SUMMARY OF OPERATIONS

BELTZ 12
ASR PILOT TEST PROJECT

SANTA CRUZ ASR PROJECT
PHASE 2 FEASIBILITY INVESTIGATION

Prepared for:

SANTA CRUZ WATER DEPARTMENT

JUNE 2020

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PUEBLO
water resources

June 5, 2020
Project No. 15-0112

Santa Cruz Water Department
212 Locust Street, Suite C
Santa Cruz, California 95060

Attention: Mr. Isidro Rivera, Associate Civil Engineer

Subject: Santa Cruz ASR Project; Beltz 12 ASR Pilot Test Summary of Operations Report

Dear Isidro:

We are transmitting one hard copy and a digital image (PDF) of the subject report documenting the operations and findings developed from the Beltz 12 ASR Pilot Test Project. The project was the initial step of Phase 2 of the Santa Cruz Water Department's (SCWD) investigation of Aquifer Storage and Recovery (ASR) in the Santa Cruz Mid-County Groundwater Basin (MCGB). Overall, the pilot test project was a success and generally verified the findings of the Phase 1 Technical Feasibility Investigation regarding the Beltz 12 well.

A total volume of approximately 20.8 million gallons (mg) of Graham Hill Water Treatment Plant (GHWTP) product water from the SCWD distribution system was injected into the Purisima Aquifer of the MCGB at rates ranging between approximately 375 to 405 gallons per minute (gpm) and approximately 24.5 mg was recovered from the aquifer at rates ranging between approximately 405 to 700 gpm. During injection, well plugging rates were relatively low, and no adverse geochemical interactions were observed during aquifer storage or recovery pumping. The favorable results of the ASR pilot test program support converting the Beltz 12 well into a permanent ASR facility. Analysis of the pilot testing results indicates a long-term operational ASR capacity of approximately 335 gpm injection and 455 gpm extraction/recovery pumping (equivalent to approximately 0.48 and 0.65 mgd, respectively).

We appreciate the opportunity to provide ongoing assistance to the SCWD on this important community water-supply project. Please contact us with any questions.

Sincerely,

PUEBLO WATER RESOURCES, INC.

Robert C. Marks, P.G., C.Hg.
Principal Hydrogeologist

Copies submitted: 1 hard, 1 digital (PDF)

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (continued)

TABLES

FIGURES

FIGURES (continued)

APPENDICES

INTRODUCTION

GENERAL STATEMENT

Presented in this report is a summary of operations and analysis of well and aquifer water-level and water-quality data developed from an Aquifer Storage and Recovery (ASR) pilot test project implemented at the Santa Cruz Water Department's (SCWD) Beltz 12 Well, located at 2750 Research Park Drive, Soquel, California. The location of the project site is shown on **Figure 1**. The project generally involved cyclic recharge, storage and subsequent recovery of treated drinking water originating from the SCWD's Graham Hill Water Treatment Plant (GHWTP) into the Purisima Aquifer system within the Santa Cruz Mid-County Groundwater Basin (MCGB) via injection and extraction/pumping at Beltz 12. The overall goal of the project was to verify the findings from the Phase 1 ASR Technical Feasibility Analysis and to empirically determine site-specific hydrogeologic and water-quality factors that will allow a technical and economic assessment of a permanent ASR operation at the site.

BACKGROUND

ASR is a form of managed aquifer recharge (MAR) that involves the enhanced conjunctive use of surface water and groundwater resources to "bank" water in an aquifer during times when excess surface water is available for storage (typically wet periods) and subsequent recovery of the water from the aquifer when needed (typically dry periods). ASR utilizes dual-purpose injection/recovery wells for the injection of water into aquifer storage and the subsequent recovery of the stored water by pumping. In order to feasibly implement ASR, the following four basic project components are required:

1. A supply of excess surface water for injection;
2. A system for the diversion, treatment and conveyance of water between the source and groundwater storage basin;
3. A suitable groundwater basin with available storage space; and,
4. Wells to inject and recover the stored water.

As applied to Santa Cruz, ASR involves the diversion of "excess" winter and spring flows from SCWD's North Coast sources and the San Lorenzo River (SLR), treated to potable standards at the Graham Hill Water Treatment Plant (GHWTP), then conveyed through the existing (and/or improved) water distribution system(s) to ASR wells located in the MCGB and/or the Santa Margarita Groundwater Basin (SMGB). In this context, "excess" flows are those flows that exceed SCWD demands, meet in-stream flow requirements and are within water rights.

As a consultant to the Water Supply Advisory Committee (WSAC) Technical Team, Pueblo Water Resources, Inc. (PWR) developed an implementation strategy for the ASR element of the Water Supply Augmentation Plan that consisted of three phases:

- **Phase 1 – Technical Feasibility Analyses**: Performance of detailed technical feasibility investigations, including the use of groundwater modeling, completion of site-specific injection capacity and geochemical interaction analyses, and development of a pilot ASR testing program.

- **Phase 2 – ASR Pilot Testing**: Performance of pilot ASR testing programs and assessments of probable ASR system performance, cost and schedule to complete build-out of the ASR system.
- **Phase 3 – Project Implementation**: Development of full-scale ASR project basis-of-design, construction of ASR system facilities (perhaps incrementally), establishment of ASR project operational parameters, and long-term operation of project to achieve target storage volumes.

The Phase 1 investigation is still ongoing as of this writing (the majority of outstanding work is in the groundwater modeling task); however, the findings developed thus far have been documented in task-specific Technical Memoranda (TM)[1] presented to the SCWD, and the key Phase 1 findings related to Beltz 12 are summarized below:

- Task 1.1 – Existing Well Screening identified SCWD's Beltz 12 Well as the preferred existing well for conducting ASR pilot testing of the AA and Tu Units of the western Purisima Aquifer system of the MCGB.
- Task 1.2 – Site-Specific Injection Capacity Analysis resulted in an estimated maximum long-term injection capacity for Beltz 12 of approximately 440 gallons per minute (gpm, equivalent to approximately 0.63 million gallons per day [mgd]).
- Task 1.3 – Geochemical Interaction Analysis indicated that there is limited potential for adverse geochemical reactions as a result of injecting treated SLR water at Beltz 12 (assuming GHWTP pH is maintained at less than 7.6); additionally, the potential for beneficial reduction of manganese concentrations in the recovered waters (relative to native groundwater) was identified and to be investigated further during the ASR pilot test program.
- Task 1.4 – Phase 2 ASR Pilot Testing Work Plan for Beltz 12 was prepared, which included detailed descriptions of the following:
    - Permitting Requirements
    - Site Preparation Details

[1] Pueblo Water Resources, Inc. (November 2016), *Task 1.1 Existing Wells Screening*, Technical Memorandum prepared for Santa Cruz Water Department (revised draft).

Pueblo Water Resources, Inc. (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.

Pueblo Water Resources, Inc. (August 2017), *Geochemical Interaction Analysis (Task 1.3)*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

Pueblo Water Resources, Inc. (April 2018), *Task 1.4 ASR Pilot Test Work Plan for Beltz 12*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

- ASR Pilot Test Program
- Sampling and Analysis Plan
- Preliminary Project Schedule

Based on the favorable results of the Phase 1 Technical Feasibility Investigation to date, the SCWD is advancing the ASR investigation to Phase 2 ASR Pilot Testing in the MCGB at the Beltz 12 Well while the Phase 1 groundwater modeling of full-scale ASR projects continues on a parallel track. The overall objective of the Phase 2 pilot testing is to field verify the findings developed from Phase 1 and empirically determine site-specific hydrogeologic and water-quality factors that will allow a technical and economic viability assessment of ASR technology in this area of the MCGB. If feasible, the data gathered may also be used to complete CEQA documentation and permitting for a full-scale permanent ASR project.

PURPOSE AND SCOPE

The primary purpose of the Beltz 12 ASR Pilot Test Program is to field demonstrate the potential application of ASR in the AA and Tu Units of the Purisima Aquifer system in the MCGB. The data will be used to assess both the economic and logistical viability of ASR and will provide the basis for the design, environmental planning, and permitting for a long-term full-scale ASR project in the area.

The scope of work essentially consisted of implementing the ASR Pilot Test Work Plan that was developed for Beltz 12 as part of Task 4 of the Phase 1 investigation, which is presented in **Appendix A** for reference. The scope of work consisted of the following main tasks:

1. Project permitting assistance
2. Site preparation
3. Implementation of ASR Cycle Testing Program
4. Data collection, analysis and reporting
5. Project management and meetings

The findings developed from the Beltz 12 ASR Pilot Test Program are presented in the following section.

FINDINGS

HYDROGEOLOGIC SETTING

The Beltz 12 Well site is located in the western portion of the Santa Cruz Mid-County Groundwater Basin (MCGB). The Purisima Aquifer constitutes the western portion of the MCGB (the eastern portion of the MCGB consists of the Aromas Aquifer, which is connected to the Pajaro Valley Groundwater Basin and is not currently under consideration for an ASR project). The hydrogeology of the Purisima Aquifer has been documented in detail in reports prepared by the United Stated Geological Survey (USGS), the California Department of Water Resources (DWR), and various individual consultants and consulting firms. These documents describe the stratigraphy, structure, and hydraulic characteristics of the regional aquifer systems. The most recent comprehensive study was prepared for the Soquel Creek Water

District (SqCWD) by Johnson, et al, (2004), which synthesizes more than 35 years of previous investigations and forms the primary basis for the description presented herein.

As described, the Purisima Aquifer consists of several distinct zones within the geologic Purisima Formation (Tp). The Purisima Formation is a consolidated to semi-consolidated marine sandstone with siltstone and claystone interbeds and an uneroded thickness of approximately 2,000 feet. The Purisima Aquifer has been subdivided by Johnson (2004) into hydrostratigraphic units (from youngest to oldest, Aquifers F through Tu) for purposes of conceptualizing the distribution of hydrogeologic properties and pumping stresses. Underlying the Purisima Formation are older sedimentary formations, the presence of which varies depending on location. The Monterey Formation and Santa Cruz Mudstone are essentially non-water bearing; however, the Butano, Lompico and Santa Margarita Sandstones serve as productive aquifers in other areas (e.g., Scotts Valley and Seaside Groundwater Basin in Monterey) and constitute a lower extension of the Purisima Aquifer (the Tu Unit) in the Beltz wellfield area.

Site Hydrostratigraphy

The hydrostratigraphy of the Beltz 12 site is well established from the lithologic and geophysical logs from the well. Review of the geophysical logs in conjunction with the lithologic logs for the subject wells suggests the following stratigraphic interpretation:

Table 1. Site Hydrostratigraphy

Hydrostratigraphic Unit[1]	Depth (feet bgs)	Thickness (feet)
Aquifer A	0 – 60	60
Aquifer AA	60 - 470	410
Aquitard "Tp?"	470 - 550	80
Aquifer Tu	550 to 660	110

Notes:
1 – Designations based on Johnson (2004)

Due to the dip in the formation, only remnants of the Purisima Formations lower-most strata occur within the SCWD service area, and the younger Aquifers F through B stratigraphic units are not present at the Beltz 12 Well site.

As-Built Well Construction

Beltz 12 was constructed in 2012 under the supervision of a PWR California Professional Geologist / Certified Hydrogeologist. An as-built schematic of the well is presented on **Figure 2** and a summary of the as-built well construction features of the well is presented below in **Table 2**:

Table 2. As-Built Well Construction Summary

Design Feature	As-Built	Comment
Total Well Depth (ft bgs)	650	
Seal Depth (ft bgs)	150	10.5-sack cement sand slurry
Casing Material	Stainless Steel	16-inch Blank and Screen
Screen Intervals (ft bgs)	200 - 290	Aquifer AA
	310 - 390	
	410 - 470	
	550 - 640	Aquifer Tu
Total Screen Length (feet)	320	
Perforation Aperture	0.040-inch slots	Stainless Steel Wire-Wrapped
Gravel Pack (gradation)	8 x 16	Carmeuse Industrial Sands
Cellar Section (ft bgs)	640 - 650	

PERMITTING

Injection operations during the Beltz 12 ASR pilot test program were authorized under State Water Resources Control Board (SWRCB) General Waste Discharge Requirements for Aquifer Storage and Recovery Projects that Inject Drinking Water into Groundwater (Water Quality Order 2012-0010). A Notice of Intent (NOI) package was prepared by PWR and submitted by the SCWD to the Central Coast Regional Water Quality Control Board (RWQCB) on November 8, 2018 and the project was authorized via a Notice of Applicability (NOA) letter from the Central Coast RWQCB, dated January 16, 2019.

Discharges during the pilot test program were sent to the municipal storm drain system via the Beltz facility on-site storm drain inlet, and were performed under the existing SWRCB Statewide NPDES Permit for Drinking Water System Discharges to Waters of the United States (Order WQ 2014-0194-DWQ, General Order No. CAG140001), which the SCWD was previously enrolled.

SITE PREPARATION

Temporary modifications to the Beltz 12 well facility required for implementation of the ASR pilot test program were installed between November 27 and December 7, 2018 by Maggiora Bros Drilling, Inc (Maggiora) under subcontract to PWR, and generally consisted of the following activities:

- Removal of SCWD's existing 75 HP submersible pump assembly from the well
- Performance of a pre-testing downhole video survey
- Fabrication of a special temporary well head seal plate to accommodate a test pump, injection drop tubes and sounding tubes

- Installation of a 75 HP submersible test pump
- Installation of three injection drop tubes and two water-level sounding tubes
- Installation of temporary piping, valving, metering and storage tanks to route injection supply water to the well and discharge water from well to storm drain inlet and/or temporary storage tanks
- Removal of test pump and injection drop tubes from the well
- Performance of post-testing downhole video survey
- Reinstallation of SCWD's existing 75 HP submersible pump assembly
- Disinfection of the well and pump assembly in accordance with State Well Standards

The existing 75 HP submersible pump was removed from the well on November 27, 2018, and a pre-testing downhole video survey of the well was performed by Newman Surveys. The primary purpose of the video survey was to document pre-testing well structural conditions. The video showed that the well screens were mostly clear and open, with some moderate plugging of the lower-most screen section between approximately 550 and 640 feet below ground surface (bgs), with damage to the screen or casing observed. The pre-testing video survey report is presented in **Appendix B**.

A 75 HP submersible test pump was installed to a depth of approximately 293 feet bgs, with the pump intake placed in the blank casing section just below the upper screen interval. Three 2-inch-diameter schedule 40 PVC injection drop tubes were installed to depths of approximately 291 ft bgs. The bottom of each injection tube was fitted with a fixed-orifice end cap of a specific size (orifice sizes were 0.75, 1.10 and 1.50 inches diameter), which allowed positive pressures to be maintained within the piping system and drop tubes at all times during injection testing at variable rates to prevent water cascading in the well (which can lead to gas-binding and plugging of the well screen).

Maggiora furnished and installed temporary PVC injection and discharge water piping from the wellhead, a flow meter, several valves, pressure gages, and other appurtenances. The 2-inch-diameter injection drop tubes were connected to a 4-inch-diameter PVC manifold that was connected to the on-site 4-inch-diameter reduced pressure (RP) backflow preventer, which was connected to the SCWD municipal water supply pipeline located in Research Park Dr. Pressure gages were installed at the wellhead on each injection tube and at various points in the temporary piping system. Maggiora also installed temporary 6-inch-diameter PVC discharge piping from the wellhead to two interconnected 21,000-gallon settling tanks, with 4-inch-diamter PVC piping installed from the second settling tank to the on-site storm drain inlet.

ASR PILOT TEST SUMMARY OF OPERATIONS

ASR operations generally consist of three steps:

1. Injection of potable-quality drinking water into the aquifer;
2. Storage of the injected/recharged water within the aquifer, and;
3. Recovery of the stored water.

The structure of the ASR pilot test program included numerous incremental steps of ASR operations to provide multiple checkpoints in the event that pilot operations deviate significantly from the predicted responses. The test program generally involved three repeated ASR cycles of operations and monitoring, each of larger volume and duration than the preceding cycle, so that if adverse conditions were encountered at any point, the program could be adjusted.

The primary purpose of the ASR pilot testing was to demonstrate injection well hydraulics and operational performance characteristics of Beltz 12 and to monitor the local aquifer hydraulic and geochemical responses to recharge and recovery operations. These data can then be used to both assess the economic and logistical viability of ASR and as a basis for environmental planning and permitting documentation for a long-term, full-scale ASR project.

The primary issues investigated can be generally categorized into two areas of investigation:

1. Well and Aquifer Hydraulics:
    - Determination of injection well efficiency and specific capacity.
    - Evaluation of injection well plugging rates (both active and residual).
    - Determination of optimal rates, frequency, and duration of backflushing in order to maintain long-term injection capacity.
    - Determination of long-term sustainable injection rates.
    - Determination of local aquifer response to injection at the Beltz 12 site.
2. Water Quality:
    - Monitor geochemical reaction mechanisms.
    - Evaluate water quality changes during storage.
    - Monitor recovery efficiency.
    - Monitor injected water quality stability and equalization in the aquifer.
    - Monitor THM and HAA fate.
    - Quantify aquifer mixing/dispersion parameters.
    - Monitor recovered water ‘post extraction’ for re-chlorination and THM/HAA reformation.

Summary of ASR Cycles

The ASR pilot test program generally consists of a pre-ASR baseline pumping performance test, a 1-day hydraulic “pre-test” to establish injection system hydraulics, followed by three (3) repeated cycles of injection-storage-recovery, with each cycle of greater duration and volume. A robust dataset of aquifer response and water quality information will be developed, while minimizing the risk of adverse effects to the well or aquifer system. It is noted that ASR Cycles 1 and 2 included recovery volumes that were approximately 150 to 175 percent of the injection volumes in order to recover a sufficient volume to assess the degree of mixing between the injected water and native groundwater in the recovered water. As discussed in the

Site-Specific Injection Capacity TM[2], under current conditions the aquifer system at the site is theoretically capable of supporting a long-term continuous injection rates of approximately 400 gallons per minute (gpm). The testing program was designed around this rate, and is summarized in **Table 3** below:

Table 3. ASR Pilot Test Program Summary

ASR Cycle	ASR Phase	Dates / Times		Duration (days)	Total Volume		Avg Rate	
		Start	End		(gals)	(af)	(gpm)	(mgd)
Baseline Performance Test	Pre-ASR	12/14/18 13:00	12/14/18 15:00	0.08	84,173	0.26	701	1.01
Injection System Pre-Test	Injection	1/17/19 15:00	1/17/19 16:30	0.06	10,008	0.03	111	0.16
1	Injection	1/18/19 9:15	1/19/19 9:15	1.00	582,542	1.79	405	0.58
	Storage	1/19/19 9:15	1/21/19 9:30	2.01	--	--	--	--
	Recovery	1/21/19 9:30	1/22/19 9:30	1.00	1,009,870	3.10	701	1.01
2	Injection	1/23/19 10:50	1/30/19 10:50	7.00	3,942,214	12.10	391	0.56
	Storage	1/30/19 10:50	2/19/19 16:30	20.24	--	--	--	--
	Recovery	2/19/19 16:30	2/25/19 13:30	5.88	5,914,773	18.15	699	1.01
3	Injection	3/6/19 15:30	4/5/19 15:35	30.00	16,256,553	49.89	376	0.54
	Storage	4/5/19 15:35	7/1/19 9:00	86.73	--	--	--	--
	Recovery	7/1/19 9:00	7/31/19 9:00	30.00	17,596,241	54.00	407	0.59
Total Injection Duration (days):			38.07					
Total Extraction Duration (days):			36.96					
Cummulative Total Injection Volume (af):			63.81					
Cummulative Total Extraction Volume (af):			75.51					
Cummulative Total Net Volume (af):			-11.70					

In addition, the well was thoroughly backflushed following each of the injection tests to limit residual plugging of the well due to injection and assess the efficacy of well backflushing (discussed in a following section).

The primary test objectives for each ASR Cycle are summarized below:

ASR Cycle 1

- Establish short-term injection hydraulics
- Monitor short-term ion exchange reactions

ASR Cycle 2

- Measure well plugging rates (active and residual)
- Evaluate backflushing efficacy
- Monitor longer-term ion exchange reactions
- Monitor redox reactions
- Evaluate water chemistry changes during storage

[2] Pueblo Water Resources, Inc. (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.

- Monitor recovery efficiency (the percentage of recharged water that is recovered during each cycle)
- Monitor Disinfection Byproducts (DBP's) during recovery
- Define volume of potential "buffer zone" around ASR well

ASR Cycle 3

- Evaluate longer-term well performance and plugging rates
- Monitor injected water quality stability during storage
- Monitor DBP ingrowth/degradation during storage and recovery
- Monitor recovery efficiency (the percentage of recharged water that is recovered during each cycle)

Procedures and Monitoring Program

Injection feed water was potable water provided from the SCWD distribution system. Injection rates were controlled by several butterfly valves on the temporary piping system and ball valves on the injection drop tubes. Injection flow rates and total injected volumes were measured with a totalizing meter. Injection operations were performed through three 2-inch-diameter Schedule 40 PVC drop tubes fitted with fixed orifice caps at the bottom of each tube. Positive pressures were maintained within the piping system and drop tubes during injection testing to prevent water cascading and cavitation in the well. Field data sheets collected during the course of the testing program are presented in **Appendix C**.

Water levels in Beltz 12, the on-site Cory St. monitoring wells, and several offsite monitoring wells owned by both the SCWD and SqCWD were measured during the testing program with pressure transducer data loggers and were periodically verified with a manual electric sounder. The locations of the project wells are shown on **Figure 3**. A summary of the construction details of the test program wells is presented in **Table 4** below. Water-level data collected from the project wells during the course of the ASR pilot test program are shown on **Figures 4 through 10**. Water-level data collected during each phase of the test program are presented and discussed in more detail in following sections.

Pre-Injection Pumping Performance Test

An initial pre-injection pumping performance test was conducted on December 14, 2018 to establish baseline well performance. The performance test was limited to an approximate 100-minute constant rate discharge test. A 100-minute duration test (approximately three measurable log-cycles) was performed because the long-term response of a well is a logarithmic function, and a pumping test of this duration is sufficient to document well performance (i.e., specific capacity).

Throughout the test, water levels in the pumping well were measured and recorded using the transducer and data logger, and the discharge rate was measured using the totalizing flow meter. The static water level in the well prior to pumping was approximately 93.8 feet below top of casing (btoc). The discharge was maintained at an average rate of approximately 701 gpm during the test. The pumping level after 100-minutes was approximately 167.7 feet btoc, corresponding to a drawdown of 73.9 feet, and a 100-minute baseline specific capacity of approximately 9.49 gallons per minute per foot of drawdown (gpm/ft).

Table 4. Project Well Construction Summary

Well	Distance from Beltz 12 (ft)	Depth (ft bgs)	Dia (in)	Screen Intervals (ft bgs)				Tp Unit(s) Completed
Beltz 12	--	650	16	200 - 290	310 - 390	410 - 470	550 - 640	AA - Tu
Cory St	75							
shallow		110	2	70 - 110				A (lower)
medium		240	2	200 - 240				AA (upper)
deep		350	2		310 - 350			AA (lower)
#4		650	2.5				550 - 640	Tu
O'Neill Ranch *	1670	655	16	200 - 300	340 - 420	470 - 540	550 - 650	AA - Tu
Coffee Ln Park	2250							
shallow		150	2	110 - 150				A
deep		250	2		210 - 250			AA
Auto Plaza	2490							
medium		290	2	250 - 290				A (lower)
deep		430	2		380 - 430			AA
SC-22 **	3250							
shallow		240	2	150 - 230				A
medium		500	2		460 - 490			AA (upper)
deep		705	2			640 - 700		AA (lower)
30th Ave	4640							
shallow		240	2	200 - 240				A
medium		410	2		370 - 410			AA
deep		800	2.5			720 - 740	780 - 800	Tu
Notes:								
Tp - Purisima Formation								
* - SqCWD production w ell								
** - SqCWD monitoring w ell								

Injection Hydraulics Pre-Test

An injection hydraulics pre-test was performed on January 17, 2019. The purpose of the pre-test was to establish well and injection system hydraulic relationships prior to initiating the formal ASR pilot test program. The pre-test generally consisted of initiating injection with each of the three injection tubes for periods of 20 minutes each over a range of flow rates and drop tube head pressures. The resulting hydraulic relationships are summarized in **Table 5** below:

Table 5. Injection Hydraulics Pre-Test Summary

Drop Tube Orifice (in dia)	Rate (gpm) vs. Pressure	
	10 psi	30 psi
0.8	90	105
1.1	140	165
1.5	205	245

As shown, injection rates for each tube ranged between approximately 90 to 105 gpm, 140 to 165 gpm, and 205 to 245 gpm with the 0.8-, 1.1- and 1.5-in-diameter tubes, respectively, over drop tube head/driving pressures of 10 to 30 pounds per square inch (psi) on each.

ASR Cycle 1 Injection

Following termination of the injection hydraulics pre-test, backflushing (discussed in a later section) and a period of water level recovery, ASR Cycle 1 Injection Test was initiated on January 18, 2019 and continued until January 19, 2019. This phase of testing consisted of a continuous rate injection test performed at an average injection rate of approximately 405 gpm, with a total volume of approximately 0.583 million gallons (1.79 acre-feet) injected.

