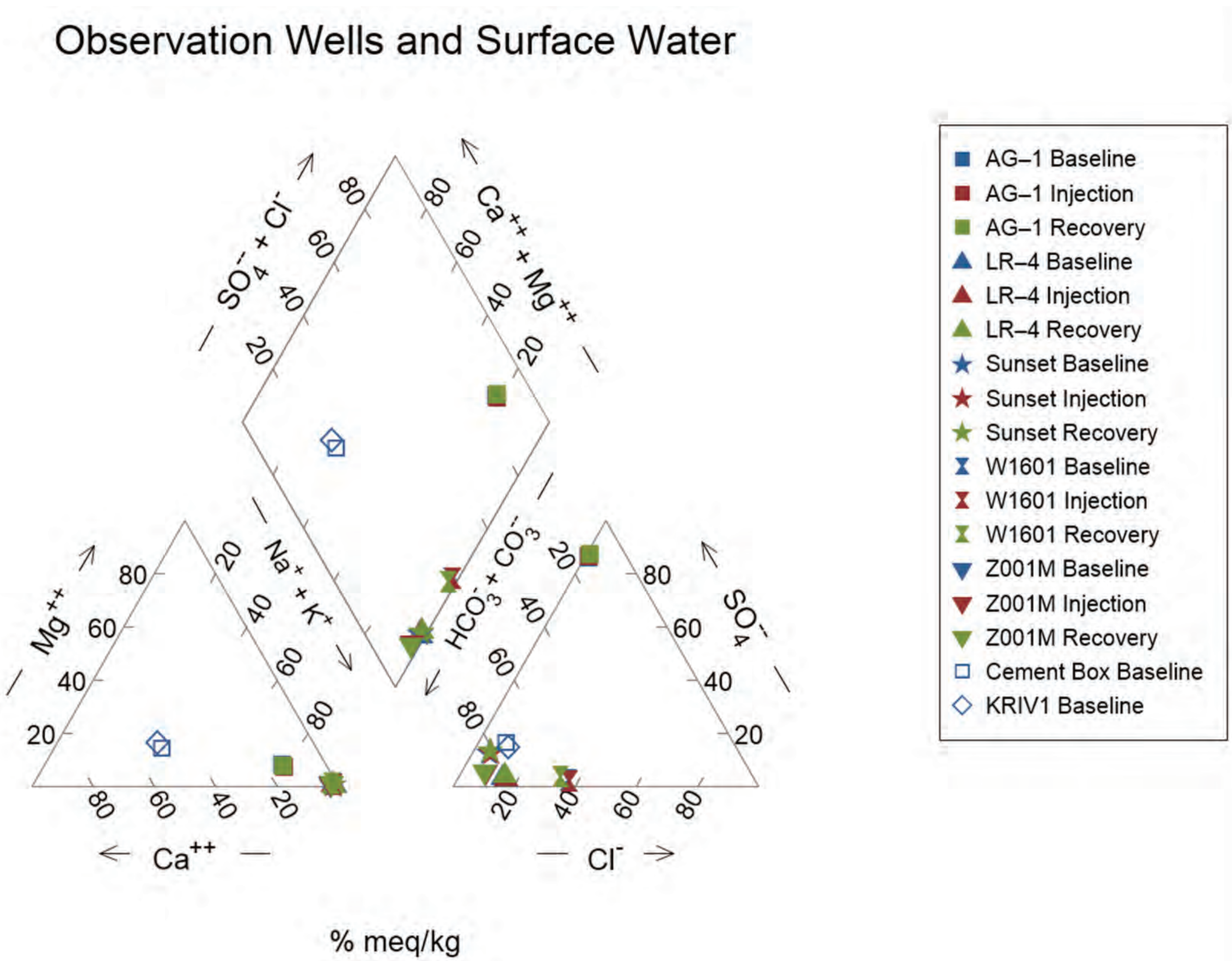
SAC229A | April 2022

Figure 3-8



Notes
% meq/kg = percent milliequivalents per kilogram
ASR = Aquifer Storage and Recovery
GSA = Groundwater Sustainability Agency