Water-level data for ASR Cycle 1 Injection Test are graphically presented on **Figure 11**. As shown, the static water level in the well prior to injection was 95.2 feet below ground surface (bgs). During injection, maximum drawup in the well was approximately 65.3 feet, corresponding to a 24-hr specific injectivity of approximately 6.20 gpm/ft. Also apparent in the water-level data are the effects of diurnal pressure variations in the SCWD distribution system, which affected the injection rate and water-level response. During injection, the system pressures were observed to fluctuate by approximately 4 to 6 psi, which corresponded to variations in the driving head/pressure at the injection drop tubes and in the injection rate of approximately 20 gpm. The effects of distribution system pressure fluctuations on injection rates and water levels were more noticeable during the longer duration ASR Cycles 2 and 3, discussed in following sections.

ASR Cycle 1 Recovery

Following a 2-day period of aquifer storage, ASR Cycle 1 Recovery Test was initiated on January 21 and continued until January 22, 2019. The discharge rate was maintained at an average rate of approximately 701 gpm during the 1-day test and a total volume of 1.01 million gallons (3.10 acre-feet) was extracted, equivalent to approximately 170 percent of the previously injected volume.

Water-level data for ASR Cycle 1 Recovery Test are graphically presented on **Figure 12**. As shown, the static water level in Beltz 12 prior to pumping was approximately 90.6 feet bgs. The pumping level recorded after 100 minutes was approximately 161.9 feet, corresponding to a drawdown of 71.3 feet, and a 100-minute specific capacity of approximately 9.83 gpm/ft. This 100-minute specific capacity value is slightly greater (4 percent) than the pre-injection 100-minute specific capacity of 9.49 gpm/ft, indicating that backflushing was effective at removing any plugging particulates that were introduced into the well during the ASR Cycle 1 Injection Test and maintaining well hydraulic performance. The pumping level recorded after

24-hours was approximately 190.9 feet, corresponding to a drawdown of 100.3 feet, and a 24-hour specific capacity of approximately 6.99 gpm/ft.

ASR Cycle 2 Injection

Following termination of ASR Cycle 1 Recovery and a brief period of water-level recovery, ASR Cycle 2 Injection Test was initiated on January 23 and continued until January 30, 2019. This phase of testing consisted of a continuous rate injection test performed at an average injection rate of approximately 391 gpm, with a total volume of approximately 3.94 million gallons (12.1 acre-feet) injected

Water-level data for ASR Cycle 2 Injection Test are graphically presented on **Figure 13**. As shown, the static water level in the well prior to injection was 98.4 feet bgs. During injection, drawup in the well was approximately 63.5 and 82.9 feet after 24 hours and 7 days of injection, respectively, corresponding to specific injectivities of approximately 6.15 and 4.72 gpm/ft, respectively. The 24-hr value is essentially the same as the specific injectivity observed during the Cycle 1 Injection Test, indicating that backflushing of the well was effective and no residual plugging of the well occurred following the initial injection test.

Also apparent in the water-level data for the ASR Cycle 2 Injection Test are the effects of generally diurnal pressure fluctuations in the SCWD distribution system that were related to the intertie with SqCWD opening and closing in response to system demands, which resulted in fluctuations in the injection rate. In general, the incoming system pressure fluctuated between approximately 40 to 48 psi with corresponding fluctuations in the injection rate of 375 to 400 gpm, resulting in an average rate of approximately 390 gpm. As shown, although the injection rate and water-levels fluctuated somewhat on a diurnal basis over the course of the 7-day injection test, the range in injection rate fluctuations were relatively minor (approximately 6 percent of the average) and did not significantly affect the overall trend or slope of water-level drawup curve.

ASR Cycle 2 Recovery

Following an approximate 20-day period of aquifer storage, ASR Cycle 2 Recovery Test was initiated on February 19 and continued until February 25, 2019. The discharge rate was maintained at an average rate of approximately 699 gpm during the test and a total volume of 5.91 million gallons (18.2 acre-feet) was extracted, equivalent to approximately 150 percent of the Cycle 2 injected volume.

Water-level data for ASR Cycle 2 Recovery Test are graphically presented on **Figure 14**. As shown, the static water level in Beltz 12 prior to pumping was approximately 88.2 feet bgs. It is noted that this is approximately 10.2 feet higher than the static water level prior to ASR Cycle 2 Injection Test and after the subsequent Storage Period, reflecting the effects of the increased storage in the aquifer system. The pumping level recorded after 24-hours was approximately 191.7 feet, corresponding to a drawdown of 103.5 feet, and a 24-hour specific capacity of approximately 6.75 gpm/ft. This 24-hr specific capacity value is very slightly lower (approximately 3 percent) than the Cycle 1 Recovery Test 24-hour specific capacity of 6.99 gpm/ft, indicating that little residual plugging (discussed in more detail in a later section) of the well had occurred as result of the previous injection test. The final pumping level at the end of the approximate 6-day test was 206.8 feet bgs. It is noted that this pumping level is below the top of well screen located at approximately 200 ft bgs, indicating that 700 gpm is not a sustainable long-term pumping rate for Beltz 12 (discussed in more detail in a later section).

It is noted that response to the ASR Cycle 2 Recovery pumping was observed at Cory Medium, Deep and #4, with approximately 45.9, 61.5 and 76.3 feet of drawdown, respectively, observed at the end of the 6-day test. The Cory Shallow monitoring well again displayed a slight response during recovery pumping, with a total drawdown of approximately 1.4 feet at the end of the test, indicating that a small amount of vertical leakage may have occurred from the overlying shallow aquifer back into the underlying injection target aquifers.

ASR Cycle 3 Injection

Following termination of ASR Cycle 2 Recovery and a 9-day water-level recovery period, ASR Cycle 3 Injection Test was initiated on March 6 and continued until April 5, 2019. This phase of testing consisted of an essentially continuous rate injection test performed at an average injection rate of approximately 376 gpm, with a total volume of approximately 16.3 million gallons (49.9 acre-feet) injected. During the 30-day test, injection operations were briefly interrupted on a weekly basis for backflushing in order to limit plugging and maintain well performance.

Water-level data for ASR Cycle 3 Injection Test are graphically presented on **Figure 15**. As shown, the static water level in the well prior to injection was 94.3 feet bgs (a recovery level of approximately 95 percent). During injection, drawup in the well was approximately 63.0, 84.3 and 92.5 feet after 24 hours, 7 days and 30 days of injection, respectively, corresponding to specific injectivities of approximately 5.96, 4.46 and 4.07 gpm/ft, respectively. These 24-hr and 7-day specific injectivity values are approximately 3 to 6 percent less than those observed during the Cycle 2 injection test, indicating that the wells performance declined slightly due to residual plugging (as mentioned above and discussed in detail in a later section). Also shown is that the water level was within 5 feet of ground surface (at times exceeding ground level[3]) after the second week of injection following the initial backflushing event.

Post-Injection Video Survey and Performance Test

During the ASR Cycle 3 Storage Period, the temporary test pump and injection drop tube assembly was removed from the well on May 1, 2019. A post-injection testing downhole video survey was performed on May 2, 2019, to verify the structural integrity of the well and document the condition of the screen. The results did not show any significant changes from

[3] On March 24, 2019 the water-level was observed to exceed ground level and was approximately 1.06 feet below the top of casing (1.5 above ground surface); however, the injection rate had significantly increased at this time to approximately 418 gpm, which coincided with an approximate 10 psi *decrease* in drop tube pressure. The rate was subsequently reduced back down to the test average rate, and the water level declined down to approximately 6.87 feet below top of casing. The cause of this incident was discovered after removing the temporary injection drop tubes from the well after the test program was completed, and the 1.1-in-dia orifice cap was missing (i.e., had become detached from the bottom of the tube).

the pre-injection downhole conditions of the well. The post-injection video survey report is also presented in **Appendix B**.

SCWD permanent pump was reinstalled on May 7, 2019 and then the well was disinfected with sodium hypochlorite solution in accordance with State Well Standards. The chlorine was flushed from the well on May 8, 2019 and samples collected on May 9, 2019, which tested non-detect (absent) for both Total and Fecal Coliform.

The post-injection performance test was conducted on May 15, 2019. The static water level in the well prior to pumping was approximately 94.7 feet. The discharge was maintained at an average rate of approximately 702 gpm during the test. The pumping level after 100-minutes was approximately 173.1 feet, corresponding to a drawdown of 78.4 feet and a 100-minute post-injection specific capacity of approximately 8.95 gpm/ft. This compares to the pre-injection baseline performance test 100-minute specific capacity of approximately 9.49 gpm/ft, representing an approximate 6 percent decline in performance, indicating a slight amount of residual plugging had occurred; however, by the time ASR Cycle 3 recovery began, the residual plugging had been fully mitigated over the course of the remaining ASR Cycle 3 Storage Period sampling events.

ASR Cycle 3 Recovery

Following an approximate 87-day period of aquifer storage, ASR Cycle 3 Recovery Test was initiated on July 1 and continued until July 31, 2019. It is noted that the ASR Cycle 3 Storage Period was extended beyond the planned 60-day period. ASR Cycle 3 was originally planned to consist of 30 days of injection, 60 days of storage, and 30 days of recovery, with the delivery of the recovered water into the distribution system following treatment at the Beltz Treatment Plant. As discussed in the preceding section, the City's permanent pump was reinstalled and the well was successfully disinfected (as demonstrated by the May 9, 2019 sampling results) during the ASR Cycle 3 storage period. Based on the May 9th results, and additional confirmation sampling by the Water Department on May 29th and June 5th, initial approval was granted from the California Division of Drinking Water to turn the well into the system; however, because the well sat idle for several days prior to being turned into the system, the Water Department decided to obtain confirmation samples to ensure that bacterial results were still favorable. The results for this second round of bacterial sampling failed. PWR was not involved in the subsequent sampling or well disinfection attempts by the Water Department, and it is unclear what occurred at the well or during sampling collection to cause the subsequent sample results to fail. Because there was some uncertainty as to the cause of the positive bacterial results, recovered water from ASR Cycle 3 was not turned into the system as planned, and instead of all of the ASR Cycle 3 recovered water was sent to the storm drain system. Nonetheless, the discharge rate was maintained at an average rate of approximately 407 gpm during the test as planned, and a total volume of 17.6 million gallons (54.0 acre-feet) was extracted, equivalent to approximately 108 percent of the Cycle 3 injected volume.

Water-level data for ASR Cycle 3 Recovery Test are graphically presented on **Figure 16**. As shown, the static water level in Beltz 12 prior to pumping was approximately 100.9 feet bgs. The pumping level recorded after 24-hours was approximately 157.0 feet, corresponding to a drawdown of 56.1 feet, and a 24-hour specific capacity of approximately 7.25 gpm/ft. This

24-hr specific capacity value is slightly greater (approximately 7 percent) than the Cycle 2 Recovery Test 24-hour specific capacity of 6.75 gpm/ft, indicating that not only had no residual plugging of the well occurred as result of the previous injection tests, but had actually improved slightly. The final pumping level at the end of the 30-day test was 174.5 feet bgs.

Again, response to the ASR Cycle 3 Recovery Test was observed at Cory Medium, Deep and #4, with approximately 29.7, 39.3 and 50.7 feet, respectively, of water-level decrease observed at the end of the 30-day test. Similar to the Cycle 3 Injection Test, Cory Shallow displayed a more significant and measurable response to this 30-day test than the previous two recovery tests, with approximately 4.2 feet of water-level decrease at the end of the test.

Injection vs. Extraction Specific Capacity Ratios

Most injection wells display a difference in injection and extraction specific capacities, with the injection specific capacity (aka specific injectivity) usually being lower than the extraction specific capacity, even when plugging is taken into account. Typically, injection wells display injection specific capacities that are 25 to 80 percent of the extraction specific capacities (Huisman and Olsthoorn, 1983, and Pyne, 1994). 24-hour injection and extraction specific capacities observed during the Beltz 12 ASR Pilot Test Program are summarized in **Table 6** below:

Table 6. Injection vs. Extraction Specific Capacity Ratio Summary

ASR Cycle	Injection					Extraction					Q/s Ratio
	Rate (gpm)	SWL (ft bgs)	IWL (ft bgs)	DUP (ft)	Q/s (gpm/ft	Rate (gpm)	SWL (ft bgs)	IWL (ft bgs)	DDN (ft)	Q/s (gpm/ft	
1	405	95.2	29.9	65.3	6.20	701	90.6	190.9	100.3	6.99	**0.887**
2	391	98.4	34.9	63.5	6.16	699	88.2	191.7	103.5	6.75	**0.912**
3	376	94.3	31.3	63.0	5.97	407	100.9	157.0	56.1	7.25	**0.823**
Notes:											
SWL - Static Water Level											
IWL - Injection Water Level											
DUP - Draw up											
DDN - Draw dow n											
Q/s - Specific Capacity/Injectivity											

As shown, the injection to extraction specific capacity ratios displayed by Beltz 12 are at the high end of the typical range (i.e., approximately 80 to 90 percent). The reason(s) for the difference in injection vs. extraction specific capacities has been the subject of considerable discussion in the ASR community. Some of the reasons for the difference that have been advanced include:

- Particle rearrangement,
- Differential hydraulic well losses, and
- Differential aquifer response.

The reason(s) for the slight differences in injection vs. extraction specific capacities observed at Beltz 12 are not precisely known, and are likely due to some combination of the above-listed factors; nonetheless, the testing results are at the high end of typical values and demonstrate that well performance conditions at the Beltz 12 site are favorable for ASR.

Backflushing

Following each injection test, backflushing was performed on the well. In addition, backflushing was performed during the ASR Cycle 3 Injection Test on a weekly basis. Backflushing operations generally consisted of pumping the well to the temporary settling tanks at rates ranging between approximately 680 and 975 gpm for a period of 15 to 20 minutes. The pump was then shut off and the water contained in the pump column pipe allowed to surge back into the well, followed by a 15-minute idle period. The pump was then restarted and pumped to waste for another 15 minutes, resulting in a double-backflush procedure. During each backflushing pumping event, the well discharge was initially turbid (approximately 10 to 50 NTU) and of dark brown color for the first 2 minutes or so, followed by a significant decrease in turbidity for the remaining backflushing cycle. Discharge water during the subsequent backflushing cycles was essentially clear (typically less than 5 NTU in the first 2 minutes), indicating that the majority of particulates were removed from the well during the initial 15 minutes of backflushing.

Following each backflushing event, controlled 10-minute specific capacity tests were performed to track well performance and the efficacy of backflushing. Additional 10-minute specific capacity data were developed during the storage period water-quality sampling events. The 10-minute specific capacity results are summarized in **Table 7** below and presented graphically on **Figure 17**.

As shown, the well displayed a pre-injection 10-minute specific capacity of 11.6 gpm/ft, and during the course of the testing program generally ranged between approximately 10.4 and 13.3 gpm/ft (i.e., within -10 to +15 percent of baseline). Specifically, following the ASR Cycle 1 and Cycle 2 Injection Tests and backflushing, the specific capacity did not change; however, upon initiation of ASR Cycle 2 Recovery pumping, the specific capacity had declined to 11.3 gpm/ft, representing a slight decline in performance of approximately 3 percent. Following ASR Cycle 3 Injection Test and during the Cycle 3 Storage Period various sampling and pumping events, the 10-minute specific capacity varied somewhat between approximately 10.4 and 13.3 gpm/ft. At the start of the ASR Cycle 3 Recovery Test, the 10-minute specific capacity was 12.2 gpm/ft, which is approximately 5 percent greater than the pre-injection baseline performance, but is considered statistically insignificant given the relatively short duration (10 minutes) of the tests. In general, these results indicate that weekly backflushing was effective at removing particulates introduced into the well during injection and maintaining well performance.

Table 7. 10-Minute Specific Capacity Summary

Date / Time	SWL (ft btoc)	PWL (ft btoc)	DDN (ft)	Q (gpm)	Q/s (gpm/ft)	% Change*	Comments
12/14/18 13:00	93.8	154.5	60.7	702	11.57	--	Pre-Injection Performance Test
1/17/19 16:50	96.4	165.9	69.5	805	11.58	0.15	Post Initial system hydraulics test
1/19/19 10:00	81.3	152.7	71.4	828	11.60	0.27	Post Cycle 1 Injection and 1x backflush
1/21/19 9:30	92.3	151.5	59.2	699	11.81	2.10	Start of Cycle 1 Recovery
1/30/19 16:30	73.2	136.1	62.9	729	11.59	0.21	Post Cycle 2 Injection and 2x backflush
2/19/19 16:30	89.7	154.0	64.3	725	11.28	-2.51	Start of Cycle 2 Recovery
4/5/19 14:45	55.9	129.6	73.7	927	12.58	8.76	Post Cycle 3 Injection and 2x backflush
4/10/19 14:45	76.1	166.9	90.8	952	10.48	-9.34	Cycle 3 Storage sampling
4/16/19 13:50	80.7	153.7	73.0	973	13.33	15.25	Cycle 3 Storage sampling
4/25/19 8:00	84.4	150.4	66.0	824	12.48	7.95	Cycle 3 Storage sampling
5/1/19 8:10	85.5	151.1	65.6	693	10.56	-8.66	Cycle 3 Storage sampling
5/15/19 14:30	94.7	160.4	65.7	702	10.68	-7.61	Post-Injection Performance Test
5/22/19 14:00	98.7	164.9	66.2	688	10.39	-10.14	Cycle 3 Storage sampling
5/29/19 14:00	100.1	164.1	64.0	678	10.59	-8.40	Cycle 3 Storage sampling
6/5/19 16:15	100.9	166.2	65.3	735	11.26	-2.67	Cycle 3 Storage sampling
7/1/19 9:00	102.7	136.7	34.0	414	12.18	5.29	Start of Cycle 3 Recovery
Notes:							
SWL - Static Water Level			min	678	10.4		
ft btoc - feet below top of casing			max	973	13.3		
PWL - Pumping Water Level							
DDN - Draw down							
Q - Discharge Rate							
gpm - gallons per minute							
Q/s - Specific Capacity							
* - compared to pre-injection baseline							

Plugging Rate Analysis

Experience at injection sites around the world shows that all injection wells are subject to some amount of plugging because no water source is completely free of particulates. During injection, trace amounts of suspended solids are continually being deposited in the gravel pack and aquifer pore spaces, much as a media filter captures particulates in the filter bed. The effect of plugging is that it impedes the flow of water from the injection well into the aquifer, causing increased injection heads in the well to maintain a given injection rate, or reduced injection rates at a given head level. Well plugging reduces injection and extraction capacity, and consequently, well life.

Plugging can occur due to water quality issues, improper system operation, or poor well design practices. In general, plugging issues fall into four general categories: physical plugging (by particulate matter), chemical reaction (between the injectate and native waters or aquifer minerals), biofouling (the proliferation of bacteria in the gravel pack or aquifer), and gas binding (the vapor locking of the aquifer by entrained or evolved gasses in the injectate). **Figure 18** shows the characteristic plugging mechanisms from suspended solids, biological growth, and air entrainment and the increased resistance to flow over time.

Silt Density Index Testing. Relative measurements of the particulate matter in the injectate (and hence the potential for physical plugging) were made through silt density index (SDI) testing during injection. The SDI was originally developed to quantitatively assess particulate concentrations in reverse osmosis feed waters. The SDI involves pressure filtration of source water through a 0.45-micron membrane, and observation of the decrease in flow over time; the resulting value of SDI is dimensionless and used as a comparative value for tracking relative well plugging rates versus water quality or other parameters. SDI test results are summarized in **Table 8** below.

As shown, during pre-injection pipeline flushing, SDI values started out relatively high (up to 4.7 initially) and gradually declined to approximately 2.0 to 3.5 as particulates were purged from the distribution system piping. SDI values during injection testing were very consistent, ranging between approximately 1.3 and 3.7. Values within this range are generally representative of source waters with relatively low amounts of particulates and, therefore, favorable for injection.

Active Plugging Rates. Active plugging rates during injection testing of Beltz 12 were estimated utilizing the Graphical Observed vs. Theoretical Drawup Method (Pyne, 1994). Water level rise in an injection well is a combination of both aquifer response and well losses. Theoretically, at any given constant injection rate, well losses should remain constant; therefore, in the absence of plugging, any water level rise in the well would be due only to aquifer response. The difference between the theoretical water level and the observed water can be presumed to be caused by plugging.

It is important to note that the theoretical water level rise corresponds to the water level that would occur if well losses were negligible. In order to account for well efficiency losses, the graphical method involves drawing a straight line through moderate elapsed time data points (100 to 1000 minutes). Assuming no plugging is occurring, the theoretical water level rise during injection would plot along a straight line on a semi-log plot. The variance from the straight line is assumed to be indicative of the amount of plugging.

The amount of plugging, in feet of water level rise, was calculated for the ASR Cycles 2 and 3 continuous injection tests[4]. The plugging rate analyses for these long-term continuous rate injection tests are presented graphically on **Figures 19 and 20**. As shown, at the end of ASR Cycle 2 Injection, the observed water level rise was 85.1 feet. The theoretical water level rise was estimated to be approximately 75.7 feet. Total water level rise due to plugging was, therefore, approximately 9.4 feet, yielding an average plugging rate of approximately 1.34 feet per day (ft/day) for ASR Cycle 2 Injection Test. As shown on **Figure 20**, calculated plugging rate for ASR Cycle 3 Injection Test was a slightly greater, but comparable value of 1.49 ft/day.

[4] ASR Cycle 1 Injection Test was limited to 1 day of injection, which is too short for a meaningful plugging rate analysis. Only the first week of continuous injection of ASR Cycle 3 Injection Test was analyzed, as the well was backflushed on a weekly basis for the remainder of the 30-day test period (i.e., was non-continuous after the first week).

Table 8. Silt Density Index (SDI) Test Results

Date / Time	t_0 (secs)	t_{15} (secs)	SDI (unitless)	Comments
1/17/19 14:10	27	92	4.71	Pre-Injection line flushing
1/17/19 14:30	26	56	3.57	Pre-Injection line flushing
1/18/19 8:10	25	42	2.70	Pre-Injection line flushing
1/18/19 8:30	25	36	2.04	Pre-Injection line flushing
1/18/19 16:20	26	51	3.27	Cycle 1 Injection
1/18/19 20:20	25	48	3.19	Cycle 1 Injection
1/19/19 8:30	27	39	2.05	Cycle 1 Injection
1/23/19 9:50	28	50	2.93	Pre-Injection line flushing
1/23/19 10:10	29	53	3.02	Pre-Injection line flushing
1/23/19 12:00	40	70	2.86	Cycle 2 Injection
1/23/19 15:50	39	82	3.50	Cycle 2 Injection
1/24/19 9:50	40	68	2.75	Cycle 2 Injection
1/25/19 9:30	39	67	2.79	Cycle 2 Injection
1/26/19 11:35	41	86	3.49	Cycle 2 Injection
1/27/19 10:05	40	64	2.50	Cycle 2 Injection
1/28/19 8:30	42	58	1.84	Cycle 2 Injection
1/29/19 8:50	40	65	2.56	Cycle 2 Injection
1/30/19 10:20	41	67	2.59	Cycle 2 Injection
3/6/19 14:00	42	98	3.81	Pre-Injection line flushing
3/6/19 14:20	40	88	3.64	Pre-Injection line flushing
3/6/19 14:40	41	90	3.63	Pre-Injection line flushing
3/6/19 16:00	41	92	3.70	Cycle 3 Injection
3/7/19 9:30	42	97	3.78	Cycle 3 Injection
3/14/19 8:30	42	68	2.55	Cycle 3 Injection
3/20/19 16:30	41	64	2.40	Cycle 3 Injection
3/21/19 13:00	40	50	1.33	Cycle 3 Injection
3/27/19 16:30	39	54	1.85	Cycle 3 Injection
4/4/19 14:05	39	64	2.60	Cycle 3 Injection
4/15/19 14:45	38	59	2.37	Cycle 3 Injection

Notes:
t_0 - elapsed time 0 minutes
t_{15} - elapsed time 15 minutes
secs - seconds
SDI - Silt Density Index

Normalized Plugging Rates. Normalizing plugging rates to a reference velocity at the well screen of 3 feet per hour and a water temperature of 20 degrees allows for comparison of data from wells that have different constructions, injection rates, and water temperatures. The observed plugging rate is normalized by the following equation (Olsthoorn, 1982):

$$PR_{norm} = PR_{obs} (Vs/V)^2 (n_{20}/n) \qquad \text{(Eq.2)}$$

Where:

PR_{norm} = plugging rate in feet/day normalized to 20 degrees Celsius and a borehole velocity of 3 ft/hr

PR_{obs} = calculated observed plugging rate in ft/day

Vs = standard velocity at borehole wall of 3 ft/hr

V = calculated velocity at borehole wall in ft/hr

n_{20} = viscosity (in centipose) at standard temperature of 20 degrees Celsius

n = viscosity (in centipose) at measured temperature

A summary of the plugging rate calculations is presented in **Table 9** below:

Table 9. Summary of Pugging Rate Calculations

ASR Cycle Injection Test	Injectate Temp (^{0}C)	Injection Rate (gpm)	Duration of Injection (days)	Flux at B.H. Wall (ft/hr)	Obs. Plug Rate (ft/day)	Norm. Plug Rate (ft/day)
2	14.2	391	7	9.98	1.34	0.165
3	13.5	376	7	9.60	1.49	0.196

As shown, the observed plugging rates during ASR Cycles 2 and 3 Injection Tests ranged between 1.34 and 1.49 ft/d, averaging approximately 1.42 ft/d. Normalization of these observed plugging rates yields plugging rates of approximately 0.165 and 0.196 ft/d. Both the observed active and normalized plugging rates are considered quite low and compare favorably with other ASR well sites PWR has studied in California.

Residual Plugging. As discussed previously, following backflushing operations controlled 10-minute specific-capacity tests were performed to track well pumping performance. Residual plugging is the plugging that remains following backflush pumping. Residual plugging increases drawdown during pumping and drawup during injection, and is manifested as declining specific capacity / injectivity. The presence of residual plugging is indicative of incomplete removal of plugging particulates during backflushing and has the cumulative effect of reducing well performance and capacity over time. Presented in **Table 10** below is a summary of the residual plugging calculations for the Beltz 12 ASR pilot test program.

As shown, there was a slightly negative amount of approximately 3.0 feet of residual plugging observed over the course of the pilot test program; in other words, no residual plugging of Beltz 12 occurred as a result of the ASR pilot testing, indicating that the weekly schedule of a double-backflush operation was successful at maintaining well performance.

Table 10. Residual Plugging Summary

Date / Time	Pumping Rate (gpm)	10-min Drawdown (ft)	10-min Q/s[1] (gpm/ft)	Normalization Ratio[2]	Normalized Drawdown[2] (ft)	Residual Plugging (ft)
12/14/18 13:00	702	60.7	11.6	1.00	60.5	--
1/17/19 16:50	805	69.5	11.6	0.87	60.4	-0.1
1/19/19 10:00	828	71.4	11.6	0.85	60.4	-0.2
1/21/19 9:30	699	59.2	11.8	1.00	59.3	-1.2
1/30/19 16:30	729	62.9	11.6	0.96	60.4	-0.1
2/19/19 16:30	725	64.3	11.3	0.97	62.1	1.6
4/5/19 14:45	927	73.7	12.6	0.76	55.7	-4.9
4/10/19 14:45	952	90.8	10.5	0.74	66.8	6.2
4/16/19 13:50	973	73.0	13.3	0.72	52.5	-8.0
4/25/19 8:00	824	66.0	12.5	0.85	56.1	-4.5
5/1/19 8:10	693	65.6	10.6	1.01	66.3	5.7
5/15/19 14:30	702	65.7	10.7	1.00	65.5	5.0
5/22/19 14:00	688	66.2	10.4	1.02	67.4	6.8
5/29/19 14:00	678	64.0	10.6	1.03	66.1	5.5
6/5/19 16:15	735	65.3	11.3	0.95	62.2	1.7
7/1/19 9:00	414	34.0	12.2	1.69	57.5	-3.0

Notes:

1 - Specific Capacity. Ratio of pumping rate to drawdown.

2 - Normalized based on ratio of 700 gpm to actual test pumping rate.

AQUIFER RESPONSE TO INJECTION AND RECOVERY

The response of the regional aquifer system to ASR testing at Beltz 12 was monitored throughout the pilot test program. The locations of the project wells are shown on **Figure 3** and summary of the construction details of the test program wells was presented in **Table 4** above. Water-level data collected from the project monitoring wells during the course of the ASR pilot test program are shown on **Figures 6 through 10**. In addition, water-level data collected from the onsite Cory St. monitoring wells during each injection test are shown on **Figures 11, 13 and 15**.

Aquifer Response to Injection

Summaries of the aquifer water-level response observations during the ASR pilot test program injection tests are presented in **Table 11** and discussed below:

Table 11. Aquifer Response to Injection Summary

Well	Distance from Beltz 12 (ft)	Tp Unit(s) Completed	ASR Cycle 1			ASR Cycle 2			ASR Cycle 3		
			Injection			Injection			Injection		
			SWL (ft bgs)	IWL (ft bgs)	DUP (ft)	SWL (ft bgs)	IWL (ft bgs)	DUP (ft)	SWL (ft bgs)	IWL (ft bgs)	DUP (ft)
Cory St	75										
shallow		A (lower)	81.9	81.5	**0.4**	82.4	81.8	**0.6**	82.9	78.4	**4.5**
medium		AA (upper)	82.6	58.8	**23.8**	84.6	51.7	**32.9**	82.7	46.1	**36.6**
deep		AA (lower)	85.6	55.2	**30.4**	89.5	44.9	**44.6**	85.9	37.9	**48.0**
#4		Tu	92.7	58.2	**34.5**	96.1	41.6	**54.5**	91.4	28.5	**62.9**
Composite		AA - Tu[1]	87.0	57.4	**29.6**	90.1	46.1	**44.0**	86.7	37.5	**49.2**
O'Neill Ranch *	1670	AA - Tu	97.4	92.2	**5.2**	97.5	79.5	**18.0**	93.4	69.4	**24.0**
Coffee Ln Park	2250										
shallow		A	35.4	35.4	**0.0**	35.3	35.1	**0.2**	34.3	34.0	**0.3**
deep		AA	35.0	35.0	**0.0**	34.9	34.8	**0.1**	34.0	33.6	**0.4**
Auto Plaza	2490										
medium		A (lower)	73.3	73.2	**0.1**	73.1	72.4	**0.7**	72.1	70.8	**1.3**
deep		AA	71.8	71.7	**0.1**	71.5	70.8	**0.7**	70.6	69.3	**1.3**
SC-22 **	3250										
shallow		A	49.5	49.4	**0.1**	49.4	48.9	**0.5**	48.8	47.9	**0.9**
medium		AA (upper)	51.1	51.2	**-0.1**	51.1	50.7	**0.4**	50.5	49.6	**0.9**
deep		AA (lower)	53.9	51.0	**2.9**	NA	NA	**NA**	51.5	24.6	**26.9**
30th Ave	4640										
shallow		A	51.5	51.5	**0.0**	51.5	51.1	**0.4**	50.1	49.8	**0.3**
medium		AA	51.5	51.6	**-0.1**	51.5	51.2	**0.3**	50.3	49.9	**0.4**
deep		Tu	47.2	47.2	**0.0**	47.1	45.3	**1.8**	46.7	39.0	**7.7**

Notes:
Tp - Purisima Formation
* - SqCWD production well
** - SqCWD monitoring well
1 - Composite of Cory St. Medium, Deep and #4 (corresponding to Beltz 12 screen intervals).
SWL - Static Water Level
IWL - Injection Water Level
DUP - Draw up

Cory St. The Cory St. monitoring wells are located approximately 75 feet from Beltz 12. Response to the ASR Cycle 1 Injection Test was observed at the Cory St. monitoring wells screened in aquifer zones corresponding to the screen interval of Beltz 12 (Cory Medium, Cory Deep, and Cory #4), which displayed drawups of approximately 23.8, 32.9 and 36.6 feet at the end of the test, respectively. The Cory Shallow well, which is screened above the Beltz 12 screen interval, displayed a very slight response during injection of 0.4 feet.

Immediate response to the ASR Cycle 2 Injection Test was observed at the Cory St. Medium, Deep and #4 monitoring wells, which displayed drawups of approximately 23.8, 30.4 and 34.4 feet at the end of the test, respectively. The Cory Shallow monitoring well displayed a slight response during injection, with a total drawup of approximately 0.6 feet at the end of the test, indicating that a very small amount of vertical leakage may have occurred from the injection target aquifers into the overlying shallow aquifer.

Response to the ASR Cycle 3 Injection Test was observed at Cory Med, Deep and #4, with approximately 36.6, 47.9 and 63.0 feet, respectively, of water-level increase observed at the end of the 30-day test.

Cory Shallow displayed a more significant and measurable response to this 30-day test than the previous two injection tests, with approximately 4.5 feet of water-level increase at the end of the test, again indicating that a very small amount of vertical leakage may have occurred from the injection target aquifers into the overlying shallow aquifer; however, as noted previously, Cory Shallow also displayed a more significant and measurable response to the Cycle 2 and 3 Recovery Tests, with approximately 1.4 and 4.2 feet of water-level decrease at the end of the tests, respectively, indicating that a small amount of vertical leakage may have occurred from the overlying shallow aquifer back into the underlying injection target aquifers during recovery pumping.

In summary, the Cory St monitoring wells that directly correspond to the Beltz 12 screen intervals displayed variable responses to injection, generally increasing with depth. The differential responses of the various aquifer intervals are likely due to two primary factors: 1) the degree of aquifer confinement, which generally increases with depth, and; 2) differences in the interval transmissivities and the vertical distribution of flow across the Beltz 12 well screen. While a downhole velocity profiling (spinner survey) could not be performed during this ASR pilot test[5], the spinner survey performed at Beltz 12 during pumping tests following its construction showed that approximately 65 percent of the total flow was contributed from the lower-most screen interval corresponding to the Tu Unit, with the remainder provided by the overlying AA Unit. These findings suggest that similar relationships may occur during injection as well.

O'Neill Ranch. SqCWD's O'Neill Ranch municipal production well is located approximately 1,670 feet from Beltz 12 and is screened in the same aquifer intervals as Beltz 12. SCWD coordinated with SqCWD prior to and during the Beltz 12 ASR Pilot Test Program, and SqCWD staff provided valuable assistance by both providing water-level monitoring data and adjusting the well pumping schedule to minimize interference with the Beltz 12 ASR pilot test as much as practicable. As shown on **Figure 6**, SqCWD limited the pumping of O'Neill Ranch to short duration "exercise" pumping during the ASR injection tests (although it was placed into its normal Time of Use [TOU] daily pumping schedule during ASR Cycle 3 Storage Period in order to meet demands during this period).

As shown in **Table 11**, O'Neill Ranch displayed significant measurable responses to all of the ASR Cycle 1, 2 and 3 Injection Tests, with approximately 5.2, 18.0 and 24.0 feet of water level increase at the end of each test, respectively (these observed responses are compared to the pre-test predicted responses in a later section).

Coffee Ln Park. The Coffee Ln Park monitoring wells are located approximately 2,250 feet from Beltz 12 and are completed in both the overlying A Unit aquifer (shallow) and the AA

[5] The pump was set below the top of screen in order to maximize available drawdown and pumping capacity for effective backflushing to limit well plugging.

Unit aquifer (deep) that the upper screen of Beltz 12 is completed. As shown, neither well displayed a significant measurable response to the ASR Cycle 1 and 2 Injection Tests; however, both wells displayed similar responses to the longer-term ASR Cycle 3 Injection Test, with approximately 0.3 and 0.4 feet of water-level increase at the end of the test, respectively.

Auto Plaza. The Auto Plaza monitoring wells are located approximately 2,490 feet from Beltz 12 and, similar to Coffee Ln Park, are completed in both the overlying A Unit aquifer (shallow) and the AA Unit aquifer (deep) that the upper screen of Beltz 12 is completed. Similar to the Coffee Ln Park wells, the Auto Plaza wells did not display significant measurable responses to the ASR Cycle 1 Injection Test. The wells did, however, display identical responses to the ASR Cycle 2 and 3 Injection Tests with approximately 0.7 and 1.3 feet of water-level increase at the end of the tests, respectively.

SC-22. The SC-22 monitoring wells are owned by SqCWD and are located approximately 3,250 feet from Beltz 12. Similar to the Coffee Ln Park and Auto Plaza monitoring wells, the SC-22 wells are reported to be completed in both the overlying A Unit aquifer (shallow) and the AA Unit aquifer (medium and deep) that the upper screen of Beltz 12 is completed in. As shown, the shallow and medium wells displayed comparable levels of response to injection at Beltz 12 as the Auto Plaza wells, with approximately 0.5 and 0.9 feet of water-level increase at the end of the ASR Cycle 2 and 3 Injection Tests, respectively.

The deep monitoring well, however, displayed a much more significant response, with approximately 2.9 and 26.9 feet of water-level increase at the end of the ASR Cycle 1 and 3 Injection Tests[6]. While this well was believed to be screened in the lower portion of the AA Unit aquifer, these levels of response are much greater than the responses observed in the other wells completed in this aquifer unit that are in closer proximity to Beltz 12. These observations suggest that this well may actually be completed in the Tu Unit. This issue should be explored further, but is beyond the scope of this study.

30th Ave. The 30th Ave monitoring wells are located approximately 4,640 feet from Beltz 12. As shown, none of the wells displayed a response to the 1-day ASR Cycle 1 Injection Test. All of the wells displayed responses to the longer-term ASR Cycle 2 and 3 Injection Tests. Both the shallow and deep wells, completed in the overlying A Unit and the AA Unit, respectively, displayed somewhat limited responses of approximately 0.3 to 0.4 feet to both tests. The deep well, however, completed in the Tu Unit, displayed significant responses, with 1.8 and 7.7 feet of water-level increase at the end of the ASR Cycle 2 and 3 injection tests, respectively. Again, the disproportionate response of the Tu Unit is due primarily to both the higher degree of confinement of this unit, as well as the likelihood that more of the injected water at Beltz 12 flows into the Tu Unit compared to the overlying AA Unit.

[6] The SC-22 Deep monitoring well transducer/data logger apparently malfunctioned during the ASR Cycle 2 Injection Test. Manual data are plotted on Figure 9; however, the available data are insufficient for this aquifer response analysis.

Aquifer Response to Recovery / Extraction

Summaries of the aquifer water-level response observations during the ASR pilot test program recovery tests are presented in **Table 12** and discussed below:

Table 12. Aquifer Response to Recovery / Extraction Summary

Well	Distance from Beltz 12 (ft)	Tp Unit(s) Completed	ASR Cycle 1 Recovery			ASR Cycle 2 Recovery			ASR Cycle 3 Recovery		
			SWL (ft bgs)	PWL (ft bgs)	DDN (ft)	SWL (ft bgs)	PWL (ft bgs)	DDN (ft)	SWL (ft bgs)	PWL (ft bgs)	DDN (ft)
Cory St	75										
shallow		A (lower)	81.8	82.0	**0.2**	81.4	82.8	**1.4**	79.1	83.2	**4.1**
medium		AA (upper)	80.7	117.9	**37.2**	79.5	125.4	**45.9**	84.4	114.1	**29.7**
deep		AA (lower)	85.6	130.4	**44.8**	82.0	143.5	**61.5**	88.3	127.6	**39.3**
#4		Tu	87.3	141.6	**54.3**	85.6	161.9	**76.3**	99.5	150.2	**50.7**
Composite		AA - Tu[1]	84.5	130.0	**45.4**	82.4	143.6	**61.2**	90.7	130.6	**39.9**
O'Neill Ranch *	1670	AA - Tu	93.5	99.8	**6.3**	90.6	109.6	**19.0**	107.8	118.6	**10.8**
Coffee Ln Park	2250										
shallow		A	35.2	35.4	**0.2**	34.9	34.6	**-0.3**	33.8	33.8	**0.0**
deep		AA	34.9	35.0	**0.1**	34.5	34.2	**-0.3**	33.4	33.4	**0.0**
Auto Plaza	2490										
medium		A (lower)	73.1	73.1	**0.0**	72.2	72.6	**0.4**	73.0	73.4	**0.4**
deep		AA	71.5	71.6	**0.1**	70.8	71.2	**0.4**	71.0	71.6	**0.6**
SC-22 **	3250										
shallow		A	49.2	49.4	**0.2**	48.9	49.2	**0.3**	48.5	49.0	**0.5**
medium		AA (upper)	51.0	51.1	**0.1**	50.6	50.8	**0.2**	50.3	50.9	**0.6**
deep		AA (lower)	50.1	53.2	**3.1**	NA	NA	**NA**	59.2	75.4	**16.2**
30th Ave	4640										
shallow		A	51.3	51.4	**0.1**	50.8	50.6	**-0.2**	48.9	48.5	**-0.4**
medium		AA	51.5	51.5	**0.0**	50.9	50.8	**-0.1**	49.0	48.7	**-0.3**
deep		Tu	47.0	47.0	**0.0**	44.6	46.5	**1.9**	46.4	51.7	**5.3**

Notes:
Tp - Purisima Formation
* - SqCWD production w ell
** - SqCWD monitoring w ell
1 - Composite of Cory St. Medium, Deep and #4 (corresponding to Beltz 12 screen intervals).
SWL - Static Water Level
PWL - Pumping Water Level
DDN - Draw dow n

Cory St. Response to the ASR Cycle 1 Recovery Test was observed at the Cory St. monitoring wells screened in aquifer zones corresponding to the screen interval of Beltz 12 (Cory Medium, Cory Deep, and Cory #4), which displayed drawdowns of approximately 37.2, 44.8, and 54.3 feet at the end of the test, respectively. The Cory Shallow well, which is screened above the Beltz 12 screen interval, displayed a very slight response during pumping of 0.2 feet.

Immediate response to the ASR Cycle 2 Recovery Test was observed at the Cory St. Medium, Deep and #4 monitoring wells, which displayed drawdowns of approximately 45.9, 61.5, and 76.3 feet at the end of the test, respectively. The Cory Shallow monitoring well displayed a slight response during pumping, with a total drawdown of approximately 1.4 feet at the end of the test, indicating that a very small amount of vertical leakage may have occurred from the the overlying shallow aquifer.

Response to the ASR Cycle 3 Recovery Test was observed at Cory Med, Deep and #4, with approximately 29.7, 39.3 and 50.7 feet, respectively, of water-level decline observed at the end of the 30-day test.

Similar to the injection tests, Cory Shallow displayed a more significant and measurable response to this 30-day pumping test than the previous two tests, with approximately 4.1 feet of water-level decrease at the end of the test, again indicating that a very small amount of vertical leakage may have occurred from the overlying shallow aquifer back into the underlying injection target aquifers during recovery pumping.

In summary, similar to the injection test results, the Cory St monitoring wells that directly correspond to the Beltz 12 screen intervals displayed variable responses to recovery pumping, generally increasing with depth, with the overlying shallow aquifer displaying apparent leakage responses.

O'Neill Ranch. O'Neill Ranch displayed significant measurable responses to all of the ASR Cycle 1, 2 and 3 Recovery Tests, with approximately 6.3, 19.0 and 10.8 feet of water level declines at the end of each test, respectively (these observed responses are compared to the predicted responses in a later section).

Coffee Ln Park. As shown, neither of the Coffee Ln Park monitoring wells displayed a discernable response to any of the ASR Recovery Tests.

Auto Plaza. The Auto Plaza wells did not display significant measurable responses to the ASR Cycle 1 Recovery Test. The wells did, however, display near identical responses to the ASR Cycle 2 and 3 Recovery Tests with approximately 0.4 to 0.6 feet of water-level decrease.

SC-22. The shallow and medium SC-22 wells displayed comparable levels of response to pumping at Beltz 12 as the Auto Plaza wells, with approximately 0.2 and 0.6 feet of water-level decrease at the end of the ASR Cycle 2 and 3 Recovery Tests, respectively. Similar to the injection test results, the deep monitoring well displayed a much more significant response, with approximately 3.1 and 16.2 feet of water-level decrease at the end of the ASR Cycle 1 and 3 Recovery Tests[7].

30th Ave. None of the 30th Ave wells displayed a response to the 1-day ASR Cycle 1 Recovery Test, and the shallow and medium wells did not display a response to any of the recovery tests. The deep well, however, completed in the Tu Unit, displayed measurable responses to both the ASR Cycle 2 and 3 Recovery Tests, with 1.9 and 5.3 feet of water-level decrease at the end of the tests, respectively. Again, the disproportionate response of the Tu Unit is due primarily to both the higher degree of confinement of this unit, as well as the

[7] The SC-22 Deep monitoring well transducer/data logger apparently malfunctioned during the ASR Cycle 2 Injection Test. Manual data are plotted on Figure 9; however, the available data are insufficient for this aquifer response analysis.

likelihood that more of the injected water at Beltz 12 flows into the Tu Unit compared to the overlying AA Unit.

Observed vs. Predicted Responses

As part of the ASR Pilot Test NOI Technical Report, PWR estimated the area of hydrologic influence affected hydraulically (i.e., water-level changes) by the injection tests utilizing the Theis Non-Equilibrium Equation and the following assumptions:

Table 13. Theis Equation Calculations Assumptions

Parameter	Value
Injection Rate (Q) (gpm)	400
Transmissivity (T) (gpd/ft)	14,100
Storativity (S) (dimensionless)	1.0×10^{-3}
Time (t) (days)	30

The above hydrogeologic parameters were developed from the pumping test program conducted at Beltz 12 following its construction in 2012. The Theis-predicted theoretical drawup vs. distance calculations for the ASR Cycle 3 Injection Test specifically estimated the amount of predicted water-level drawup within the aquifer system at the nearest test program monitoring well (Cory St) and at the nearest offsite production well (SqCWD's O'Neill Ranch Well).

As shown in **Table 11**, the composite water-level data for the Cory St monitoring wells (i.e., medium, deep and #4 corresponding to the Beltz 12 screen intervals) showed an actual drawup response of approximately 49.2 feet to the Cycle 3 Injection Test compared to the Theis-predicted response of approximately 33.0 feet. Similarly, O'Neill Ranch displayed a water-level drawup response of approximately 24.0 feet compared to the Theis-predicted response of approximately 13.0 feet.

As shown in **Table 12**, the composite water-level data for the Cory St monitoring wells showed an actual drawdown response of approximately 39.9 feet to the Cycle 3 Recovery Test compared to the Theis-predicted response of approximately 32.6 feet, and O'Neill Ranch displayed a water-level drawdown response of approximately 10.8 feet compared to the Theis-predicted response of approximately 12.5 feet.

Both the greater-than-predicted response of the aquifer system to injection at Beltz 12, as well as the differential response between injection and recovery pumping, suggests that the site-specific aquifer parameters at Beltz 12 are likely not representative of the broader regional aquifer system and/or there are negative boundary effects (e.g., the western basin boundary) not accounted for by the relatively simplistic Theis-based analytical calculations[8] that are

[8] The Theis Equation assumes that the aquifer is homogenous and infinite in areal extent.

affecting the aquifer system response to injection. These results should be investigated further with the calibrated groundwater flow model of the MCGB as part of a future investigation.

WATER QUALITY

A critical component of the Beltz 12 ASR Pilot Test Program was the empirical assessment of water-quality issues through the Injection-Storage-Recovery (ISR) cycles of ASR operations. For the SCWD ASR program, potable Title-22 compliant water produced from the GHWTP and conveyed to the site via the SCWD distribution system was used for injection into the aquifer. The ASR pilot program was designed to monitor and verify that potability was maintained throughout the ASR cycle sequence of injection, aquifer storage, and recovery operations.

The principal focus of the water-quality investigation was on parameters associated with potability; however, additional water-quality parameters were monitored that are known to affect well and aquifer performance vis-à-vis well screen and/or aquifer plugging. Such adverse reactions can occur between the injection source water (from GHWTP) and the native groundwater (NGW); the injected water and the geologic matrix of the aquifer; or both. Beneficial reactions may also occur, and are discussed in a later section.

The potential reactions between injected waters, native groundwaters, and aquifer matrix minerals can be classified into the following general categories:

- **Precipitation reactions** result from aqueous reactions which create oversaturated mineral conditions and produce precipitates of minerals in order to balance geochemical equilibrium. Such reactions can occur as a result of chemical mixing between disparate waters, or via temperature or pressure changes that may occur during ASR operations. The result on ASR operations is the same; a reduction in well performance due to well screen or aquifer porosity plugging and/or water-quality degradation via color or turbidity increases from the formation of colloidal or suspended solids.
- **Ion Exchange reactions** can occur when recharge waters interact with aquifer minerals facilitating a substitution of cations (or anions) based on their relative affinity for geochemical equilibrium in the aquifer mineral matrix. The most common ion exchange reactions in ASR operations are cationic exchanges between Na and Ca ions, and are especially problematic in the presence of smectite or montmorillonite clays; if high-sodium recharge waters displace native groundwaters in a high-clay content matrix, swelling can occur and result in lower aquifer permeability.
- **Redox reactions** occur when significant differentials in oxidation states are present in the injected water, native groundwater, and aquifer minerals. Redox reactions can demerit water quality, cause decreases in aquifer permeability, release soluble contaminants, or mobilize otherwise stable elements present in aquifer minerals.
- **Solubilization reactions** can also leach undesirable elements from aquifer minerals and contaminate stored waters in the aquifer. Leaching processes can occur when injected waters are significantly undersaturated and/or unbuffered with respect to various minerals. Common leaching processes that adversely affect stored water

quality include Fe, Mn, As, or Hg; major cations such as Ca, Mg, or K, while also susceptible to leaching, generally do not render waters non-potable.

- **Biochemical reactions** can be significant and especially detrimental to ASR operations. Microbial populations, whether indigenous within the aquifer or introduced via ASR operations, can proliferate under certain environmental and nutritional conditions; this can result in mineral precipitation, taste and/or odor creation, corrosion of well screens and piping, and formation of slimes and biomass that can significantly plug well screens and/or near-well aquifer matrices.