Piper Diagram of Observation Well Groundwater and Surface Water During Pilot Test
ASR Pilot Test Final Report
South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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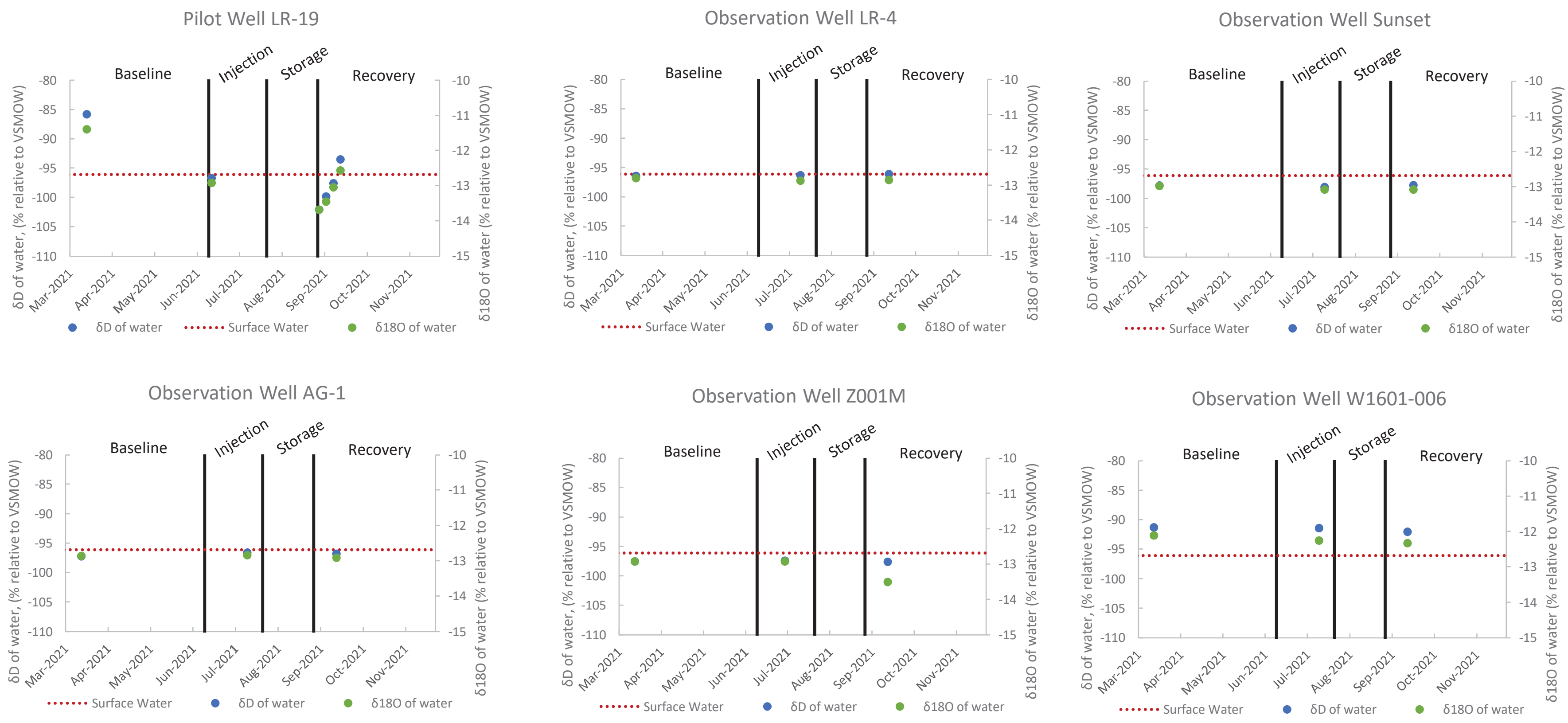
SAC229A | April 2022