It is common for many of these mechanisms to occur simultaneously in natural waters; however, the identification of reaction processes is useful in assessing and mitigating potential water-quality issues that could adversely affect ASR operations.

Previous Studies

PWR performed a preliminary geochemical assessment of the SCWD's proposed ASR program as part of the Phase 1 Technical Feasibility Investigation[9] based on water-quality sampling of Beltz 12 native groundwater and the GHWTP injection source water. The investigation included assessment of the geochemical stability of these waters individually, and in various mixtures to assess the geochemical reactions that could potentially occur during aquifer storage. The principal findings of the geochemical modeling assessment included the following:

- The treated GHWTP water is an excellent source of ASR injection water and would have an overall diluting effect in the aquifer.
- There is potential for calcite precipitation (which can lead to well plugging); however, this potential is very dependent on the actual pH of the injected water, where at a pH of 7.6 and TDS of 300 mg/L or less, the potential for calcite precipitation is essentially eliminated.
- Dissolved manganese in all of the NGWs exceeds drinking water standards; however, none of the dissolved constituents (including manganese) in recovered waters are estimated to be higher than their original concentrations in the NGW.
- A potential ancillary benefit of aquifer recharge with treated GHWTP water may be the reduction of manganese in the stored and recovered waters, perhaps persisting for some time after 100 percent of the previously injected water has been recovered; however, as recovery pumping progresses, the manganese concentrations will likely eventually tend to approach NGW levels over time.
- Overall, the modeling predicted that the potential for significant adverse geochemical reactions during ASR operations were unlikely except as noted

[9] Pueblo Water Resources, Inc. (August 2017), *Geochemical Interaction Analysis (Task 1.3)*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

above, and no geochemical interaction-related "fatal flaws" for the ASR project were identified.

It is noted that the geochemical investigation did not assess the fate of DBP's, as DBP equilibrium data are not included in the geochemical database. Similarly, microbially mediated reactions were not assessed in the geochemical modeling. These processes are necessarily assessed empirically during actual ASR operations.

ASR Pilot Test Program Results

Numerous samples were collected during the Beltz 12 ASR Pilot Test Program in accordance with the project Sampling and Analysis Plan (SAP) developed as part of the project Work Plan (refer to **Appendix A**). Samples were collected at Beltz 12 and the three Cory St. monitoring wells that are screened in the same aquifer zones as Beltz 12 (Cory Medium, Deep and #4). Laboratory analyses were provided by a State Certified Laboratory (Eurofins Eaton Analytical, LLC.), which included a variety of constituent groups: general parameters, major anions and cations, nutrients, metals, miscellaneous, and DBPs. Some samples were analyzed for the complete list of constituents while other samples were analyzed for a partial list (e.g. DBPs), depending on the timing of an ASR period, as summarized in **Table 14** below:

Table 14. Water-Quality Sampling Schedule

Cycle 1						
Analyte Group	Injection		Storage		Recovery	
	Injectate	Cory St.	Beltz 12	Cory St.	Beltz 12	Cory St.
F-1	Once	--	@end	--	@25, 50, 75, 100, 125 & 150%	--
G-1	Once	--	@end	--	@ 50 and 100%	--
DBP	Once	--	@end	--	@ 100%	--
S-1	--	--	--	--	@ 25, 75, 125, & 150%	--
Cycle 2						
Analyte Group	Injection		Storage		Recovery	
	Injectate	Cory St.	Beltz 12	Cory St.	Beltz 12	Cory St.
F-1	Once	--	Weekly	@end	@0, 25, 50, 75, 100, 125 & 150%	@end
G-1	Once	--	Weekly	@end	@ 50 and 100%	@end
DBP	Once	--	Weekly	@end	@ 100%	@end
S-1	--	--	--	--	@0, 25, 75, 125, & 150%	--
Cycle 3						
Analyte Group	Injection		Storage		Recovery	
	Injectate	Cory St.	Beltz 12	Cory St.	Beltz 12	Cory St.
F-1	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, 100, 125 & 150%	Weekly
G-1	Once	Once	Once	Once	@ 50 and 100%	@ 50 and 100%
DBP	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, 100, 125 & 150%	Weekly
S-1	Weekly	Weekly	Weekly	Weekly	@ 25, 75, 125, & 150%	Weekly

Laboratory reports are provided in **Appendix D**. **Tables 15, 16, and 17** summarize the respective laboratory results for Beltz 12 from ASR Cycles 1, 2 and 3, respectively. **Tables 18,**

19 and 20 summarize laboratory results for the three Cory St. monitoring wells screened in the same intervals as Beltz 12 (Cory St. Med, Deep and #4, respectively). As shown, the majority of water-quality data collected from the Cory St. monitoring wells was during ASR Cycle 3, because the volumes of injection for ASR Cycles 1 and 2 were more limited and not sufficient to fully envelope the Cory St. wells.

Recovery Efficiency

Recovery efficiency is defined as the percentage of stored water volume that is recovered before a water-quality limitation is exceeded. In most cases, the water quality limitation is the potable water standards set by the State of California or by the U.S. EPA. It is assumed that for the SCWD, the minimum standard would be State Drinking Water Standards, and that the desired recovery efficiency would be 100 percent, i.e. the SCWD would recover 100 million gallons (mg) of potable water for every 100 mg of water injected (minus any hydraulic losses from the basin). From an operational standpoint, ASR typically involves repeated ISR cycles, either on a seasonal basis or for extended periods to mitigate drought or emergency conditions. As ISR cycles are repeated, the aquifer minerals and background water quality typically change (incrementally) towards the chemical nature of the injectate. This is a result of the development of a "buffer zone" of mixed water that gradually increases over time, and a natural effect of the equilibration of the injected water with aquifer minerals during storage.

It is important to note that in this context, the term “recovery efficiency” refers to the water-quality of the recovered water relative to both the injectate and native groundwater water chemistries, and is important for quantifying and understanding the effects of dilution on the water-quality results. It should not be confused with ASR project recoverable yields (i.e., water quantity/volume vs. water quality), as there should be no expectation for “molecule-for-molecule” recovery of water that is recharged. Some of the molecules of water injected via an ASR well would be expected to drift downgradient and away from the capture zone of the ASR well. The amount of drift would be dependent on a variety of factors, such as the duration of storage, amount of seasonal pumping by offsite wells, etc. Numerical groundwater modeling is currently underway (as part of the Phase 1 Technical Feasibility Investigation) to quantify estimates of volumetric increases in outflow from the basin (hydraulic losses) and associated recoverable yields of a SCWD ASR project in the basin.

A total of three ISR cycles were implemented during the Beltz 12 ASR Pilot Test Program. Each cycle consisted of injection of a predetermined amount of potable water from the SCWD distribution system; followed by a storage, or idle period, to allow subsurface equilibrium and simulate "off season" storage of water; and finally a recovery process whereby approximately 100 to 150 percent of the volume of previously injected water was recovered[10] as part of the test program to assess the level of subsurface mixing of the injectate with native groundwaters and monitor for other chemical reaction processes.

[10] Normal ASR operations would likely not recover more than the previously injected volume.

Table 15. Beltz 12 ASR Cycle 1 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date								
Group ID						12/14/18	1/18/19	1/21/19	1/21/19	1/21/19	1/21/19	1/22/19	1/22/19	1/22/19
Field Parameters / Sample Description						**Pre-Injection**	**Injection**	**Recovery**						
Cl Residual	on-site	Hach	mg/L	0.05		ND	0.94	ND	ND	ND	ND	ND	ND	ND
Diss O2	on-site	Hach	mg/L	0.2		3.6	13.2	2.5	3.9	5.0	4.1	7.0	1.8	2.5
EC	on-site	EPA 120.1	umho/cm	10		649	433	472	507	532	529	546	638	655
ORP	on-site	USGS	mV	10		-81	564	40	-56	-20	-19	-39	-24	-57
pH	on-site	EPA 150.1	Std Units	0.01		7.54	7.54	7.42	7.67	7.69	7.07	7.40	7.63	7.67
Temperature	on-site	SM 2550	°C	0.5		18.7	14.0	14.7	14.8	15.2	15.5	16.5	17.4	18.1
Turbidity	on-site	Hach 2100Q	NTU	0.1		0.86	0.33	0.30	0.24	0.22	0.13	0.18	0.29	0.34
General Mineral Analysis														
Alkalinity (Total)	Lab	SM2320B	mg/L	5		170	110	120	120	130	130	140	170	170
Ca	Lab	EPA 200.7	mg/L	0.03		68	58	67	66	65	63	61	70	68
Cl	Lab	EPA 300.0	mg/L	0.5	250	33	18	19	19	21	23	23	32	34
EC	Lab	EPA 120.1	umho/cm	10	900	640	470	510	500	520	530	540	630	640
F	Lab	EPA 300.0	mg/L	0.1	2	0.59	0.18	0.24		0.36		0.45		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.011	ND	0.003	0.0041	0.003	0.0049	0.0083	0.013	0.013
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	**1.0**	0.0072	0.037	0.032	0.033	0.0049	0.034	0.013	0.013
K	Lab	EPA 200.8	mg/L	1		4.3	2.2	3.0	3.3	3.4	3.5	4.5	4.6	4.2
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	0.043		ND		ND		
Mg	Lab	EPA 200.8	mg/L	0.5		29	10	12	12	15	16	19	25	27
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.40	ND	0.050	0.045	0.082	0.10	0.16	0.210	0.250
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	**0.35**	0.00064	0.048	**0.058**	**0.08**	**0.12**	**0.15**	**0.25**	**0.29**
Na	Lab	EPA 200.7	mg/L	0.05		27	22	23	23	23	23	23	26	26
NH3	Lab	EPA 350.1	mg/L	0.05		0.14	ND	0.013		0.044		0.10		
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	0.028		0.01		ND		
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	0.27	0.059		0.058		0.095		
P (Total)	Lab		mg/L	0.001		0.34	1.9	0.89		0.58		0.46		
pH	Lab	EPA 150.1	Std Units	0.01		8.2	7.5	7.8	7.9	7.8	7.8	7.8	7.8	7.7
SiO2	Lab	EPA 370.1	mg/L	2		72	18	29	30	34	40	49	59	64
SO4	Lab	EPA 300.0	mg/L	0.5	250	110	93	110	100	100	100	96	100	110
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1			ND	ND		ND		ND		
TDS	Lab	SM2540C	mg/L	5	500	450	290	320	330	330	340	350	430	430
TKN	Lab	EPA 351.2	mg/L	0.2		0.11	0.097	0.13		0.14		0.17		
Inorganic Trace Metals														
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND		ND		ND		
Al	Lab	EPA 200.8	ug/L	10	200	ND	14	1.2	1.4	1.9	2.7	2.2	3.7	3.7
As	Lab	EPA 200.8	ug/L	1	10	ND	0.19	0.7		0.54		0.71		
B	Lab	EPA 200.8	ug/L	50		60	49	51		49		48		
Ba	Lab	EPA 200.7	ug/L	1	1000	15	36	33		33		31		
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND		ND		ND		
Br	Lab	EPA 200.9	ug/L	100		140	14	34	37	54	63	69	140	150
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND		ND		0.057		
Co	Lab	EPA 200.8	ug/L	1		ND	ND	0.13		0.15		0.19		
Cr	Lab	EPA 200.8	ug/L	10	50	0.24	ND	ND		ND		ND		
Cu	Lab	EPA 200.8	ug/L	5	1000	1.3	2.2	2.8		1.4*		1.3		
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND		ND		ND		
I	Lab	EPA 200.8	ug/L	100		8.9	ND	9.1		8.5		9.0		
Li	Lab	EPA 200.7	ug/L	1		4.9	15	21		24		31		
Ni	Lab	EPA 200.8	ug/L	1	100	0.99	0.78	1		1.1		1.1		
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		0.038		
Sb	Lab	EPA 200.8	ug/L	1	6	ND	0.28	1.3		1.2		0.74		
Se	Lab	EPA 200.8	ug/L	5	50	0.38	1	0.94		0.74		0.67		
Sr (Total)	Lab	EPA 200.7	ug/L	1		300	290	320		310		280		
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND		ND		0.12		
U	Lab	EPA 200.8	ug/L	0.5		ND	0.12	1.3		2.0		1.4		
V	Lab	EPA 200.8	ug/L	1		ND	0.27	1.8		2.1		2.9		
Zn	Lab	EPA 200.8	ug/L	10	5000	6.9	2.7	4.2		2.7		3.6		
Bio / Organics														
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	31	20				10		
HPCs	Lab	SM9215B	CFU	<1		590	<1	500				1200		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		0.86	2.0	2.1				1.6		
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		0.71	1.9	2.1				1.8		
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	40	30				7.9		
Miscellaneous														
CH4	Lab	RSK-175	ug/L	5		5.34	0.1	0.348		1.81		2.41		
Gross Alpha	Lab	EPA 900.0	pCi/L		15	**25**	ND	ND		6.4		ND		
Color	Lab	SM2120B	Color Units	3	15	**20**	ND	ND	ND	ND	ND	ND	ND	ND
Hardness	Lab	SM2340B	mg/L	10		290	190	220		220		230		
Tu	Lab	EPA 180.1	NTU	0.1	5	4.3	0.097	0.16	0.13	0.11	0.12	0.12	0.14	0.12
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND		ND	ND	ND	ND	ND

Notes:

Values denoted in **bold** text exceed MCL.

Table 16. Beltz 12 ASR Cycle 2 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date								
Group ID						1/24/19	2/8/19	2/19/19	2/20/19	2/21/19	2/22/19	2/23/19	2/24/19	2/25/19
Field Parameters / Sample Description						Injection	Storage	Recovery						
Cl Residual	on-site	Hach	mg/L	0.05		0.88	ND	0.04	0.07	0.02	ND	ND	ND	ND
Diss O2	on-site	Hach	mg/L	0.2		11.2	1.6	1.3	2.2	0.6	ND	ND	0.1	0.6
EC	on-site	EPA 120.1	umho/cm	10		468	522	364	416	428	468	456	502	531
ORP	on-site	USGS	mV	10		56.6	-18.2	-40.2	50.7	16.3	-28.2	-18.4	-29.4	51.3
pH	on-site	EPA 150.1	Std Units	0.01		7.15	7.33	7.38	7.53	7.53	7.51	7.53	7.56	7.6
Temperature	on-site	SM 2550	°C	0.5		14.2	14.8	14.9	14.1	15.8	16.3	17.1	18.1	18.3
Turbidity	on-site	Hach 2100Q	NTU	0.1		0.5	0.58	0.25	0.27	0.17	0.00	0.00	0.00	0.65
General Mineral Analysis														
Alkalinity (Total)	Lab	SM2320B	mg/L	5		98	110	110	110	110	120	130	160	170
Ca	Lab	EPA 200.7	mg/L	0.03		54	65	57	61	59	60	59	67	70
Cl	Lab	EPA 300.0	mg/L	0.5	250	19	23	22	22	22	23	25	30	32
EC	Lab	EPA 120.1	umho/cm	10	900	450	530	480	490	490	510	540	610	640
F	Lab	EPA 300.0	mg/L	0.1	2	0.18	0.14	0.21		0.3		0.4		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	0.034	ND	ND	ND	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	ND	0.11	0.098	0.033	0.031	0.03	0.03	0.03	0.029
K	Lab	EPA 200.8	mg/L	1		2.1	3.2	2.4	2.8	3.6	3.8	4.4	4.7	4.6
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND		ND		ND		
Mg	Lab	EPA 200.8	mg/L	0.5		9.7	11	10	11	11	14	17	24	28
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	0.093	0.069	0.038	0.067	0.110	0.180	0.240	0.270
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	ND	**0.092**	**0.063**	0.043	**0.068**	**0.120**	**0.180**	**0.270**	**0.310**
Na	Lab	EPA 200.7	mg/L	0.05		23	23	23	24	23	23	23	26	29
NH3	Lab	EPA 350.1	mg/L	0.05		ND	ND	ND		ND		0.076		
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND		ND		ND		
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	0.3	ND	ND		ND		ND		
P (Total)	Lab		mg/L	0.001		1.9	1.2	0.96		0.54		0.48		
pH	Lab	EPA 150.1	Std Units	0.01		7.6	7.6	7.7	7.8	7.7	7.8	7.8	7.8	7.9
SiO2	Lab	EPA 370.1	mg/L	2		19	26	28	31	33	37	43	53	60
SO4	Lab	EPA 300.0	mg/L	0.5	250	89	110	92	94	95	97	98	100	100
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND		ND		ND		
TDS	Lab	SM2540C	mg/L	5	500	280	350	300	340	330	350	380	410	430
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	ND		ND		ND		
Inorganic Trace Metals														
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND		ND		ND		
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND	ND	ND	ND	ND	ND	ND
As	Lab	EPA 200.8	ug/L	1	10	ND	ND	ND		ND		ND		
B	Lab	EPA 200.8	ug/L	50		ND	56	ND		51		ND		
Ba	Lab	EPA 200.7	ug/L	1	1000	34	49	33		39		35		
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND		ND		ND		
Br	Lab	EPA 200.9	ug/L	100		15	79	42	40	41	54	73	120	140
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND		ND		ND		
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND		ND		ND		
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	5.6	ND		ND		ND		
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND		ND		ND		
I	Lab	EPA 200.8	ug/L	100		ND	14	5.8		6.4		9.9		
Li	Lab	EPA 200.7	ug/L	1		0.014	0.029	0.02		0.022		0.031		
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND		ND		ND		
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND		ND		ND		
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND		ND		ND		
Sr (Total)	Lab	EPA 200.7	ug/L	1		0.28	0.31	0.27		0.28		0.28		
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND		ND		ND		
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND		1.3		1.2		
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND		ND		ND		
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND	ND		ND		ND		
Bio / Organics														
HAA5's	Lab	EPA 552.2	ug/L	1	60	32	21	2.8				4.4		
HPCs	Lab	SM9215B	CFU	<1		<1	>5700	760		830		3100		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		2.0	2.1	1.7				1.4		
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		1.9	2.5	2.1				1.4		
TTHM's	Lab	EPA 502.2	ug/L	1	80	38	44	1.6				0.96		
Miscellaneous														
CH4	Lab	RSK-175	ug/L	5		ND	0.172	0.275		3.54		3.54		
Gross Alpha	Lab	EPA 900.0	pCi/L		15	ND	ND	ND		ND		ND		
Color	Lab	SM2120B	Color Units	3	15	ND	5	ND	ND	ND	ND	ND	ND	ND
Hardness	Lab	SM2340B	mg/L	10		170	210	180		190		220		
Tu	Lab	EPA 180.1	NTU	0.1	5	0.11	0.3	0.36	0.33	0.18	0.2	0.15	0.3	0.36
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:

Values denoted in **bold** text exceed MCL.

Table 17. Beltz 12 ASR Cycle 3 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date																				
Group ID						3/7/19	3/14/19	3/20/19	3/27/19	4/4/19	4/10/19	4/16/19	4/25/19	5/1/19	5/9/19	5/15/19	5/22/19	5/29/19	6/5/19	6/19/19	6/27/19	7/1/19	7/9/19	7/16/19	7/23/19	7/30/19
Field Parameters / Sample Description						Injection					Storage											Recovery				
Cl Residual	on-site	Hach	mg/L	0.05		0.84	0.97	0.73	0.8	0.9	0.02	0.02	0.01	0	0	0	0	0.01	0.01	0	0	0.01	0	0	0	0.01
Diss O2	on-site	Hach	mg/L	0.2		10.8	10.7	10.5	10.68	10.61	0.04	0.03	0.03	0.03	0.02	0.04	0.03	0.23	0.04	0.04	0.04	0.03	0.01	0	0.01	0.01
EC	on-site	EPA 120.1	umho/cm	10		339	362	348	330	335	370	386	482	452	459	394	436	433	437	525	454	490	519	507	537	609
ORP	on-site	USGS	mV	10		628	775	687.5	691	585	14.8	14.5	18.8	18.3	52.7	110.3	123	167.5	175.7	163.4	148.6	136.1	45.5	28.9	66.7	105.9
pH	on-site	EPA 150.1	Std Units	0.01		7.39	7.22	7.23	7.24	7.3	6.62	6.82	6.81	6.89	6.41	6.9	6.92	6.84	6.66	7.03	6.99	7.13	7.18	7.29	7.44	7.31
Temperature	on-site	SM 2550	°C	0.5		13.5	14.1	15.2	15.0	15.8	16.35	16.3	16.33	16.2	16.5	16.1	16.1	16.7	16.5	16.3	16.7	16.3	16.2	16.9	18.0	18.3
Turbidity	on-site	Hach 2100Q	NTU	0.1		0.74	1.56	1.69	1.66	1.75	1.93	1.83	1.95	1.94	2.06	2.07	2.13	2.14	3.12	2.49	2.18	2.34	2.42	2.43	2.95	2.77
General Mineral Analysis																										
Alkalinity (Total)	Lab	SM2320B	mg/L	5		75	81	80	80	84	71	75	93	88	94	89	89	92	93	95	91	99	110	120	130	120
Ca	Lab	EPA 200.7	mg/L	0.03		40	43	39	38	39	45	46	64	58	57	46	45	44	44	46	47	48	51	53	55	56
Cl	Lab	EPA 300.0	mg/L	0.5	250	20	18	18	17	16	16	17	17	17	17	17	17	18	18	18	18	19	19	22	24	25
EC	Lab	EPA 120.1	umho/cm	10	900	370	360	350	330	330	370	380	480	450	450	370	370	370	380	390	400	400	430	470	500	540
F	Lab	EPA 300.0	mg/L	0.1	2			0.14							0.11							0.22		0.33		0.36
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	0.028	0.087	ND	0.66	ND	0.065	0.13	ND	0.023	ND	ND	ND	ND	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	ND	ND	ND	ND	ND	0.18	0.14	0.25	**0.88**	0.17	0.26	0.2	0.19	**0.3**	0.094	0.098	0.083	0.056	0.052	0.054	0.048
K	Lab	EPA 200.8	mg/L	1		2.3	1.8	1.8	1.8	1.8	2.7	3.0	3.1	2.9	2.9	2.1	2.0	1.9	2.1	2.5	2.6	2.7	2.9	3.1	3.4	3.7
MBAS	Lab	SM 5540C	mg/L	0.05	0.5			ND							ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mg	Lab	EPA 200.8	mg/L	0.5		8.3	7.6	7.3	6.7	6.7	7.4	7.6	10.0	9.3	9.3	7.7	7.8	7.6	7.6	8.3	8.6	8.8	10	14	15	17
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.002		ND	ND	ND	ND	ND	0.061	0.097	0.210	0.120	0.082	0.044	0.036	0.032	0.041	0.046	0.043	0.061	0.075	0.120	0.180	0.200
Mn (Total)	Lab	EPA 200.9	mg/L	0.002	0.05	ND	ND	ND	ND	0.0022	**0.063**	**0.096**	**0.210**	**0.15**	**0.086**	0.048	0.04	0.039	0.043	**0.05**	**0.062**	**0.061**	**0.076**	**0.12**	**0.17**	**0.2**
Na	Lab	EPA 200.7	mg/L	0.05		22	18	18	17	17	17	17	18	18	19	18	18	18	18	20	20	20	20	21	22	26
NH3	Lab	EPA 350.1	mg/L	0.05				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		0.072		0.1
NO2	Lab	EPA 300.0	mg/L	0.1	1			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10			0.25							ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
P (Total)	Lab		mg/L	0.001				1.8							0.81							1		0.66		0.6
pH	Lab	EPA 150.1	Std Units	0.01		7.5	7.6	7.6	7.4	7.6	7.4	7.1	7.1	7.2	7.4	7.4	7.6	7.5	7.8	7.6	7.8	7.8	7.6	7.8	7.9	7.8
SiO2	Lab	EPA 370.1	mg/L	2		18	21	21	20	20	19	20	24	27	24	26	28	30	31	34	35	37	33	38	41	43
SO4	Lab	EPA 300.0	mg/L	0.5	250	75	67	61	51	52	78	86	120	100	97	66		62	62	67	69	71	72	80	88	90
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
TDS	Lab	SM2540C	mg/L	5	500	240	230	220	210	230	240	260	320	290	290	240	250	240	250	250	270	270	290	320	330	350
TKN	Lab	EPA 351.2	mg/L	0.2				ND							0.32							ND	ND	ND	ND	ND
Inorganic Trace Metals																										
Ag	Lab	EPA 200.8	ug/L	10	100			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND	ND	20	ND	ND	ND	27	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
As	Lab	EPA 200.8	ug/L	1	10			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
B	Lab	EPA 200.8	ug/L	50				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		0.068
Ba	Lab	EPA 200.7	ug/L	1	1000			31							53							25		28		25
Be	Lab	EPA 200.8	ug/L	1	4			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Br	Lab	EPA 200.9	ug/L	100		10	11	11	12	14	36	48	79	72	66	34	34	32	30	36	34	38	44	60	75	83
Cd	Lab	EPA 200.8	ug/L	1	5			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Co	Lab	EPA 200.8	ug/L	1				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cr	Lab	EPA 200.8	ug/L	10	50			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cu	Lab	EPA 200.8	ug/L	5	1000			ND							ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hg	Lab	EPA 200.8	ug/L	0.025	2			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
I	Lab	EPA 200.8	ug/L	100				ND							7.9							4.9		8.8		ND
Li	Lab	EPA 200.7	ug/L	1				0.015							0.023							0.02		0.024		0.035
Ni	Lab	EPA 200.8	ug/L	1	100			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb	Lab	EPA 200.8	ug/L	1				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sb	Lab	EPA 200.8	ug/L	1	6			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Se	Lab	EPA 200.8	ug/L	5	50			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Sr (Total)	Lab	EPA 200.7	ug/L	1				0.20							0.26							0.23		0.24		0.26
Tl	Lab	EPA 200.8	ug/L	1	2			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
U	Lab	EPA 200.8	ug/L	0.5				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
V	Lab	EPA 200.8	ug/L	1				ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zn	Lab	EPA 200.8	ug/L	10	5000			ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bio / Organics																										
HAA5's	Lab	EPA 552.2	ug/L	1	60	69	43	34	31	31	ND	11	5.8	ND	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HPCs	Lab	SM9215B	CFU	<1				1							>5700					180		730		320		920
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		2.4	1.5	1.4	1.2	1.2	1.1	1.2	1.7	1.4	1.4	1.2	1.2	1.0	1.2	1.2		1.1	1.0	1.0	1.0	1.3
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		2.2	1.4	1.2	1.2	1.1	1.1	1.2	ND	ND	1.1	1	1.2	0.97	0.94	1	1	1.8	1	0.95	0.96	1.2
TTHM's	Lab	EPA 502.2	ug/L	1	80	58	33	32	35	32	33	34	32	18	18	1.8	0.86	0.65	0.71	ND	0.92	0.62	ND	ND	ND	ND
Miscellaneous																										
CH4	Lab	RSK-175	ug/L	5				0.117							0.132							0.618		2.9		2.6
Gross Alpha	Lab	EPA 900.0	pCi/L		15			ND							ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Color	Lab	SM2120B	Color Units	3	15	ND	ND	ND	ND	ND	ND	ND	ND	10	ND	ND	ND	ND	ND	ND	5	ND	ND	ND	ND	ND
Hardness	Lab	SM2340B	mg/L	10				0.25							ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Tu	Lab	EPA 180.1	NTU	0.1	5	ND	ND	ND	ND	ND	0.99	0.29	0.57	0.77	0.93	0.36	0.82	0.56	1.9	0.42	0.52	0.38	0.27	0.16	0.16	0.19
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
Values denoted in **bold** text exceed MCL.

Table 18. Cory St Medium Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date																							
Group ID						12/12/19	2/19/19	3/6/19	3/14/19	3/21/19	3/28/19	4/5/19	4/11/19	4/17/19	4/25/19	5/2/19	5/9/19	5/16/19	5/23/19	5/30/19	6/6/19	6/13/19	6/19/19	6/27/19	7/1/19	7/9/19	7/17/19	7/24/19	7/30/19
Field Parameters / Sample Description						Pre-Injection	Cyc 2 Storage	Cyc 3 Injection					Cyc 3 Storage													Cyc 3 Recovery			
Cl Residual	on-site	Hach	mg/L	0.05		ND	0.04	0.06	ND	0.04	ND	ND	0.04	0.04	0.08	0.06	0.03	0.01	0.01	ND	0.01	0.02	0.02	0.03	0.02	0.02	0.02	0.02	ND
Diss O2	on-site	Hach	mg/L	0.2		3	0.4	0.1	0.0	0.02	0.0	0.02	0.01	0.01	0.02	0.02	0.02		0.02	0.03	0.03	0.03	0.02	0.02	0.03	0.01	0.01	ND	0.02
EC	on-site	EPA 120.1	umho/cm	10		642	403	507	588	565	555	535	510	502	496	721	565	473	650	634	666	745	768	657	700	697	632	535	674
ORP	on-site	USGS	mV	10		-83.8	-149.7	-40.3	-90.5	-94.7	-99.1	-114	-141.4	-134.9	-142.7	-11.2	-54.6		-33.4	26.2	28	52.7	51.8	51.7	52.5	-18.7	-21.1	11.6	4
pH	on-site	EPA 150.1	Std Units	0.01		7.41	7.46	7.77	7.25	7.31	7.48	7.51	7.51	7.52	7.49	7.25	7.32	7.21	7.21	7.16	7.17	7.18	7.17	7.15	7.12	7.12	7.11	7.12	6.98
Temperature	on-site	SM 2550	°C	0.5		18.8	19.3	19.1	19.5	19.8	19.8	18.9	20.14	20.16	20.41	19.87	19.53	18.12	19.58	20.7	21.22	20.5	20.75	21.36	20.9	21.3	20.86	21.94	20.8
Turbidity	on-site	Hach 2100Q	NTU	0.1		0.88	0.22	0.37	1.70	1.73	2.07	1.78	0.77	2.08	2.19	2.27	2.33		1.43	2.79	**47.5**	4.29	4.18	5.37	7.23	4.17	7.28	3.28	3.58
General Mineral Analysis																													
Alkalinity (Total)	Lab	SM2320B	mg/L	5		230	190	200	190	170	160	140	140	140	140	150	160	170	170	180	180	180	190	160	180	200	200	200	200
Ca	Lab	EPA 200.7	mg/L	0.03		72	65	68	65	63	63	57	59	57	56	56	60	62	63	63	72	66	65	64	66	64	67	63	65
Cl	Lab	EPA 300.0	mg/L	0.5	250	34	29	30	34	32	30	27	28	26	26	25	25	26	28	29	30	29	30	30	30	31	31	32	31
EC	Lab	EPA 120.1	umho/cm	10	900	630	580	580	580	570	580	520	520	510	510	510	540	550	550	560	580	570	580	590	580	590	590	600	600
F	Lab	EPA 300.0	mg/L	0.1	2	0.3	0.46	0.53				0.48					0.62								0.61		0.57		0.52
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.41	ND	0.34	0.25	0.33	ND	ND	ND	ND	ND	0.031	ND	ND	0.24	0.23	ND	0.27	0.57	0.28	ND	0.62	0.44	0.37	0.061
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	1.30	1.00	1.50	1.30	1.00	0.89	0.74	0.74	0.71	0.70	0.70	0.78	0.89	0.96	1.00	**19**	1.30	1.20	1.20	1.20	1.80	2.10	2.10	2.30
K	Lab	EPA 200.8	mg/L	1		3.8	3.5	3.5	3.5	3.4	3.3	3.6	3.6	3.4	3.3	3.4	3.5	3.5	3.6	3.7	5.6	3.8	3.6	3.7	3.6	3.7	4	3.8	3.8
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND				ND	ND	ND	ND	ND	ND								ND		ND		ND
Mg	Lab	EPA 200.8	mg/L	0.5		22	20	**21**	20	19	20	18	18	18	18	17	18	19	19	20	25	21	21	21	21	21	22	21	22
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.78	0.68	0.770	0.780	0.69	0.55	0.560	0.560	0.520	0.490	0.520	0.600	0.620	0.620	0.700	0.680	0.720	0.700	0.500	0.660	0.810	0.770	0.790	0.710
Mn (Total)	Lab	EPA 200.9	mg/L	0.002	0.05	**0.71**	**0.66**	**0.76**	**0.80**	**0.69**	**0.6**	**0.57**	**0.60**	**0.57**	**0.56**	**0.56**	**0.58**	**0.66**	**0.70**	**0.71**	**0.93**	**0.74**	**0.74**	**0.74**	**0.74**	**0.81**	**0.84**	**0.79**	**0.79**
Na	Lab	EPA 200.7	mg/L	0.05		25	23	24	24	23	23	22	23	22	22	22	22	23	23	23	25	24	24	24	24	25	25	24	25
NH3	Lab	EPA 350.1	mg/L	0.05		0.085	0.07	0.067				0.066					0.071								0.071		0.073		0.071
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND	ND	ND	ND	ND					ND								ND		ND		ND
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	ND	ND				ND					ND								ND		ND		ND
P (Total)	Lab		mg/L	0.001		1.3	1.2	1.4				0.9					0.95								1.1				1.6
pH	Lab	EPA 150.1	Std Units	0.01		7.7	7.8	7.8	7.7	7.8	7.7	7.7	7.8	7.6	7.7	7.7	7.8	7.5	7.8	7.7	7.9	7.7	7.7	7.6	7.7	7.7	7.6	7.6	7.5
SiO2	Lab	EPA 370.1	mg/L	2		71	71	75	74	71	72	70	70	72	70	70	70	71	73	73	120	75	73	72	73	73	76	72	73
SO4	Lab	EPA 300.0	mg/L	0.5	250	50	61	54	62	71	76	77	76	75	76	74	69	69	69	68	65	65	64	62	62	54	51	50	49
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND				ND					ND								ND		ND		ND
TDS	Lab	SM2540C	mg/L	5	500	420	390	410	390	400	390	390	370	370	350	380	380	390	380	400	430	410	400	410	410	410	410	410	400
TKN	Lab	EPA 351.2	mg/L	0.2		ND	ND	ND				ND					ND								ND		ND		ND
Inorganic Trace Metals																													
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND				ND					ND								ND				ND
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**9900**	150	63	22	ND	ND	ND	ND	ND
As	Lab	EPA 200.8	ug/L	1	10	ND	ND	ND				ND					ND								ND				ND
B	Lab	EPA 200.8	ug/L	50		ND	ND	ND				ND					ND								ND				ND
Ba	Lab	EPA 200.7	ug/L	1	1000	21	21	22				19					19								22				23
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND				ND					ND								ND				ND
Br	Lab	EPA 200.9	ug/L	100		190	160	170	170	150	150	120	120	100	90	99	110	120	130	140	150	160	88	170	170	180	170	190	190
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND				ND					ND								ND				ND
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND				ND
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND				ND					ND								ND				ND
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	ND	ND				ND					ND								ND				ND
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND				ND					ND								ND				ND
I	Lab	EPA 200.8	ug/L	100		33	20	19				8.5					14								20				36
Li	Lab	EPA 200.7	ug/L	1		35	31	35				26					32								36				36
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND				ND					ND								ND				ND
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND				ND
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND				ND					ND								ND				ND
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND				ND					ND								ND				ND
Sr (Total)	Lab	EPA 200.7	ug/L	1		300	280	270				240					250								280				260
Sr 86/Sr 87 (ratio)	Lab	EPA 200.8	ug/L	(ratio acuracy)																									
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND				ND					ND								ND				ND
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND				ND					ND								ND				ND
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND				ND
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND	ND				ND					ND								ND				ND
Bio / Organics																													
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	ND	ND	ND	ND	ND	4.7	4.2	5	5.6	5.8	4.1	4.9	3.2	3.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
HPCs	Lab	SM9215B	CFU	<1		56	620	1600				1100					360												560
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		1.7	1.6	1.1	1.2	1.2	0.91	0.81	1	1.1	1.2	1.3	1.3	1.5	1.6	1.4	1.4	1.5	1.2	1.1	0.98	1.1	1.2	1.2	1.4
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		2.6	2.2	1.1	1	0.95	ND	ND	ND	ND	ND	ND	1.3	1.4	1.3	1.1	1.1	1.2	1.1	0.95	1.1	1	1.1	1.4	1.4
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Miscellaneous																													
CH4	Lab	RSK-175	ug/L	5		45.3	15.8	14.4				7.93					10.2								13.2		39		20
Gross Alpha	Lab	EPA 900.0	pCi/L		15	ND	3.7	4.1				ND					ND								ND		ND		ND
Color	Lab	SM2120B	Color Units	3	15	10	10	10	15	ND		15	ND	5	10	15	ND	10	10	10	25	10	10	15	10	20	15	ND	15
Hardness	Lab	SM2340B	mg/L	10		270	240	260				220					220								250				250
Tu	Lab	EPA 180.1	NTU	0.1	5	13	9.2	12	11	8.8		5	4.7	4.7	4	3.8	5	4.5	5.6	7.5	**140**	7.1	5.2	9.5	11	16	20	16	12
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	**390**	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
Values denoted in **bold** text exceed MCL.

Table 19. Cory St Deep Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date																							
Group ID						12/12/19	2/19/19	3/6/19	3/14/19	3/21/19	3/28/19	4/5/19	4/11/19	4/17/19	4/25/19	5/2/19	5/9/19	5/16/19	5/23/19	5/30/19	6/6/19	6/13/19	6/19/19	6/27/19	7/1/19	7/9/19	7/17/19	7/24/19	7/30/19
Field Parameters / Sample Description						Pre-Injection	Cyc 2 Storage	Cyc 3 Injection					Cyc 3 Storage													Cyc 3 Recovery			
Cl Residual	on-site	Hach	mg/L	0.05		ND	0.03	ND	ND	0.05	0.02	ND	0.04	0.02	0.27	0.04	0.06	0.01	ND	0.02	ND	0.02	ND	0.03	ND	0.02	0.01	0.03	0.03
Diss O2	on-site	Hach	mg/L	0.2		4.1	3.1	0.1	0.02	0.02	0.03	0.02	0.02	0.01	0.02	0.03	0.05	0.02	0.03	0.04	0.03	0.04	0.03	0.03	0.03	ND	0.01	0.01	0.03
EC	on-site	EPA 120.1	umho/cm	10		753	726	623	737	735	705	692	661	676	686	725	750	754	847	812	741	933	954	803	851	841	761	716	784
ORP	on-site	USGS	mV	10		16.1	-40.9	-12.1	46	-8.1	27.5	-35.7	-91.1	-89.3	-108	61	13.7	65.8	58.8	82.6	77.2	118.8	82.2	74.2	78.3	5	23.8	27.2	66.9
pH	on-site	EPA 150.1	Std Units	0.01		7.63	7.57	8.01	7.56	7.57	7.59	7.6	7.62	7.64	7.65	7.39	7.43	7.39	7.37	7.35	7.34	7.35	7.34	7.35	7.34	7.4	7.42	7.43	7.27
Temperature	on-site	SM 2550	°C	0.5		20.4	20.1	20	21.3	21.4	21.1	20.8	21.52	21.45	21.54	21.66	20.65	21.17	20.94	21.54	22.36	21.7	22.08	22.69	22.67	22.89	22.33	22.28	22.72
Turbidity	on-site	Hach 2100Q	NTU	0.1		0.8	0.21	1.57	2.40	2.92	0.26	2.51	1.27	2.13	3.35	2.40	2.36	2.37	3.11	2.15	3.03	2.69	2.81	3.88	3.32	3.33	4.10	3.39	3.27
General Mineral Analysis																													
Alkalinity (Total)	Lab	SM2320B	mg/L	5		190	180	190	190	190	170	160	160	160	170	170	180	180	180	180	180	180	180	190	190	180	180	180	180
Ca	Lab	EPA 200.7	mg/L	0.03		75	71	80	71	75	71	71	68	70	72	71	78	77	76	75	74	74	73	74	74	69	70	64	64
Cl	Lab	EPA 300.0	mg/L	0.5	250	30	26	29	31	30	28	26	25	27	27	27	28	28	28	28	28	28	29	29	29	29	30	30	27
EC	Lab	EPA 120.1	umho/cm	10	900	730	700	740	730	740	720	680	670	680	690	700	730	720	720	720	730	730	720	730	720	710	710	700	700
F	Lab	EPA 300.0	mg/L	0.1	2	0.26	0.26	0.27				0.27					0.25								0.26		0.24		0.22
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.039	ND	ND	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	ND	ND	ND	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
K	Lab	EPA 200.8	mg/L	1		5.6	5.4	5.3	5.7	5.3	5.1	5.5	5.4	5.2	5.3	5.2	5.6	5.4	5.4	5.3	5.4	5.2	5.4	5.3	5.5	6	6.4	6.4	6.4
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND				ND					ND								0.23		ND		ND
Mg	Lab	EPA 200.8	mg/L	0.5		33	31	34	34	32	31	30	30	30	31	30	33	32	32	32	32	31	32	32	33	33	34	33	33
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.25	0.27	0.240	0.260	0.220	0.210	0.240	0.240	0.240	0.240	0.230	0.250	0.270	0.260	0.220	0.280	0.280	0.270	0.220	0.260	0.240	0.220	0.210	0.180
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	**0.24**	**0.26**	**0.27**	**0.27**	**0.28**	**0.24**	**0.24**	**0.25**	**0.26**	**0.27**	**0.26**	**0.27**	**0.29**	**0.29**	**0.29**	**0.29**	**0.29**	**0.28**	**0.29**	**0.26**	**0.24**	**0.22**	**0.21**	**0.19**
Na	Lab	EPA 200.7	mg/L	0.05		28	26	27	28	27	27	27	27	26	27	26	28	28	27	27	27	27	28	28	29	29	29	28	29
NH3	Lab	EPA 350.1	mg/L	0.05		0.25	0.23	0.22				0.23					0.24								0.24		0.23		0.24
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND				ND					ND								ND		ND		ND
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	ND	ND				ND					ND								ND		ND		ND
P (Total)	Lab		mg/L	0.001		0.45	0.5	0.52				0.52					0.55								0.45		0.45		0.44
pH	Lab	EPA 150.1	Std Units	0.01		8	7.8	7.7	7.7	7.8	7.8	7.8	7.9	7.7	7.9	7.8	7.9	7.6	7.8	7.9	7.8	7.7	7.8	7.6	8	7.9	8.1	7.7	7.8
SiO2	Lab	EPA 370.1	mg/L	2		72	71	75	73	71	71	72	72	73	73	73	71	74	72	73	73	72	73	71	71	73	73	74	70
SO4	Lab	EPA 300.0	mg/L	0.5	250	150	140	150	150	150	150	150	140	150	150	150	160	160	150	150	150	150	140	150	140	130	130	130	130
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND				ND					ND								ND		ND		ND
TDS	Lab	SM2540C	mg/L	5	500	510	480	550	520	510	500	510	460	490	490	520	510	510	520	530	530	540	510	540	510	520	520	500	490
TKN	Lab	EPA 351.2	mg/L	0.2		0.26	0.34	0.3				0.21					0.29								0.26		0.23		
Inorganic Trace Metals																													
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND				ND					ND								ND		ND		ND
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
As	Lab	EPA 200.8	ug/L	1	10	ND	ND	ND				ND					ND								ND		ND		ND
B	Lab	EPA 200.8	ug/L	50		0.085	0.079	0.077				0.082					0.085								0.087		0.093		0.09
Ba	Lab	EPA 200.7	ug/L	1	1000	25	27	29				25					28								28		27		26
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND				ND					ND								ND		ND		ND
Br	Lab	EPA 200.9	ug/L	100		92	86	98	93	90	78	75	72	72	81	83	85	85	86	88	87	89	160	89	83	91	89	90	87
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND				ND					ND								ND		ND		ND
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND		ND		ND
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND				ND					ND								ND		ND		ND
Cu	Lab	EPA 200.8	ug/L	5	1000	ND	ND	ND				ND					ND								ND		ND		ND
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND				ND					ND								ND		ND		ND
I	Lab	EPA 200.8	ug/L	100		6.2	5.9	4.7				4.1					3.5								5.3		ND		ND
Li	Lab	EPA 200.7	ug/L	1		34	43	44				41					44								44		44		49
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND				ND					ND								ND		ND		ND
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND		ND		ND
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND				ND					ND								ND		ND		ND
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND				ND					ND								ND		ND		ND
Sr (Total)	Lab	EPA 200.7	ug/L	1		480	440	480				440					480								460		470		450
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND				ND					ND								ND		ND		ND
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND				ND					ND								ND		ND		ND
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND		ND		ND
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	ND	ND				ND					ND								ND		ND		ND
Bio / Organics																													
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	ND	ND	ND	ND	5.4	2.7	2	2.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HPCs	Lab	SM9215B	CFU	<1		46	1500	2000				1100					810								990		630		690
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		ND	0.7	1.4	0.79	0.77	0.75	1	1	1	0.96	1	0.96	0.89	0.91	0.8	0.8	0.8	0.84	0.76	0.62	0.59	0.6	0.55	0.77
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		1.5	2.4	0.66	0.7	0.75	ND	ND	ND	ND	ND	ND	0.8	0.64	0.65	0.64	0.62	0.76	0.59	0.55	0.66	0.52	0.84	0.52	0.6
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Miscellaneous																													
CH4	Lab	RSK-175	ug/L	5		0.39	0.427	0.392				0.237					0.261								0.289		0.75		0.29
Gross Alpha	Lab	EPA 900.0	pCi/L		15	ND	ND	ND				6					7.1								ND		ND		ND
Color	Lab	SM2120B	Color Units	3	15	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hardness	Lab	SM2340B	mg/L	10		320	300	340				300					330								320		310		300
Tu	Lab	EPA 180.1	NTU	0.1	5	ND	0.11	0.12		0.12	0.17	0.12	ND	ND	0.13	ND	ND	ND	ND	ND	ND	ND	0.12	0.24	ND	ND	ND	0.17	ND
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:

Values denoted in **bold** text exceed MCL.