Figure 3-9



Notes:
VSMOW = Vienna Standard Mean Ocean Water

Time Series of Stable Isotopes During Pilot Test
ASR Pilot Test Final Report
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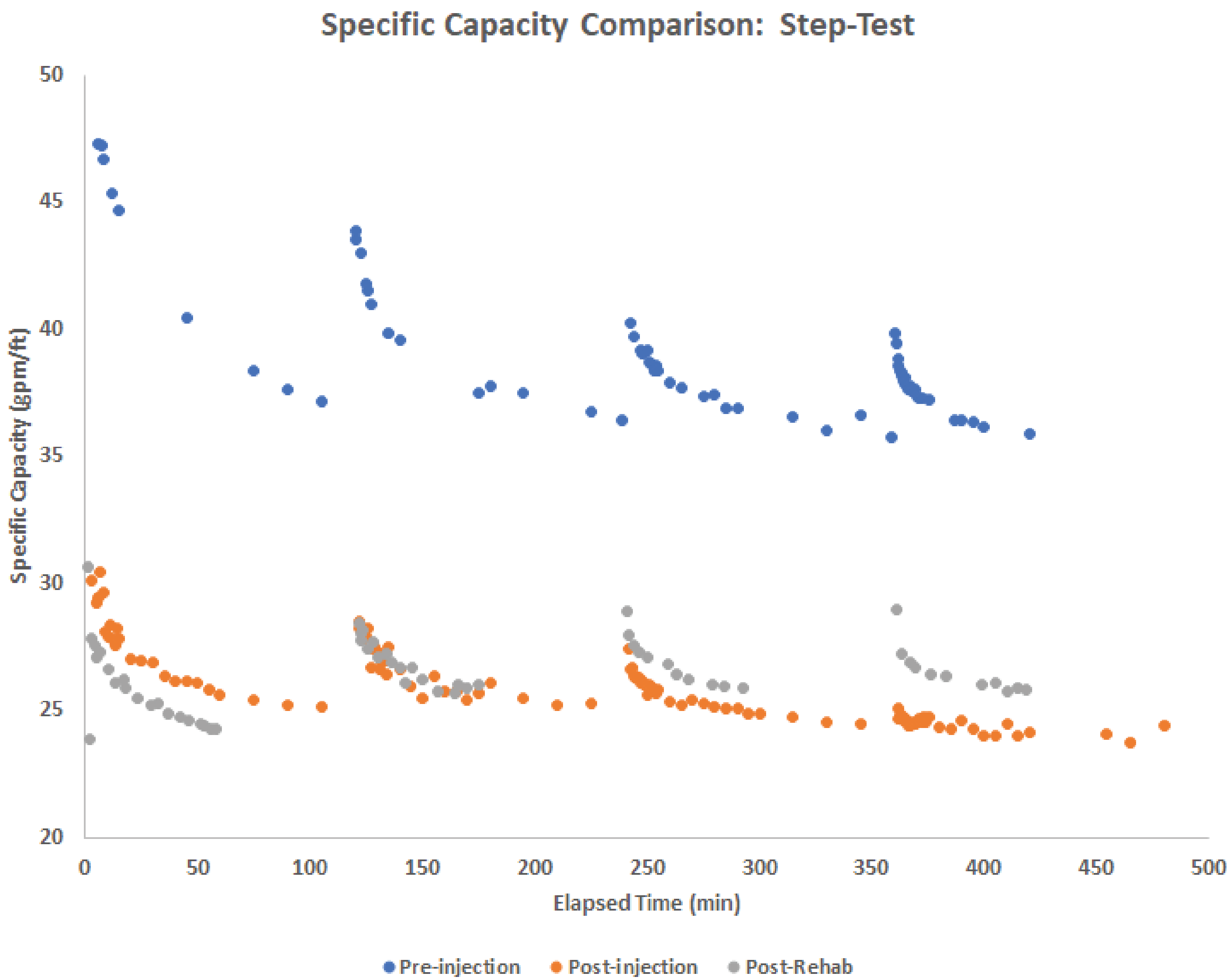
Figure 3-10



Explanation

-Pre-Injection data references baseline specific capacity measured in March 2021 during 8-hour step and 24-hour constant rate test.

-Post-injection data references specific capacity measured during 8-hour step and 24-hour constant rate test and performed after completion of the Recovery Phase in September 2021.

-Post-rehabilitation (rehab) data was collected in March 2022 as part of a 4-hour step-test performed after well rehabilitation.