Table 20. Cory St. #4 Water-Quality Data

Parameter	Location of Analysis	Method	Unit	PQL	MCL	Sample Date																							
Group ID						12/11/19	2/19/19	3/6/19	3/14/19	3/21/19	3/28/19	4/5/19	4/11/19	4/17/19	4/25/19	5/2/19	5/9/19	5/16/19	5/23/19	5/30/19	6/6/19	6/13/19	6/19/19	6/27/19	7/1/19	7/9/19	7/17/19	7/24/19	7/30/19
Field Parameters / Sample Description						Pre-Injection	Cyc 2 Storage	Cyc 3 Injection					Cyc 3 Storage												Cyc 3 Recovery				
Cl Residual	on-site	Hach	mg/L	0.05		ND	ND	0.16	ND	ND	ND	0.01	0.04	0.01	0.04	0.02	ND	0.01	0.01	0.01	ND	0.01	0.01	0.03	0.01	ND	0.01	0.01	0.02
Diss O2	on-site	Hach	mg/L	0.2		1.4	2.2	0.4	0.02	0.02	0.02	0.02	0.07	0.01	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.03	0.02	0.02	0.02	ND	0.02	0.01	0.02
EC	on-site	EPA 120.1	umho/cm	10		729	634	685	531	468	439	411	427	423	386	437	453	456	505	483	494	551	584	487	524	538	548	584	778
ORP	on-site	USGS	mV	10		62.9	-42.8	-55.4	178	17.2	75.8	-6	-80.5	-84.5	-56.9	83.7	16.9	105.9	48.8	106.7	77.1	133.4	92.8	71.1	66.8	7.4	8	1.6	63.8
pH	on-site	EPA 150.1	Std Units	0.01		7.81	7.86	7.85	7.83	7.85	7.73	7.58	7.83	7.83	7.88	7.55	7.65	7.6	7.54	7.53	7.51	7.5	7.52	7.43	7.51	7.57	7.63	7.67	7.69
Temperature	on-site	SM 2550	°C	0.5		23	21.9	23	22.4	19.83	18	17.5	18.63	18.55	18.73	19.7	18.15	18.59	18.44	19.27	19	18.86	19.4	20.4	20.11	20.71	21.13	22.77	23.39
Turbidity	on-site	Hach 2100Q	NTU	0.1		1.28	1.07	1.89	1.85	1.73	1.74	1.80	1.93	1.98	2.07	2.25	2.19	2.31	2.33	2.31	2.40	2.47	2.58	2.91	2.84	2.95	2.87	3.20	3.34
General Mineral Analysis																													
Alkalinity (Total)	Lab	SM2320B	mg/L	5		200	150	200	130	110	100	100	110	110	110	110	110	110	110	110	110	110	100	98	110	110	130	120	160
Ca	Lab	EPA 200.7	mg/L	0.03		35	38	34	32	32	33	31	33	33	34	33	34	34	33	33	32	33	34	33	34	34	35	30	35
Cl	Lab	EPA 300.0	mg/L	0.5	250	47	27	48	27	21	20	19	19	20	20	20	20	20	20	20	19	19	20	19	20	20	23	25	35
EC	Lab	EPA 120.1	umho/cm	10	900	770	590	780	530	460	450	410	430	430	430	430	430	440	430	430	430	420	440	430	440	450	510	550	690
F	Lab	EPA 300.0	mg/L	0.1	2	0.26	0.23	0.26				0.13					0.15								0.14		0.21		0.26
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Fe (Total)	Lab	EPA 200.8	mg/L	0.05	0.3	0.03	0.02	0.02	ND	ND	ND	ND	ND	ND	ND	0.02	0.02	0.02	0.02	0.02	0.02	ND	0.02	0.02	0.03	0.02	ND	ND	ND
K	Lab	EPA 200.8	mg/L	1		8	6.5	7.6	5.9	5	4.6	4.9	5	4.8	4.8	4.8	4.9	5	4.9	5	5	4.9	5.1	4.9	5	4.5	4.9	5.2	6.2
MBAS	Lab	SM 5540C	mg/L	0.05	0.5	ND	ND	ND				ND					ND								ND		ND		ND
Mg	Lab	EPA 200.8	mg/L	0.5		16	17	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	16	16	14	16
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		0.04	0.04	0.040	0.029	0.022	0.024	0.026	0.033	0.030	0.033	0.031	0.031	0.032	0.029	0.025	0.029	0.029	0.030	0.025	0.033	0.035	0.033	0.030	0.033
Mn (Total)	Lab	EPA 200.9	mg/L	0.05	0.05	0.038	0.039	0.038	0.034	0.03	0.026	0.02	0.04	0.03	0.04	0.03	0.03	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.03	0.03	0.03
Na	Lab	EPA 200.7	mg/L	0.05		120	55	120	53	35	28	25	30	29	29	28	28	30	28	28	27	27	31	29	30	34	44	57	82
NH3	Lab	EPA 350.1	mg/L	0.05		0.9	0.8	0.82				0.56					0.59								0.61		0.62		0.72
NO2	Lab	EPA 300.0	mg/L	0.1	1	ND	ND	ND				ND					ND								ND		ND		ND
NO3 (as N)	Lab	EPA 300.0	mg/L	0.1	10	ND	ND	ND				ND					ND								ND		ND		ND
P (Total)	Lab		mg/L	0.001		0.26	0.14	0.18				0.16					0.21								0.14		0.16		0.15
pH	Lab	EPA 150.1	Std Units	0.01		8.1	8	8	8.1	8	7.9	7.8	8.1	7.8	7.8	7.9	8	7.9	7.9	8	7.8	7.9	7.8	8	8	8.1	8	8.1	8
SiO2	Lab	EPA 370.1	mg/L	2		46	50	45	47	36	32	29	30	31	31	30	31	31	31	32	31	32	32	31	32	34	35	34	36
SO4	Lab	EPA 300.0	mg/L	0.5	250	120	98	120	96	84	78	70	71	72	73	73	72	74	72	72	70	68	71	70	71	78	88	97	110
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		ND	ND	ND				ND					ND								ND		ND		ND
TDS	Lab	SM2540C	mg/L	5	500	480	400	500	340	290	290	270	260	270	270	280	260	280	260	270	270	280	270	280	270	270	330	350	420
TKN	Lab	EPA 351.2	mg/L	0.2		0.83	0.96	0.92				0.52					0.62								0.57		0.57		
Inorganic Trace Metals																													
Ag	Lab	EPA 200.8	ug/L	10	100	ND	ND	ND				ND					ND								ND		ND		ND
Al	Lab	EPA 200.8	ug/L	10	200	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
As	Lab	EPA 200.8	ug/L	1	10	ND	ND	ND				ND					ND								ND		ND		ND
B	Lab	EPA 200.8	ug/L	50		0.4	0.18	0.42				0.077					0.092								0.096		0.15		0.28
Ba	Lab	EPA 200.7	ug/L	1	1000	21	18	21				12					12								13		13		16
Be	Lab	EPA 200.8	ug/L	1	4	ND	ND	ND				ND					ND								ND		ND		ND
Br	Lab	EPA 200.9	ug/L	100		170	91	180	68	61	41	40	38	41	41	43	41	43	41	42	37	37	42	41	41	39	59	70	140
Cd	Lab	EPA 200.8	ug/L	1	5	ND	ND	ND				ND					ND								ND		ND		ND
Co	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND		ND		ND
Cr	Lab	EPA 200.8	ug/L	10	50	ND	ND	ND				ND					ND								ND		ND		ND
Cu	Lab	EPA 200.8	ug/L	5	1000	2.1	ND	ND				ND					ND								ND		ND		ND
Hg	Lab	EPA 200.8	ug/L	0.025	2	ND	ND	ND				ND					ND								ND		ND		ND
I	Lab	EPA 200.8	ug/L	100		14	8.9	13				3.9					3.8								5.5		ND		ND
Li	Lab	EPA 200.7	ug/L	1		100	69	100				23					28								28		42		76
Ni	Lab	EPA 200.8	ug/L	1	100	ND	ND	ND				ND					ND								ND		ND		ND
Pb	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND		ND		ND
Sb	Lab	EPA 200.8	ug/L	1	6	ND	ND	ND				ND					ND								ND		ND		ND
Se	Lab	EPA 200.8	ug/L	5	50	ND	ND	ND				ND					ND								ND		ND		ND
Sr (Total)	Lab	EPA 200.7	ug/L	1		63	66	61				55					56								58		59		60
Tl	Lab	EPA 200.8	ug/L	1	2	ND	ND	ND				ND					ND								ND		ND		ND
U	Lab	EPA 200.8	ug/L	0.5		ND	ND	ND				ND					ND								ND		ND		ND
V	Lab	EPA 200.8	ug/L	1		ND	ND	ND				ND					ND								ND		ND		ND
Zn	Lab	EPA 200.8	ug/L	10	5000	ND	23	ND				ND					ND								ND		ND		ND
Bio / Organics																													
HAA5's	Lab	EPA 552.2	ug/L	1	60	ND	ND	ND	10	3.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
HPCs	Lab	SM9215B	CFU	<1		360	680	1100				1700					1700								1500		680		620
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1		1.5	0.9	1.1	0.8	1.6	1.3	1.2	1.1	1	1.1	1.1	1.1	1.1	1	1.1	1.1	1	1.2	1.2	0.91	1	1	1.2	1.1
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1		0.75	1.4	0.75	1.4	1.2	0.6	ND	0.3	ND	ND	ND	0.95	0.88	0.84	0.88	1	0.99	0.85	0.86	1.1	0.99	1.1	1.3	1
TTHM's	Lab	EPA 502.2	ug/L	1	80	ND	0.58	ND	4.4	8.8	9.1	6.6	2.2	1.2	0.56	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Miscellaneous																													
CH4	Lab	RSK-175	ug/L	5		3.74	3.29	2.98				ND					0.326								0.384		2.7		2.7
Gross Alpha	Lab	EPA 900.0	pCi/L		15	ND	ND	3.6				ND					ND								ND		ND		4.1
Color	Lab	SM2120B	Color Units	3	15	ND	ND	ND	ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Hardness	Lab	SM2340B	mg/L	10		150	160	150				140					150								150		150		150
Tu	Lab	EPA 180.1	NTU	0.1	5	0.64	0.34	0.12	0.13	ND		ND	ND	0.11	ND	0.15	ND	ND	0.1	0.24	0.1	0.1	0.25	0.14	0.12	0.21	ND	0.35	ND
TSS	Lab	EPA 160.2	mg/L	1		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Notes:
Values denoted in **bold** text exceed MCL.

Based on review of the chemistry of injected and native groundwaters, chloride ion was identified as a natural tracer, or "tag" ion to differentiate the two waters. Chloride ion was selected as a viable tracer based on the following criteria:

1. It does not degrade in the subsurface environment.
2. It does not readily adsorb on aquifer minerals.
3. It rarely participates in ion exchange reactions with aquifer minerals.
4. The ion ratio is approximately 2:1 between the native groundwater and injectate, thus providing a robust ion differential[11].
5. The analytic detection of chloride ion is highly reliable, inexpensive, and has no "interference" with other ion concentrations present in the aqueous mix.

Although sulfate ion is also often used as a natural tracer, in this case the two waters had similar sulfate concentrations; therefore, no differentiation could be accurately discerned.

As ISR cycles progressed, chloride ion was monitored to determine the mix ratio of injected and native groundwaters, and to "dilution correct" the compositional analysis of other pertinent constituents in the evaluation of subsurface degradation, oxidation, or ion exchange processes. Water quality was monitored at the following ASR process points during the pilot test project:

1. **Injection Supply**. Monitored for all constituents to establish a baseline of injected water quality.
2. **ASR Well**. Monitored for all constituents during storage and recovery of injected water to assess subsurface mixing and reactions occurring during storage.
3. **Monitoring Wells**. Monitored for general mineral and redox parameters to assess the occurrence of ion exchange and/or redox reactions in the subsurface.

The results of the chloride analysis versus pumping time (and recovered water volume) for ASR Cycles 1, 2, and 3 recovery tests are presented on **Figures 21, 22 and 23**, respectively. A comparison of the recovery efficiency for ASR Cycles 1, 2, and 3 Recovery Tests is presented **Figure 24**.

As shown, during ASR Cycles 1 and 3 Recovery Tests, there was relatively little early contribution of chloride (from the native groundwater), whereas during ASR Cycle 2 Recovery Test, there was a more significant early contribution of chloride, which is indicative of a higher degree of intermixing in the subsurface during ASR Cycle 2 Storage Period compared to the other two ASR Cycles. At the approximate 50 percent volume recovery levels, however, all three tests showed comparable levels of dilution, with the water still containing approximately 20 to 30 percent injectate. Similarly, at the 100 percent volume recovery level, all three tests contained approximately 50 to 70 percent injectate. At the end of ASR Cycle 1 Recovery Period, which was after 150 percent of the previously injected volume had been recovered, the

[11] Pre-injection native groundwater at Beltz 12 showed a chloride level of 33 mg/L, whereas the GHWTP injected water averaged 18 mg/L (ratio of 1.8:1)

pumped water had essentially reverted completely to 100 percent native groundwater, and at the end of ASR Cycle 2 only approximately 6 percent contribution from the injected water remained. The ASR Cycle 3 Recovery Test volume was limited to 100 percent of the injected volume, at which point the water consisted of approximately 54 percent injectate/46 percent native groundwater, indicating a moderate amount of intermixing and the development of significant buffer zone at the ASR well.

It is important to note that the test program called for recovery of 150 percent of the ASR Cycle 1 and 2 injected volumes in order to assess water-quality interactions; by recovering 100 percent or less of the injected amount, the buffer zone would be developed more rapidly than under the test conditions (i.e., as was the case with ASR Cycle 3).

The recovery results are, nonetheless, within the range of values seen in other ASR installations. **Figure 25** shows an idealized recovery curve for aquifer storage, and also presents the Beltz 12 ASR Cycle 1 results in a comparison with other data; the Beltz 12 results are in the range of expected recovery efficiency for a first ASR cycle test. As repeated cycles are performed, the "buffer" zone increases in size and water quality, and the well recovery curve will likely trend increasingly towards the idealized curve shown on **Figure 25**.

Disinfection Byproducts

The occurrence and fate of DBP's has been the subject of concern for ASR programs. Both Total Trihalomethanes (TTHMs) and Haloacetic acids (HAAs) occur as a result of free chlorine reacting with organic materials present in the injected and/or native groundwater and these compounds are regulated within Title 22 standards due to their known carcinogenic potential in humans. For ASR operations, it is generally desirable to maintain a free chlorine residual in injection waters to both maintain potability and to mitigate biofouling in the well screens and near-borehole aquifer zone. Unfortunately, the presence of free chlorine residual in injected waters also often supports the continued creation of DBP's during aquifer storage due to the presence of even minor amounts of organic compounds in the injected water, the native groundwater, and even in the aquifer mineral matrix. This continued DBP creation is referred to as "ingrowth" and can continue during aquifer storage operations until the supply of free chlorine or organic material is exhausted.

DBP reactivity typically includes both ingrowth and decay processes; however, they can vary substantially based on the specific DBP compound, the character of the injected and native groundwaters, the aquifer mineralogy, organic content, and other factors.

For the Beltz 12 ASR Pilot Test Program we focused our evaluation of DBP occurrence on ASR Cycle 3, as ASR Cycles 1 and 2 cycles were of insufficient duration to fully assess DBP processes. **Figures 26 and 27** graphically present the DBP data for ASR Cycle 3 for both TTHM and HAA compounds, respectively.

THM behavior apparent in **Figure 26** during ASR Cycle 3 showed the following trends:

- THM ingrowth during aquifer storage did not occur, as is often observed at other ASR sites, and THMs at all times were well below the state Maximum Contaminant Level (MCL) of 80 micrograms per liter (ug/L)

- Dilution-corrected THM values peaked after approximately 10 days of storage, followed by a slow decay over the next 30 days and were less than 1.0 ug/L after approximately 50 days.
- The onset of THM decay corresponded with a decline in redox conditions. Oxidation-Reduction Potential (ORP) values declined from approximately +600 mV for the injectate to less than approximately +20 mV as THM degradation occurred during aquifer storage. This correlation between declining redox potential and THM degradation is consistent with the majority of other ASR operations observed by PWR.
- Migration of the recharge water and its THM content was only observed at the proximate Cory St. #4 monitoring well; near the end of the ASR Cycle 3 Injection Test, the well showed an approximately 75 percent influence of injected water and a dilution-corrected THM concentration of 11.9 ug/L, while concurrent sampling at the ASR test well showed an injectate value of 35 ug/L. This attenuation could be the result of aquifer matrix absorption and/or other geochemical reactions. THMs were non-detect (ND) at Cory #4 within 4 weeks of aquifer storage and at both Cory St. Medium and Deep monitoring wells throughout the test program.

HAA behavior followed a similar trend of near-immediate decay following the cessation of injection; however, the process was more rapid than with THMs. This accelerated degradation behavior is typical of HAA reactivity in our experience at other ASR sites. Specific HAA trends apparent in **Figure 27** include the following:

- HAA ingrowth during aquifer storage did not occur, as is often observed at other ASR sites, and HAAs at all times were well below the state MCL of 60 ug/L.
- Dilution-corrected HAA values also peaked after approximately 10 days of storage, followed by a more rapid decay over the next 20 days and were essential non-detectable after approximately 40 days of aquifer storage.
- As with THMs, the onset of HAA decay corresponded with a decline in redox conditions, and this correlation between declining redox potential and HAA degradation is also consistent with the majority of other ASR operations observed by PWR.
- Migration of the recharge water and its HAA content was observed at the all three of the proximate Cory St. monitoring wells. Near the end of the ASR Cycle 3 Injection Test, the Medium well showed a concentration of 4.7 ug/L, while concurrent sampling at the ASR test well showed an injectate value of 31 ug/L. As with THMs, this attenuation could be the result of aquifer matrix absorption and/or other geochemical reactions. HAAs persisted for approximately 8 weeks into the Cycle 3 Storage Period at the Medium well, becoming non-detect for the remainder of the storage period and throughout the recovery period. The Deep monitoring well showed a similar pattern, but became non-detect within approximately 2 weeks of aquifer storage. HAAs were only detected at the #4 well for a couple of weeks during the Cycle 3 Injection Period and were non-detect throughout the remainder of the test program.

Overall, the behavior of DBP's was generally consistent with, but even more favorable than, other ASR programs utilizing slightly anoxic aquifer systems. The results are considered more favorable than typical because DBPs did not show the typical period of DBP ingrowth followed by decay; rather, DBPs at the Beltz 12 site began degrading within approximately 1 week of aquifer storage. It should be noted that both the chlorine residual and organic carbon content of the GHWTP injectate were fairly typical of other ASR injectate sources. The mechanism(s) associated with DBP degradation during aquifer storage are not completely understood, but some investigators have suggested it may be associated with subsurface microbial activity (e.g., iron- and/or sulfate-reducing bacteria), which may be at least part of the cause for the observed levels of degradation at the Beltz 12 site. Nonetheless, DBP fate should be carefully monitored in subsequent longer-term ASR testing and/or a permanent ASR program at the site, concurrent with redox conditions monitoring.

Leaching Reactions

ASR projects typically involve the conjunctive utilization of waters that have different origins, and in most cases the quality of the recharge and receiving (i.e., native aquifer) waters are measurably different. In a broad context, water-quality changes during aquifer storage can occur from simple dilution/mixing (as discussed above) as well as chemical interaction between injected and native groundwaters and/or from reactions between the newly introduced injection water and the aquifer minerals. The potential for adverse chemical reaction during ASR operations therefore exists and can occur under certain circumstances. Specifically, experience at some other ASR sites has shown the potential for the leaching of undesirable regulated metals from aquifer minerals in recovered waters that can affect potability, such as the following constituents:

- Arsenic (As)
- Mercury (Hg)
- Nickel (Ni)
- Uranium (U)

During the Beltz 12 ASR Pilot Test Program, the SAP implemented included robust monitoring of these constituents, as well as all other Title 22 regulated metals. As noted previously, **Tables 15, 16, and 17** provide the laboratory results for Beltz 12 from ASR Cycles 1, 2 and 3, respectively, and **Tables 18, 19 and 20** provide laboratory results for Cory St. Medium, Deep and #4, respectively.

As shown, the native groundwater at Beltz 12 was below the detection limit for Arsenic, but the GHWTP injected water contained detectable, but less than the Practical Quantification Limit of 1.0 ug/L (compared to the MCL of 10 ug/L). The stored and recovered water sampling results showed no increases in Arsenic levels. Similarly, Mercury was not detected in any sample collected from Beltz 12 during the test program. Neither Arsenic nor Mercury was detected in any sample collected from the Cory St. monitoring wells.

Uranium was essentially non-detect throughout the testing program, with the exception of two samples collected during ASR Cycle 2 Recovery Test of 1.2 and 1.3 ug/L. It is noted that throughout the much longer-term ASR Cycle 3 program, Uranium was not detected, suggesting the two sample detection results during ASR Cycle 2 may be anomalous. Uranium was not detected in any sample collected from the Cory St. monitoring wells.

Overall, the Beltz 12 ASR Pilot Test results tend to confirm the geochemical interaction analysis performed as part of the Phase 1 Technical Feasibility Investigation, which showed no potential for adverse leaching of undesirable constituents during ASR operations at the site.

Beneficial Reactions

Water quality was also monitored during the recovery phase to evaluate the potential occurrence of "beneficial" reactions during aquifer storage. For this project, the native groundwater is demerited by the presence of manganese (Mn) at 0.35 mg/L, compared to the MCL of 0.05 mg/L. The Phase 1 geochemical interaction analysis identified a potential ancillary benefit of aquifer recharge with treated GHWTP water, which could be the reduction of manganese in the stored and recovered waters, perhaps persisting after 100 percent of the previously injected water has been recovered.

Figure 28 presents Mn data for the stored and recovered water in ASR Cycle 3. As the graph shows, the presence of Mn in the stored water showed an early increase during the initial 20 days of storage compared to the injected water, peaking at a value of 0.21 mg/L, followed by a decline during the remainder of the storage period. At the start of the recovery period, the Mn concentration was approximately 0.06 mg/l, and gradually increased during the recovery period, with a final measured concentration of 0.20 mg/L after 100 percent of the previously injected volume had be recovered. This compares to the native groundwater concentration of 0.35 mg/L, representing a significant improvement; however, further review of the dilution-corrected data shows that the reduced Mn concentrations during recovery were due primarily to mixing and dilution, rather than redox-related “conditioning” of the aquifer matrix near the ASR well.

These results indicate that during future ASR operations at the well, the Mn concentrations will likely be significantly improved compared to the native groundwater at the initial stages of recovery pumping periods due to mixing and dilution in the buffer zone around the well, but as recovery pumping progresses, the concentrations can be expected to gradually increase back to native groundwater concentrations.

ASR CAPACITY ANALYSIS

Recovery Pumping Capacity

The pumping capacity of any given well is a function of specific capacity and the available drawdown in the well. While this relationship seems relatively straightforward, it is complicated by the fact that both factors vary with the duration of pumping. In addition, available drawdown itself can vary, depending on the operational assumptions utilized in its calculation. The pumping capacity of an ASR well is somewhat unique in that it needs to be considered for the two different primary pumping duties it will need to perform during its service life:

1. Backflush pumping (short-term), and,
2. Recovery pumping (long-term)

An evaluation of the Beltz 12 capacity for each of these pumping duties is presented below:

Short-Term Pumping Capacity. As discussed previously, no source of injection water is completely free of particulates; therefore, backflushing (i.e., pumping) of ASR wells must be routinely performed to create flow reversals in the well, which removes particles introduced into the well during injection (this is analogous to backwashing of media filters to clean the filter media). Periodic, vigorous backflushing is necessary to maintain injection capacity and remove the particulate loading of the gravel pack and well bore. The ability to adequately backflush ASR wells while maintaining a flooded perforated section, therefore, is a critically important consideration when designing and operating ASR wells.

Backflush pumping is typically a short-duration operation of one hour (or less); therefore, estimating the backflushing capacity by multiplying the 24-hour specific capacity by the entire available drawdown is a conservative way to account for variations in aquifer water levels and gradual losses in well efficiency that may occur over the life cycle of the well. The best operational practice for pumping wells is to maintain pumping water levels above the perforations in order to avoid cascading water conditions, which can result in air entrainment and increased wear on the pump and discharge piping. The maximum available drawdown in the well is, therefore, typically defined to be the amount of water above the top of the screen.

The available drawdown at Beltz 12 is approximately 100 feet, based on the top of screen at 200 feet and a conservative static water level of approximately 100 feet. As presented previously, Beltz 12 displays a 24-hour specific capacity of approximately 7 gpm/ft, which yields a theoretical backflushing capacity estimate of approximately 700 gpm.

It is noted that the theoretical well pumping capacity may be practically limited by the capacity of the pump that is installed in the well. Based on our review of the existing Beltz 12 pump curve (Berkley 8T-750), the existing pump is capable of pumping approximately 900 gpm @ 200 ft of total dynamic head (TDH) and is, therefore, adequate for backflushing capacity purposes.

Long-Term Pumping Capacity. While no strict guidelines exist for determining the recommended long-term pumping rates for wells, a typical rule-of-thumb for estimating the long-term production rate of a well completed in semi-consolidated sediments is to multiply the 24-hour specific capacity by two-thirds of the available drawdown. Utilizing two-thirds of the available drawdown is a conservative way to account for variations in pumping durations, seasonal changes (long-term or short-term) in aquifer water levels, and gradual losses in well efficiency that may occur over the life cycle of the well.

As discussed above, the available drawdown in Beltz 12 is estimated to be 100 feet. Two-thirds of the available drawdown of 100 feet is approximately 67 feet, which yields a theoretical rule-of-thumb long-term pumping capacity estimate of approximately 470 gpm (7 gpm/ft x 67 feet).

An alternative, more rigorous method of determining the long-term pumping capacity of a well can be developed through analysis of the drawdown curve for a specific pumping scenario. The long-term hydraulic response of a well and aquifer to pumping is a logarithmic function, and the drawdown (and corresponding specific capacity) for any given pumping duration scenario can be reasonably predicted by extrapolating the time-drawdown curve with a straight line plotted on a semi-log plot. The extrapolated specific capacity is multiplied by available drawdown to calculate the long-term pumping capacity.

The anticipated ASR recovery pumping period for Beltz 12 ranges between approximately 6 months for seasonal recovery scenarios up to 2 years for an extended drought scenario. As shown on **Figure 29**, extrapolation of the time-drawdown curve results in an estimated 6-month pumping water level of approximately 186 ft bgs, corresponding to approximately 85 ft of drawdown and a conservative 6-month specific capacity of 4.79 gpm/ft. Utilizing an available drawdown of 100 feet yields a 6-month sustainable pumping capacity of approximately 479 gpm (4.79 gpm/ft x 100 ft). Further extrapolation of the time-draw curve results in an estimated 2-year specific capacity of 4.33 gpm/ft, yielding a 2-year sustainable pumping capacity of 433 gpm.

In summary, the short-term backflushing pumping capacity of Beltz 12 is approximately 700 gpm. The long-term pumping capacity ranges between approximately 430 and 480 gpm (average of 455 gpm) depending on the assumptions utilized.

Injection Capacity

The injection capacity of any given dual-purpose ASR well is dependent on a variety of site-specific factors, which can be generally categorized into issues associated with;

1) well response to injection
2) aquifer response to injection

Examples of issues associated with the well response include allowable drawup within the well casing before some head limitation is reached, and the available drawdown for well backflushing. Issues associated with aquifer response to injection involve the available "freeboard" in the aquifer for water levels (piezometric head) to be increased without inducing undesirable results. As part of the Phase 1 Technical Feasibility Investigation, PWR analyzed the various site-specific factors affecting the injection capacity of Beltz 12 and developed a theoretical injection capacity estimate of approximately 440 gpm, which was constrained by the "hydro fracturing" criterion (an aquifer response to injection criterion) [12].

Analysis of the results of the Beltz 12 well response to injection during the ASR Pilot Test Program allows for an empirically-based well response to injection capacity estimate utilizing similar methods applied to pumping capacity analysis presented above. The injection capacity of any given well is also a function of injection specific capacity (aka specific injectivity) and the available drawup in the well before some head limitation is reached. During injection, the water level (head) in the injection well and aquifer will increase due to mounding in the aquifer. The available "freeboard" for water level drawup in the well casing for injection is

[12] Pueblo Water Resources, Inc. (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department. Excessive injection heads can lead to "hydro fracturing" of confining layers, which can create vertical cracks in the confining layers through which injected water may flow upward into overlying sediments or to the ground surface

determined based on the depth to water prior to injection (static water level) plus the amount of wellhead pressurization considered reasonable (if any). For purposes of this analysis, it is conservatively assumed that no casing pressurization during injection will be allowed; therefore, the maximum drawup water-level in the well casing is at the ground surface.

Given a conservative pre-injection static water level of approximately 90 feet bgs, two-thirds of the available drawup is approximately 60 feet. As discussed previously, Beltz 12 displayed 24-hour specific injectivities ranging between approximately 5.97 and 6.20 gpm/ft, averaging 6.11 gpm/ft. Utilizing the average value yields a theoretical rule-of-thumb long-term injection capacity estimate of approximately 370 gpm (6.11 gpm/ft x 60 feet).