Specific Capacity of LR-19 Throughout Testing Phases

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County, California

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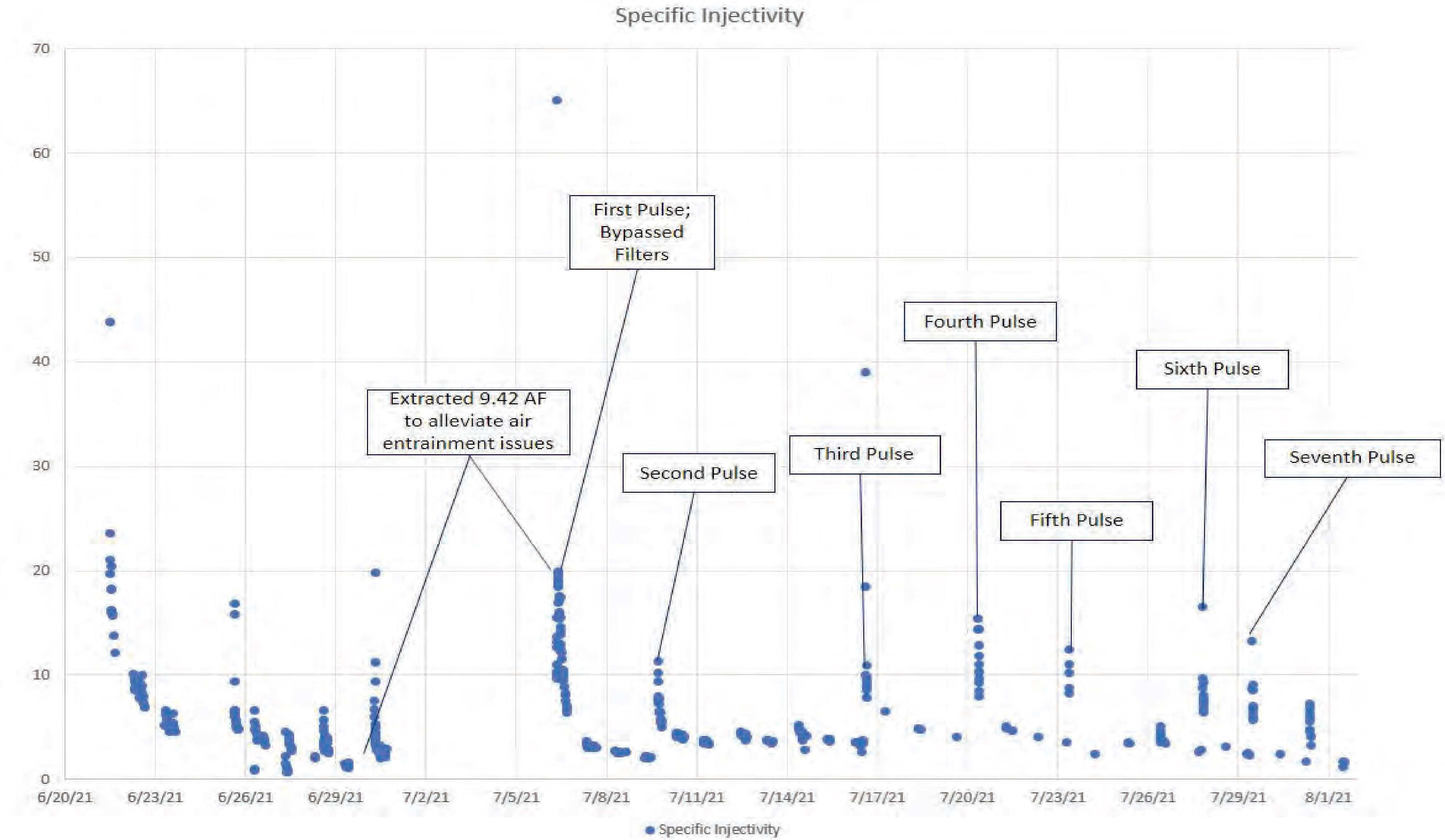
Figure **3-11**

Project No.: SAC229C | May 2022



Notes:

Specific injectivity refers to the rate of injection within the injection well (LR-19) per unit of uprise from static water levels.

Specific injectivity is plotted for the entirety of the injection phase including start-up operations that took place from June 21 to July 6, 2021. Start-up operations are discussed in Section 2.3.1.

Specific Injectivity of Well LR-19 During Injection Cycles

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Figure **4-1**

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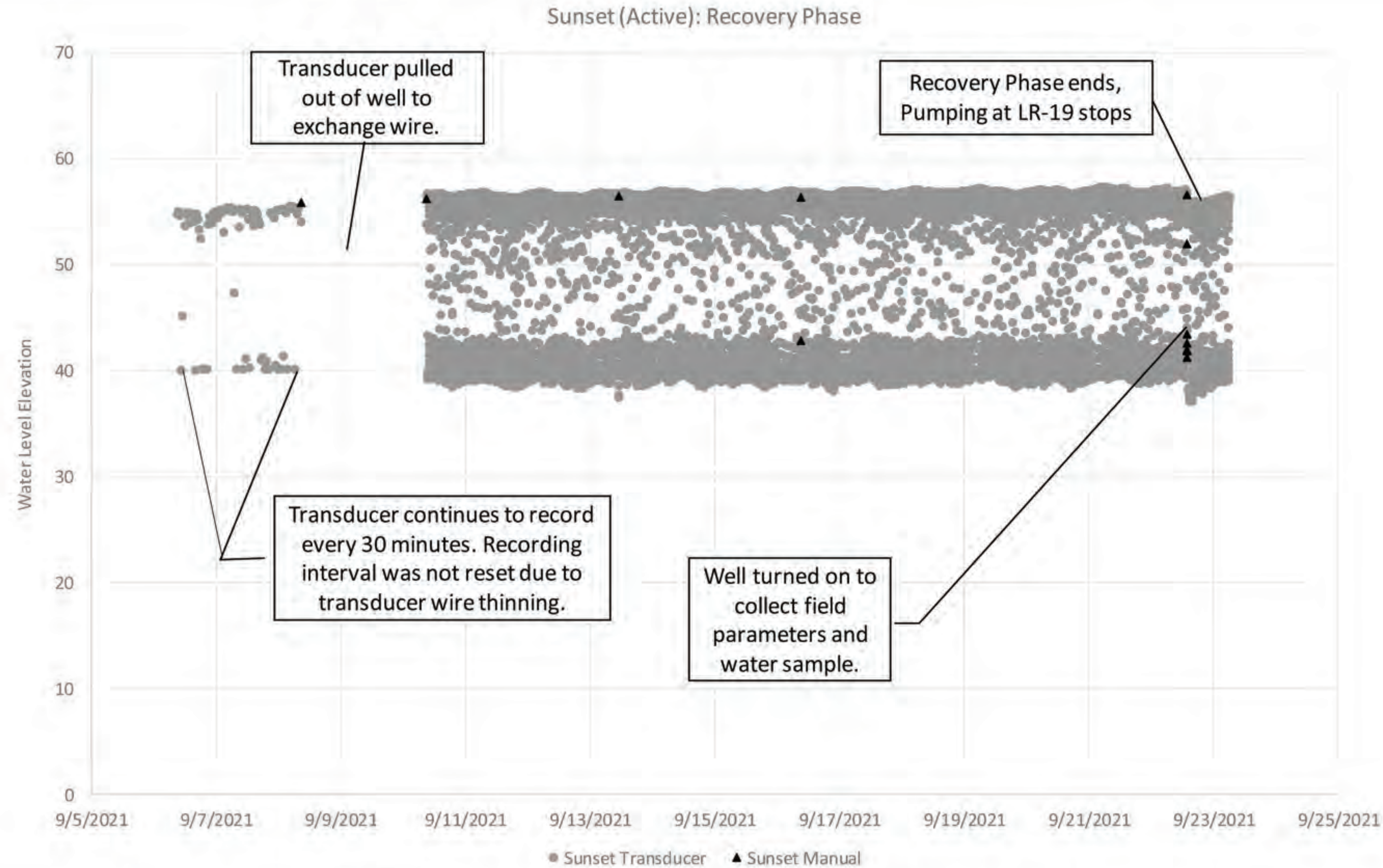

The ASR Pilot Test Recovery Phase began on 9/6/2021 at 8:05 and ended on 9/22/2021 at 15:25. The above hydrograph depicts data within the Recovery Phase and several hours after extraction ended. Water levels are presented until the start of the September 23rd pump test.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in Sunset During Recovery

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South Fork Kings GSA
Tulare Lake Subbasin, Kings County