Similar to pumping capacity analysis, a more rigorous method of determining the long-term injection capacity of Beltz 12 can be developed through analysis of the drawup curves for a specific injection scenario. As discussed previously, in the absence of plugging, the long-term hydraulic response of a well to injection is also a logarithmic function, and the drawup (and corresponding specific injectivity) for any given injection duration scenario can be reasonably predicted by extrapolating the time-drawdown curve with a straight line plotted on a semi-log plot (assuming the well is routinely backflushed to limit the long-term effects of plugging). The extrapolated specific injectivity is multiplied by available drawup to calculate the long-term injection capacity.

The anticipated ASR injection period for Beltz 12 is 6 months (i.e., during the period of excess available flows during the months of November through April). The water-level drawup curves for the initial week of injection (approximately 10,000 minutes) for ASR Cycles 2 and 3 Injection Tests[13] are shown on **Figures 30 and 31**, respectively.

As shown on **Figure 30**, extrapolation of the ASR Cycle 2 Injection Test time-drawup curve (in the presence of 1 week plugging rate) results in an estimated 6-month injection water-level of approximately 15 ft above ground surface (ags) at an injection rate of 391 gpm, corresponding to approximately 113 ft of drawup and a 6-month specific injectivity of 3.45 gpm/ft. Again, utilizing a conservative total available drawup value of 90 feet yields a 6-month sustainable injection capacity of approximately 310 gpm (3.45 gpm/ft x 90 ft). As shown on **Figure 31**, similar extrapolation of the first week of the ASR Cycle 3 Injection Test time-drawup curve results in an estimated 6-month specific injectivity of 3.39 gpm/ft and a corresponding 6-month sustainable injection capacity of approximately 305 gpm (3.39 gpm/ft x 90 ft).

ASR Capacity Summary

In summary, the long-term injection capacity based on analysis of the ASR pilot test data ranges between approximately 305 and 370 gpm, and the long-term recovery pumping capacity ranges between approximately 430 and 480 gpm, depending on the assumptions utilized. It is noted that these capacities are approximately 15 to 30 percent less than the theoretical rates derived from the Phase 1 Technical Feasibility Analysis. It should be understood that the theoretical rates derived from the Phase 1 analysis were based on estimates of well and aquifer

[13] ASR Cycle 1 Injection Test as only 1-day in duration and, therefore, of less value for purposes of this analysis compared to the longer-duration ASR Cycles 2 and 3 Injection Tests.

response to injection and pumping utilizing industry-standard groundwater equations (e.g., the Theis Equation). These equations are necessarily based on simplifying assumptions about the aquifer system, such as being homogenous, isotropic and infinite in areal extent, whereas actual aquifers are more complex, being heterogeneous, non-isotropic and limited in areal extent. Accordingly, one of the main purposes of performing ASR pilot tests is to field test (or "ground truth") the analytically-derived estimates, which by definition are approximations, because the rates derived from analysis of empirical testing data take into account the actual field conditions at the site (e.g., heterogeneity in the aquifer system and/or basin boundary effects) that affect water-level responses to injection / pumping and are, therefore, more reliable.

CONCLUSIONS

Based on our evaluation of the data and findings developed from the Betlz 12 ASR Pilot Test Program, we conclude the following:

WELL AND AQUIFER HYDRAULICS

Based on the preliminary analysis of the various factors affecting theoretical injection capacity performed by PWR as part of the Phase 1 Technical Feasibility Investigation, it was *estimated* that Beltz 12 had a long-term injection capacity of approximately 400 gpm. The ASR pilot test program was designed around this rate, and actual injection testing rates ranged between approximately 375 to 405 gpm. Analysis of the ASR testing program results showed the following key findings:

- The 6-month sustainable injection rate is estimated to range between approximately 305 and 370 gpm (0.44 to 0.53 mgd) while maintaining water levels below ground surface, depending on the assumptions utilized. On a seasonal storage basis, this is equivalent to injecting approximately 80 to 100 million gallons (mg) of surplus water over a 6-month injection season.
- Observed active plugging rates were relatively low, averaging approximately 1.4 ft/d (normalized rate of 0.18 ft/d). The low plugging rates are due largely to the low particulate content (as measured by Silt Density Index) and maintenance of pH below 7.6 of the GHWTP source water.
- No residual plugging of Beltz 12 was observed at the end of the ASR pilot test program, indicating that the weekly double-backflush routine was effective at maintaining overall well performance.
- The observed responses of the aquifer system to injection at various rates and durations at Beltz 12 were generally greater than the expected responses; however, water levels in the aquifer system were maintained below ground surface at all times, indicating that the aquifer system is capable of receiving recharge at Beltz 12 without undesirable results.
- The short-term backflushing capacity is approximately 700 gpm, which is approximately two-times the estimated injection capacity and, therefore, adequate for ongoing ASR operations.
- The long-term recovery pumping capacity is estimated at approximately 455 gpm. This long-term rate is equivalent to approximately 480 mg over a 2-yr drought period.

WATER QUALITY

The Beltz 12 ASR pilot test program results were in general agreement with the geochemical interaction analysis performed by PWR as part of the Phase 1 Technical Feasibility Investigation, and generally indicated the following key findings:

- The use of GHWTP produced waters appears to be suitable for ASR operations utilizing the AA and Tu Units of the Purisima Aquifer system.

- The program results verified that stored waters maintained full Title 22 compliance at the conclusion of all three ASR Cycles, both in waters stored in the aquifer and in the recovered waters.
- The generally low levels of active well plugging during ASR operations, and the restoration of well performance after well backflushing, support the lack of well and/or aquifer porosity plugging due to adverse water-quality reactions.
- The above evidence of limited well plugging is especially convincing in the case of Beltz 12 due to the relatively low transmissivity of the subject aquifer system; plugging mechanisms are especially amplified in low-permeability aquifer systems, and if present would be highly evident in well performance reduction.
- Disinfection Byproducts showed a very favorable degradation reaction during aquifer storage, with no apparent ingrowth period and both THMs and HAAs steadily degrading to near non-detect levels within 40 days of cessation of injection.
- No leaching of regulated metals or other constituents of concern was observed.
- The evaluation of changes in other water-quality constituents during ASR pilot testing were found to be predominantly the result of simple dilution/mixing mechanisms, further supporting the lack of significant geochemical interaction.
- Overall, the test program results did not identify any fatal flaws or critical issues with respect to water quality that would jeopardize the feasibility of long-term ASR program implementation.

RECOMMENDATIONS

Based on the findings and conclusions developed from the Beltz 12 ASR Pilot Test Program, and our experience with similar ASR projects, we offer the following recommendations:

- Given the favorable results of the pilot test program, Beltz 12 should be converted to a permanent ASR facility, which will require the following minimum items:
  a) Compliance with CEQA requirements for a permanent ASR project at the site.
  b) Filing of a Notice of Intent (NOI) to operate the facility as a permanent ASR facility with the Central Coast RWQCB under the Statewide General ASR Order (Water Quality Order 2012-0010). The results of the subject ASR pilot test will provide the information needed to support an NOI application for a permanent ASR facility.
  c) Installation of a downhole control valve (FCV) on the existing permanent pump assembly (either a Baski Valve or V-Smart Valve) for controlling injection flows into the well.
  d) Modifications to the site facility's piping, valving and metering to allow injection at the well (via the pump column and a new FCV) using source water from the SCWD distribution system.

- For planning purposes, a long-term operational ASR capacity of approximately 335 gpm injection and 455 gpm recovery pumping is recommended (equivalent to approximately 0.48 and 0.65 mgd, respectively).
- During injection periods, routine backflushing at 700 gpm should be performed on a weekly basis (minimum) to limit residual plugging and maintain long-term well performance. The backflushing procedure should consist of the same double-backflush procedure developed for and implemented during the ASR pilot test program.
- Permanent ASR operations at the well should include ongoing monitoring for geochemical interactions during aquifer storage and ASR recovery, with particular focus on long-term water-quality interactions such as solubilization/leaching and DBP fate processes. An appropriate Sampling and Analysis Plan (SAP) should be developed and included in the NOI for a permanent ASR facility.
- The existing groundwater flow model of the MCGB should be used to cross-check model predicted results with the observed aquifer responses to the ASR Pilot Test Program and recalibrated, as warranted.
- Based on the favorable water-quality results from ASR Cycle 3 at Beltz 12, which generally corroborated the Phase 1 geochemical interaction analysis, ASR pilot testing of future ASR wells that are also completed in the AA and Tu Units in the Beltz wellfield can likely be limited to two ASR cycles similar to ASR Cycles 1 and 2 implemented at Beltz 12, with focus on establishing site-specific sustainable injection/extraction rates and backflushing requirements (i.e., be limited to an approximate 2-month vs 6-month ASR pilot test program).

CLOSURE

This report has been prepared exclusively for the Santa Cruz Water Department for the specific application to the Beltz 12 ASR Pilot Test Project. The findings, conclusions, and recommendations presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

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REFERENCES

American Society of Civil Engineers (2001), *Standard Guidelines for Artificial Recharge of Ground Water*.

Brabb, E.E. (1997), *Geologic Map of Santa Cruz County, California: A digital database*, USGS Open-File Report 97-489.

California Department of Water Resources (2003), *Bulletin 118: California's Groundwater.*

Driscoll, F.G. (1986), *Groundwater and Wells, Second Edition*, published by Johnson Screens.

Hopkins Groundwater Consultants, Inc. (2004), *Summary of Operations Report, City of Santa Cruz Live Oak Monitoring Well and Test Well Project, Live Oak, California*, prepared for Carollo Engineers.

Huisman, L., and Olsthoorn, T.N. (1983), *Artificial Groundwater Recharge*, Delft University of Technology, Pitman Advanced Publishing Program.

Johnson, N.M., et al. (2004), *Groundwater Assessment of Alternative Conjunctive Use Scenarios, Technical Memorandum 2: Hydrogeologic Conceptual Model*, prepared for Soquel Creek Water District.

Meinzer, O.E., Editor (1942), *Hydrology*, McGraw Hill Book Company, New York, NY.

Pueblo Water Resources, Inc. (2013), *Summary of Operations, Well Construction and Testing, City of Santa Cruz Beltz Well No. 12*, prepared for City of Santa Cruz Water Department.

- (November 2016), *Task 1.1 Existing Wells Screening*, Technical Memorandum prepared for Santa Cruz Water Department (revised draft).
- (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.
- (August 2017), *Geochemical Interaction Analysis (Task 1.3)*, Technical Memorandum prepared for Santa Cruz Water Department (draft).
- (April 2018), *Task 1.4 ASR Pilot Test Work Plan for Beltz 12*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

Pyne, R.D. (1994), *Ground Water Recharge and Wells*, Boca Raton, Florida, CRC Press.

State Water Resources Control Board (1968), *Statement of Policy with Respect to Maintaining High Quality of Waters in California*, Resolution No. 68-16.

- (2012), *General Waste Discharge Requirements for Aquifer Storage and Recovery Projects that Inject Drinking Water into Groundwater,* Water-Quality Order 2012-0010.

Theis, C.V. (1935), *Relationship Between Lowering of Piezometer Surface on the Fate and Duration of Discharge of a Well Using Ground Water Storage*, Transactions of the Geophysical Union, vol. 16, pp. 519-524.

Walton, W.C. (1991), *Principles of Groundwater Engineering*, Lewis Publishers.

FIGURES

June 2020
Project No. 15-0112

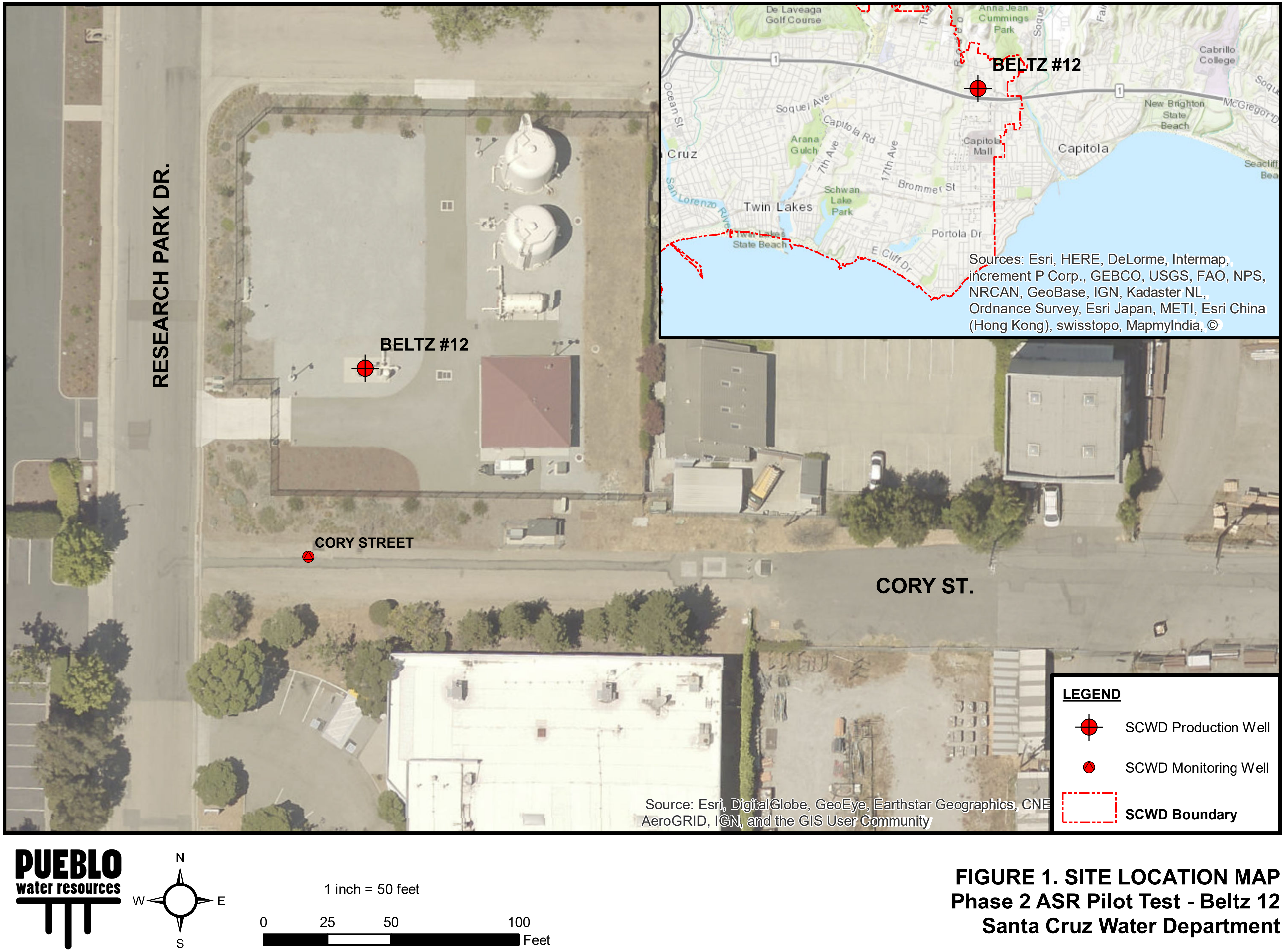

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FIGURE 1. SITE LOCATION MAP
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112

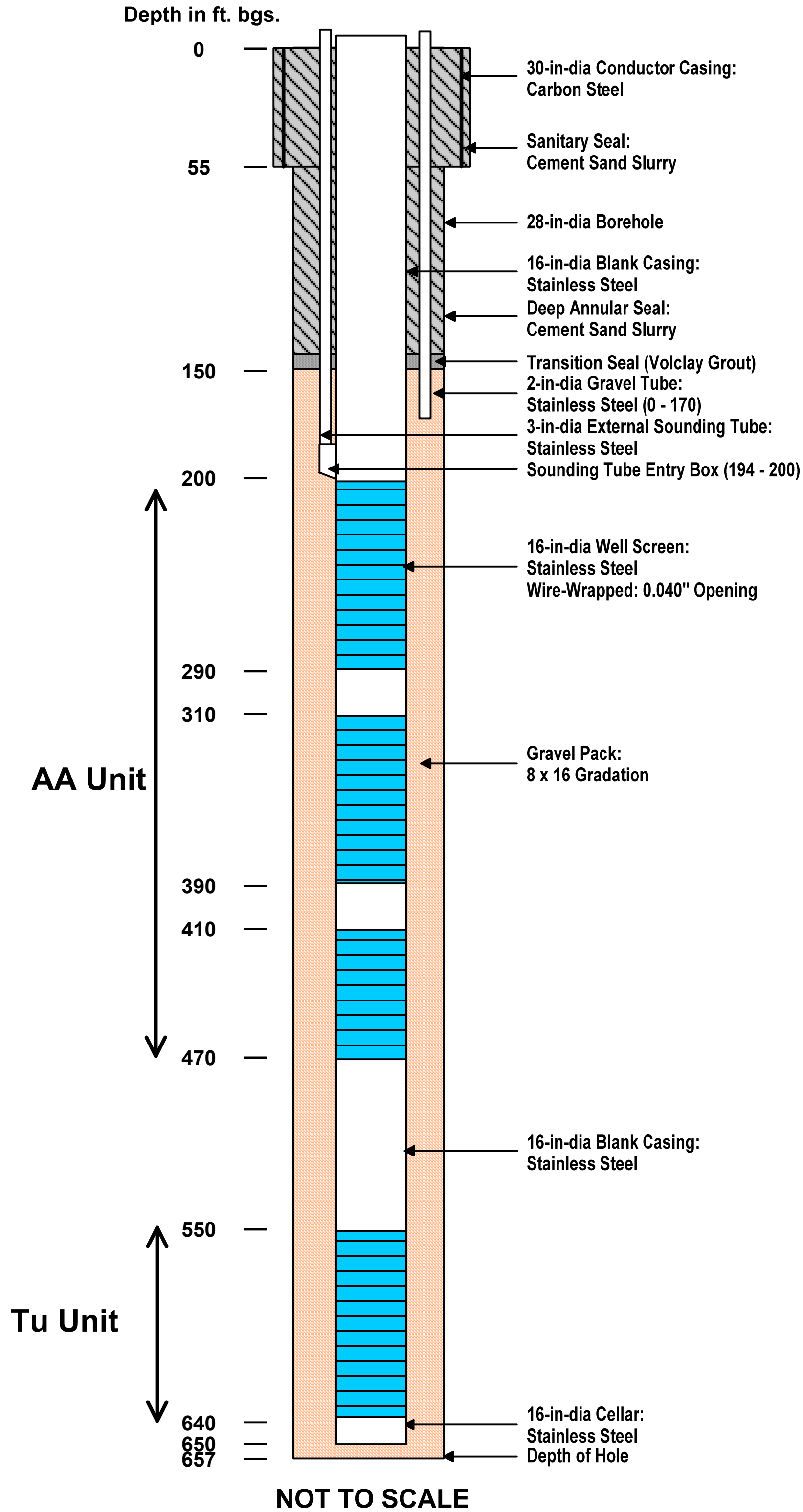

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FIGURE 2. AS-BUILT WELL SCHEMATIC
Phase 2 ASR Pilot Test - Beltz 12
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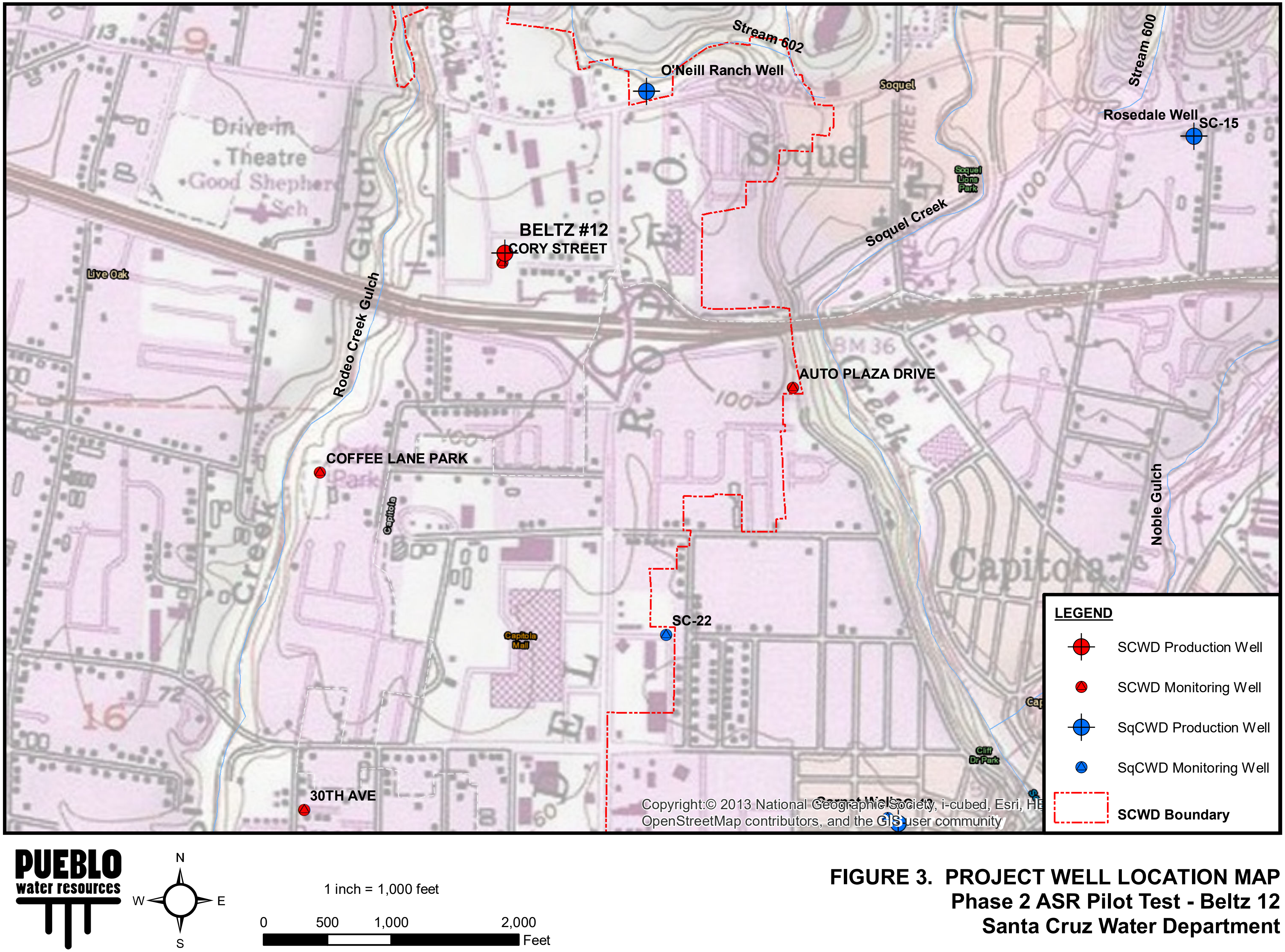

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FIGURE 3. PROJECT WELL LOCATION MAP
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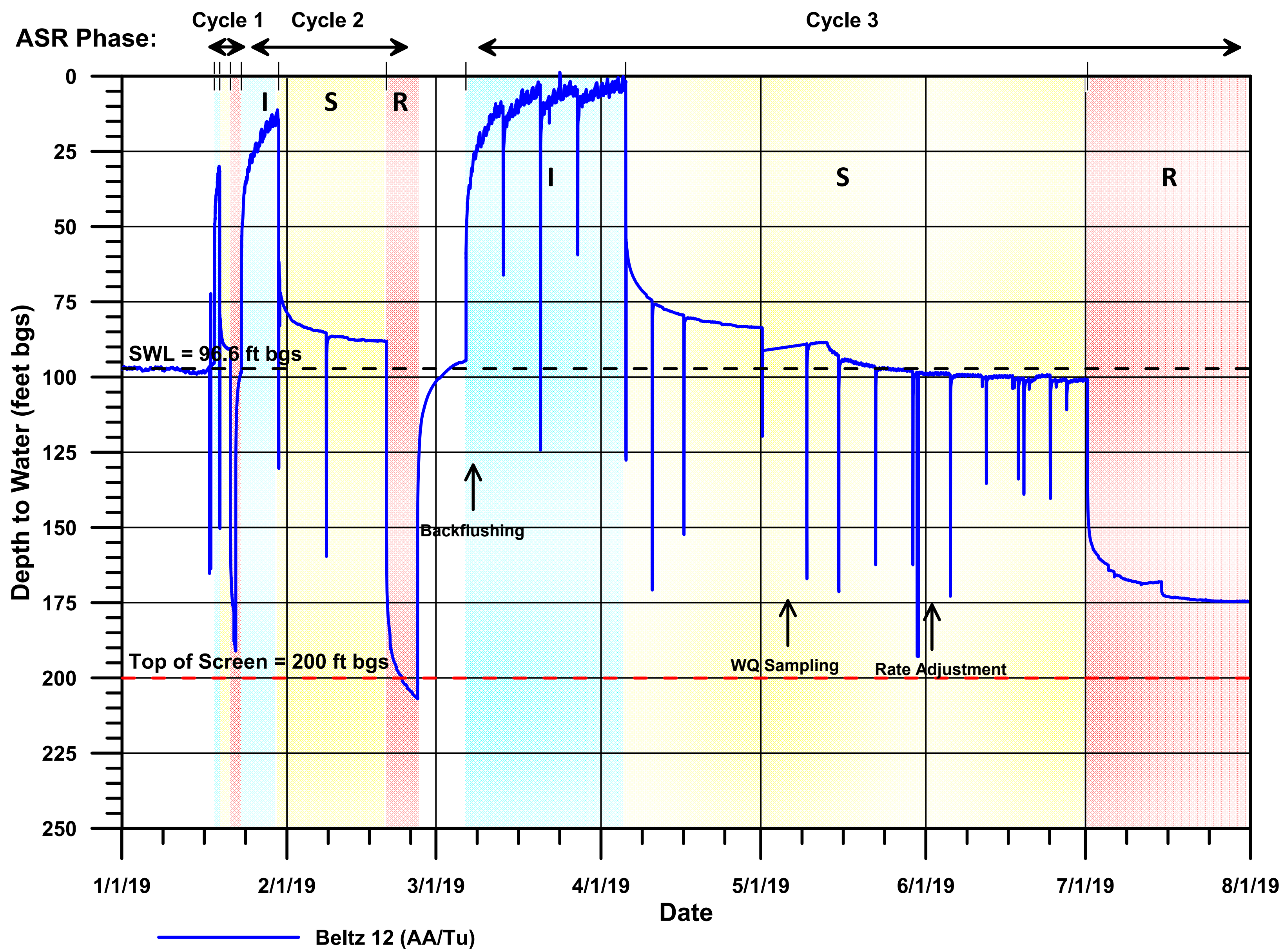