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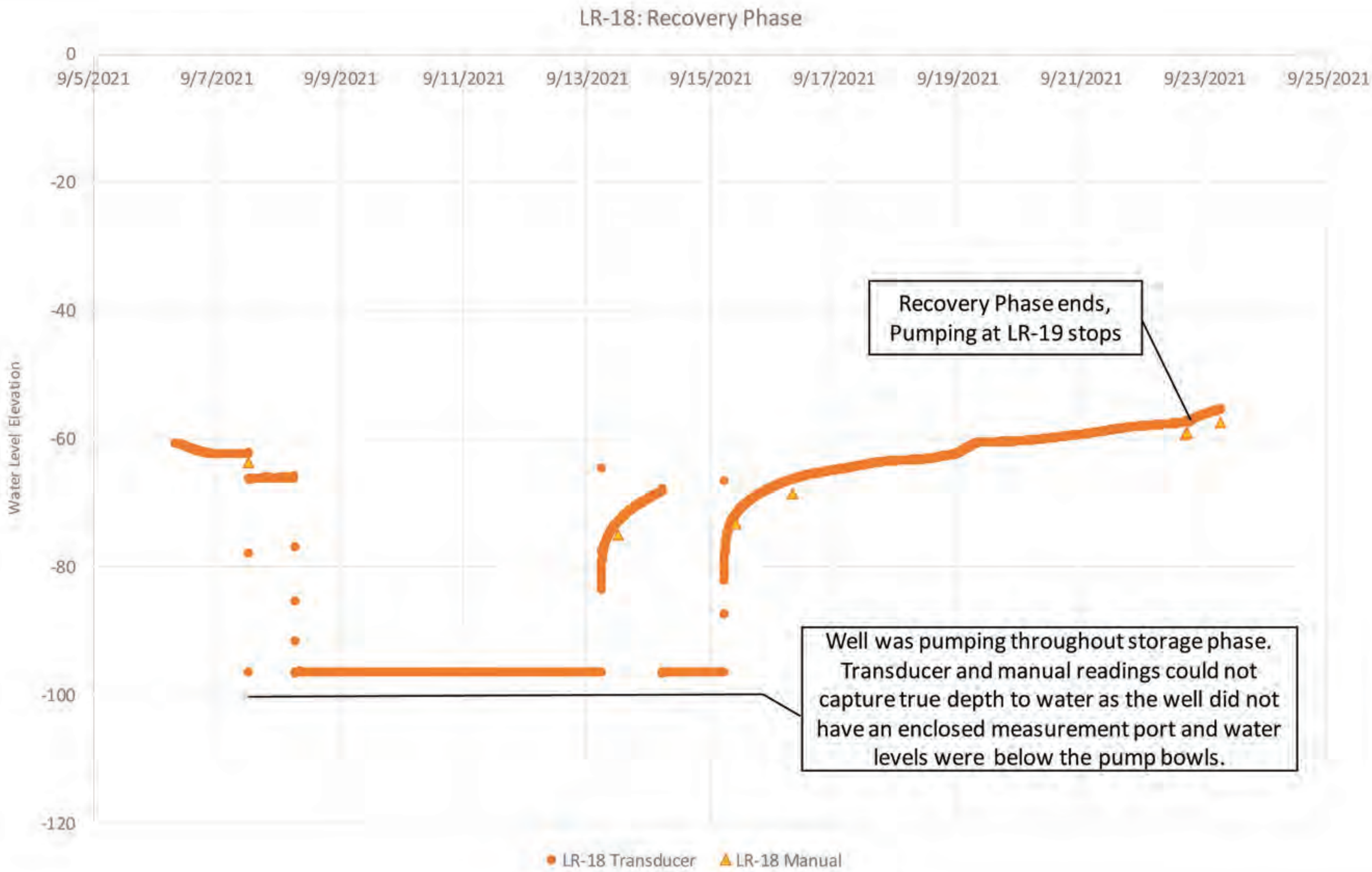
Figure 3-6a

Project No.: SAC229C | December 2021



The ASR Pilot Test Recovery Phase began on 9/6/2021 at 8:05 and ended on 9/22/2021 at 15:25. The above hydrograph depicts data within the Recovery Phase and several hours after extraction ended. Water levels are presented until the start of the September 23rd pump test.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in LR-18 During Recovery

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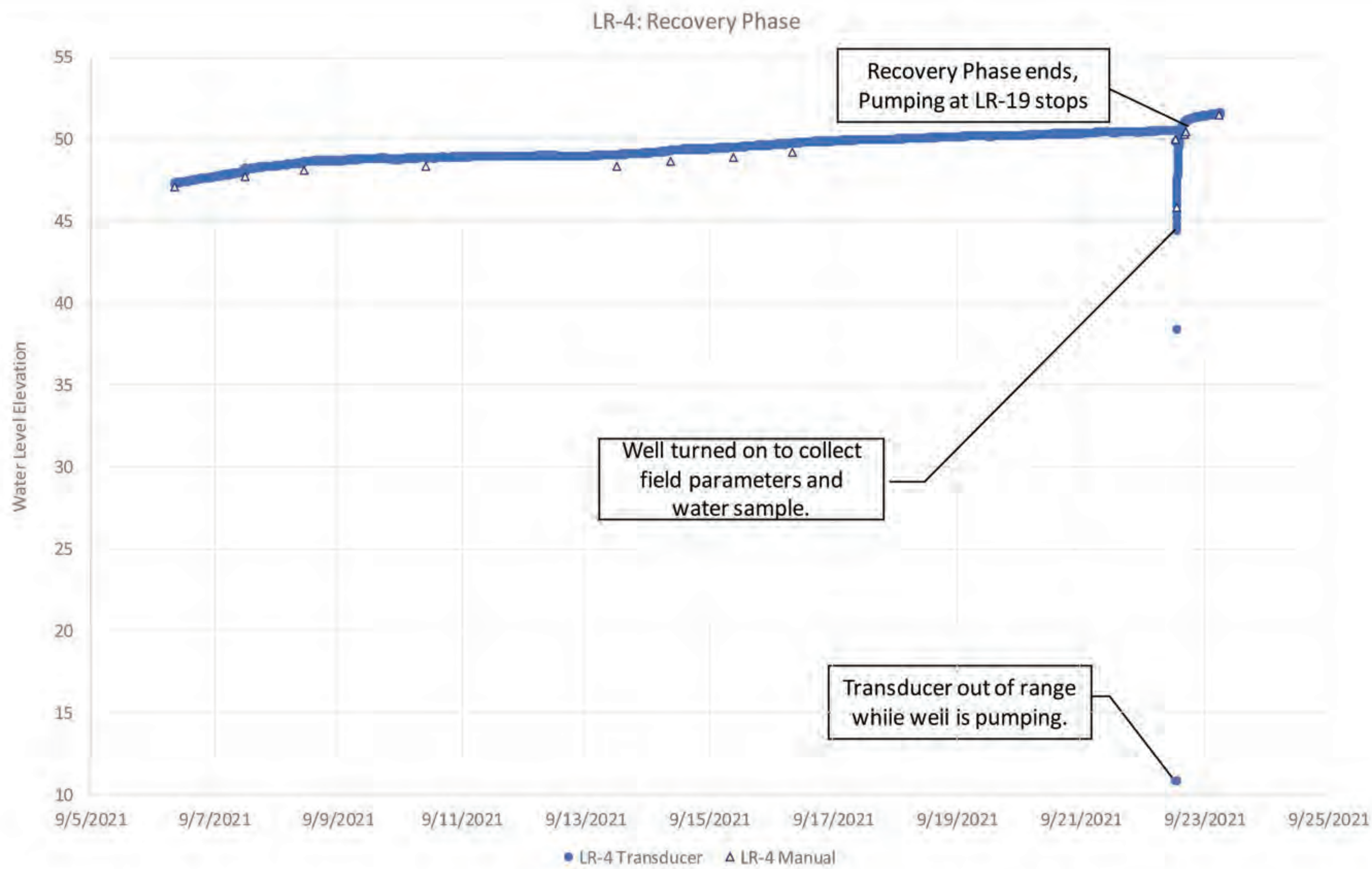
Figure 3-6b

Project No.: SAC229C

December 2021



The ASR Pilot Test Recovery Phase began on 9/6/2021 at 8:05 and ended on 9/22/2021 at 15:25. The above hydrograph depicts data within the Recovery Phase and several hours after extraction ended. Water levels are presented until the start of the September 23rd pump test.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in LR-4 During Recovery

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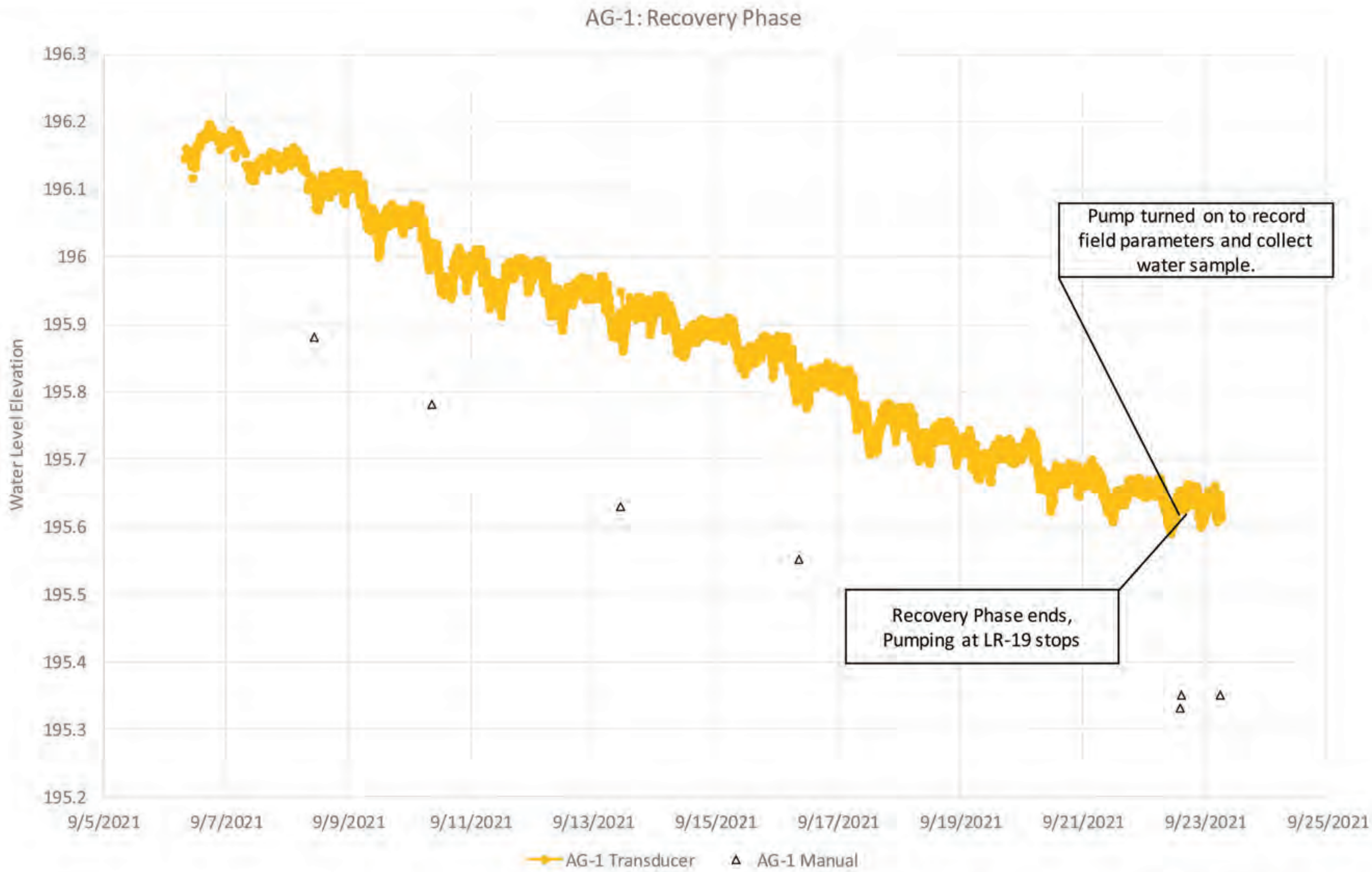
Figure 3-6c

Project No.: SAC229C

December 2021



The ASR Pilot Test Recovery Phase began on 9/6/2021 at 8:05 and ended on 9/22/2021 at 15:25. The above hydrograph depicts data within the Recovery Phase and several hours after extraction ended. Water levels are presented until the start of the September 23rd pump test.

Hydrographs include recorded readings using a pressure transducer (Transducer) and hand measurements using an electric tape sounder (Manual).

Water-Level Hydrographs in AG-1 During Recovery

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Figure 3-6d

Project No.: SAC229C | December 2021