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FIGURE 4. WATER-LEVEL DATA - BELTZ 12
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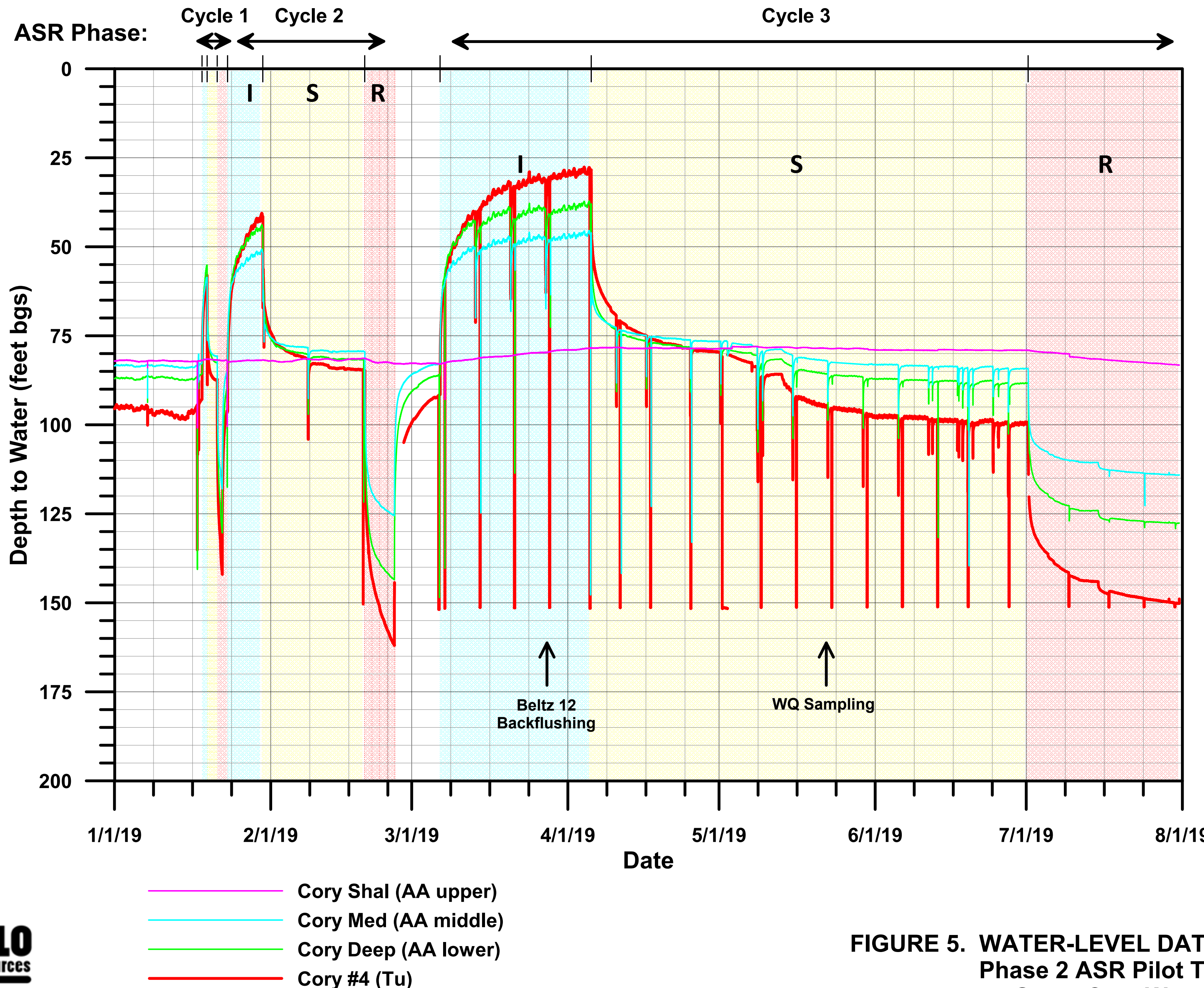

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FIGURE 5. WATER-LEVEL DATA - CORY ST
Phase 2 ASR Pilot Test - Beltz 12
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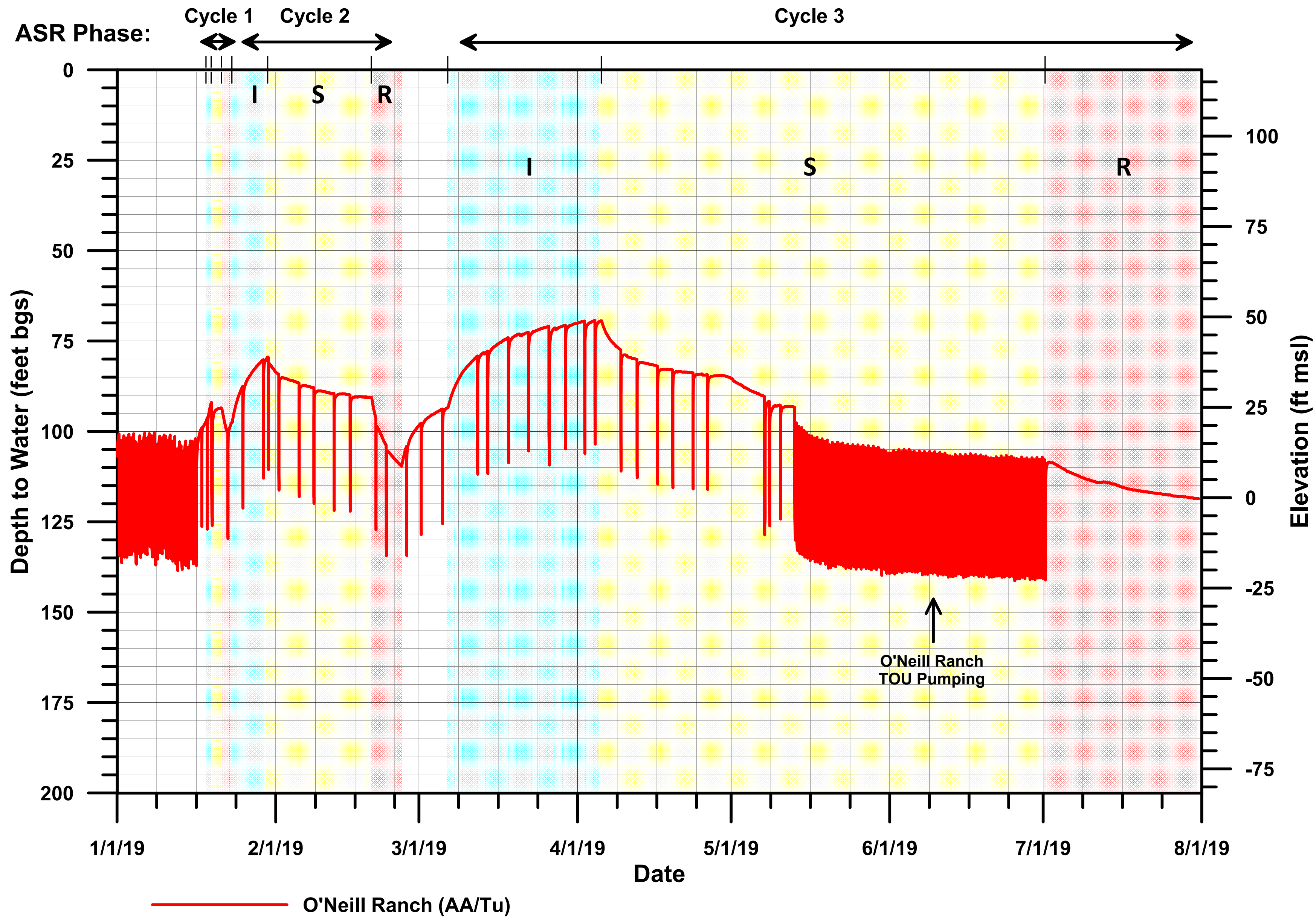

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FIGURE 6. WATER-LEVEL DATA - O'NEILL RANCH
Phase 2 ASR Pilot Test - Beltz 12
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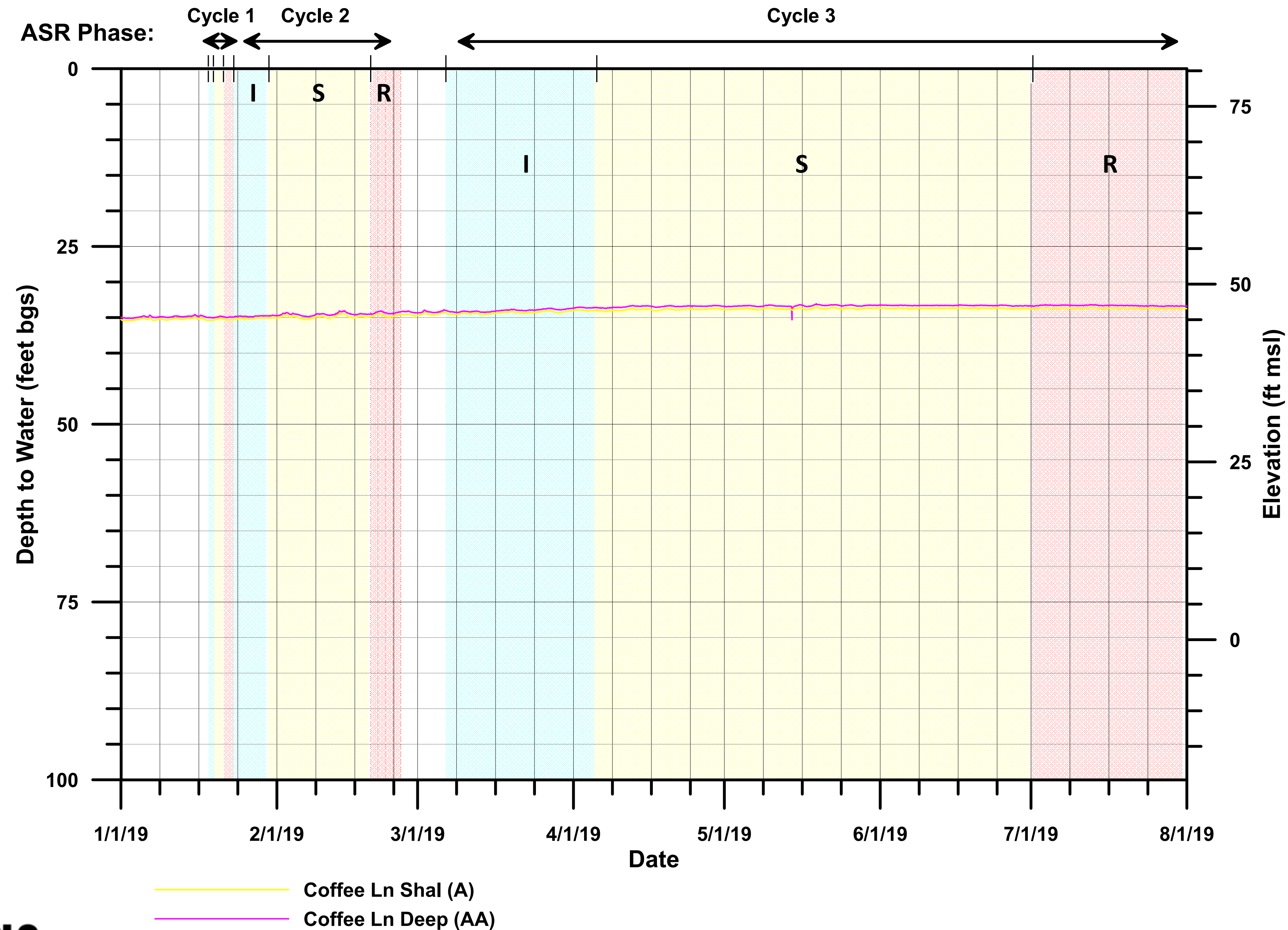

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FIGURE 7. WATER-LEVEL DATA - COFFEE LN
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

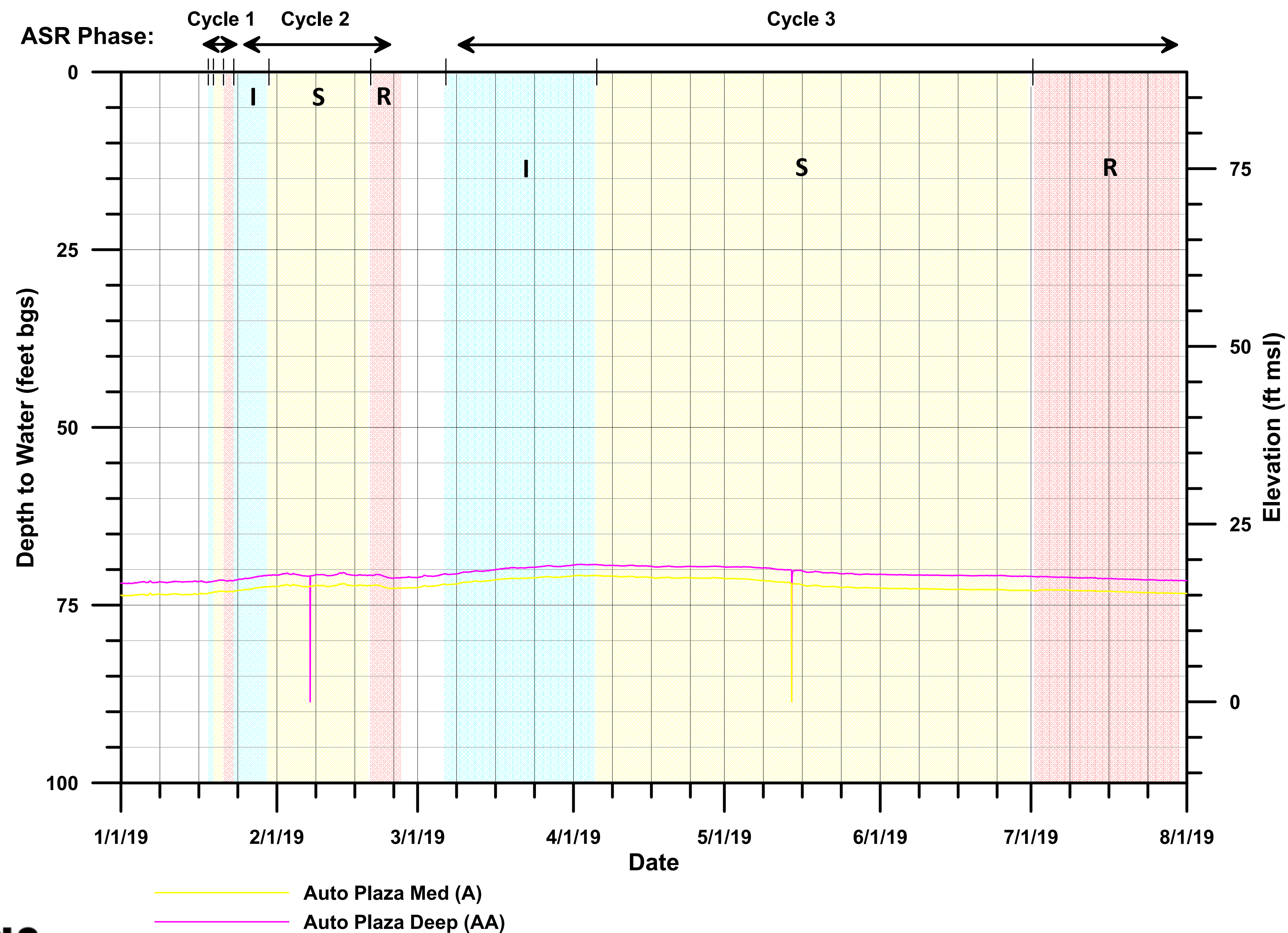

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FIGURE 8. WATER-LEVEL DATA - AUTO PLAZA MWs
Phase 2 ASR Pilot Test - Beltz 12
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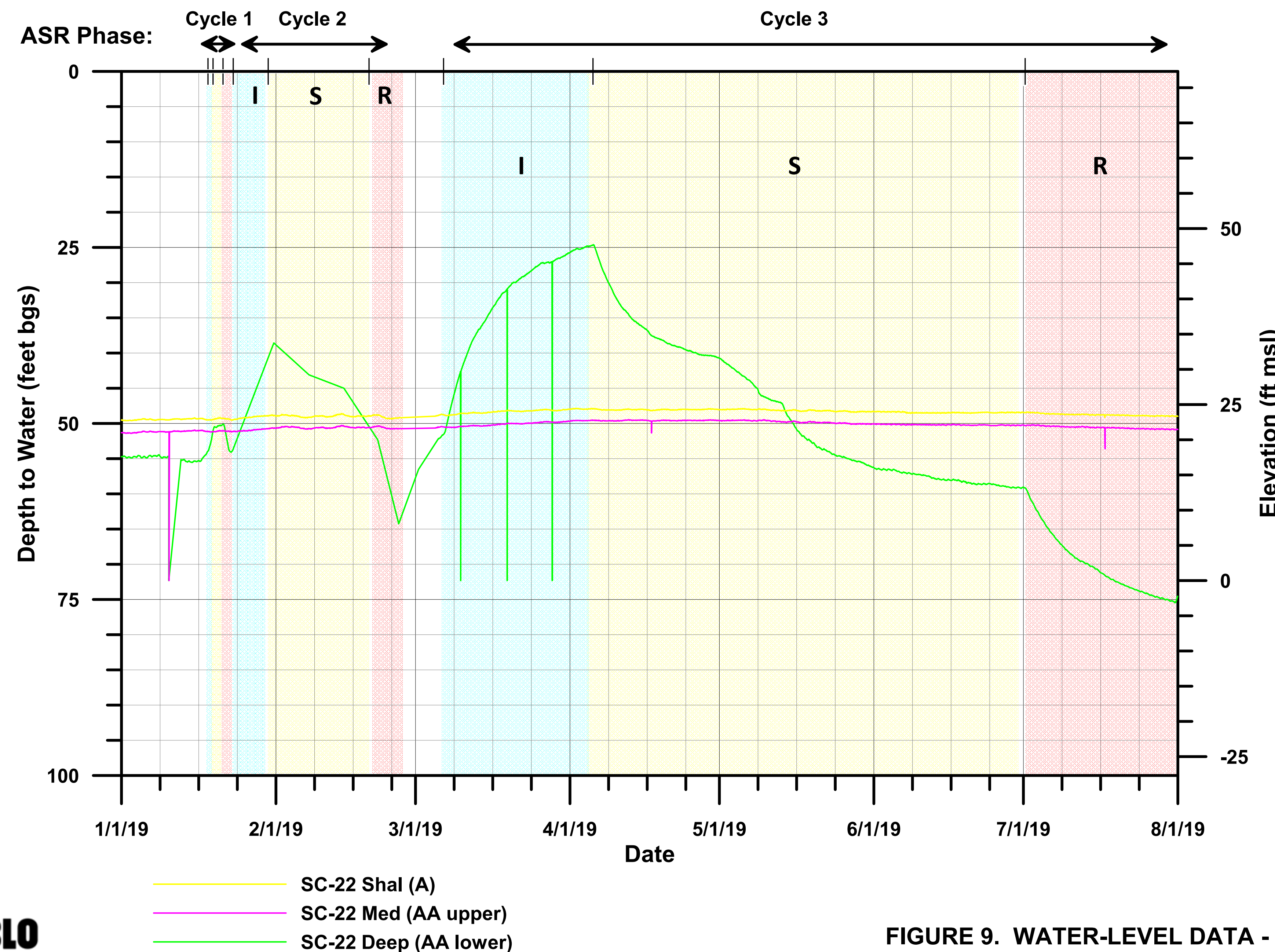

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FIGURE 9. WATER-LEVEL DATA - SC-22
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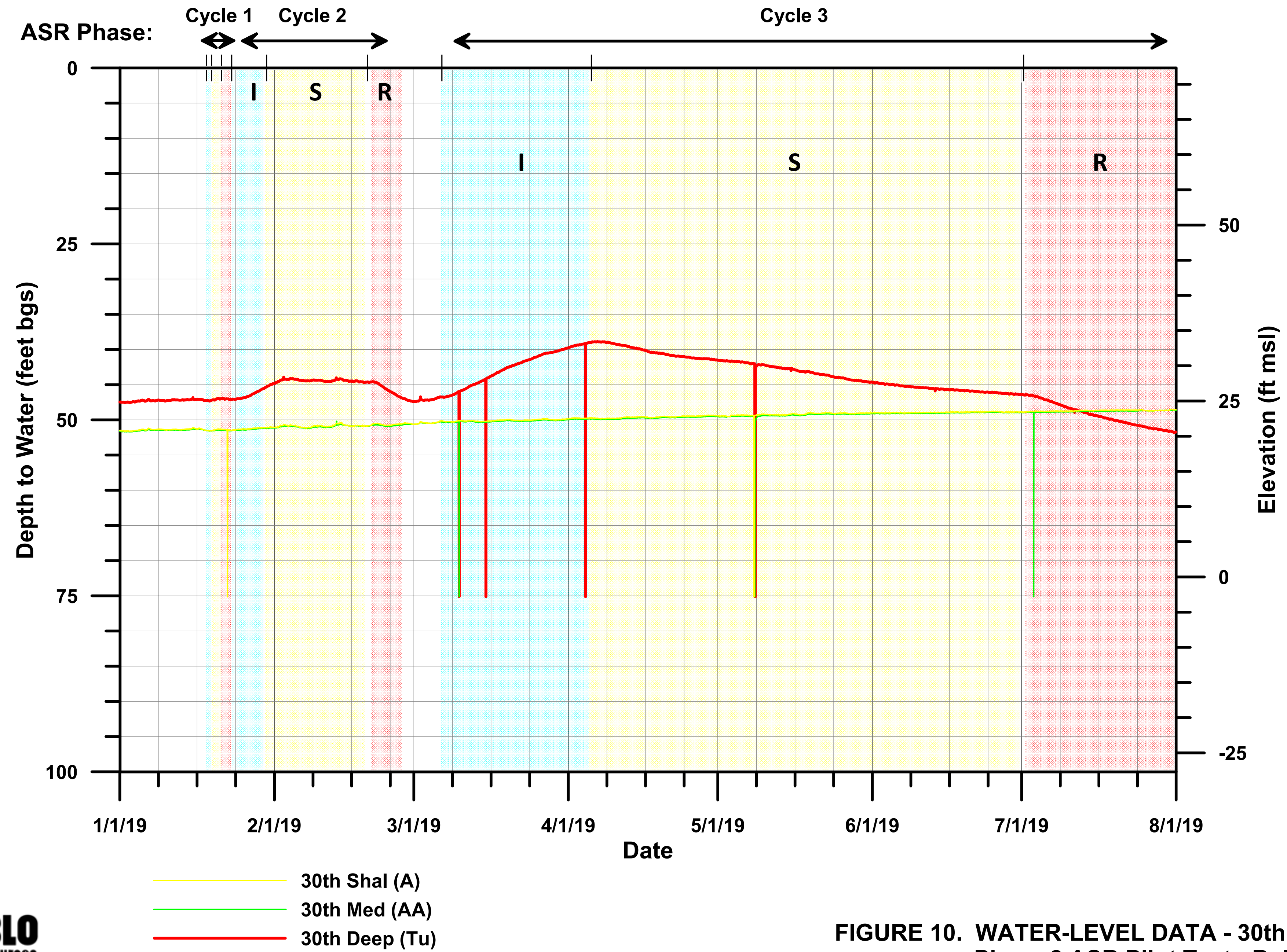

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FIGURE 10. WATER-LEVEL DATA - 30th AVE
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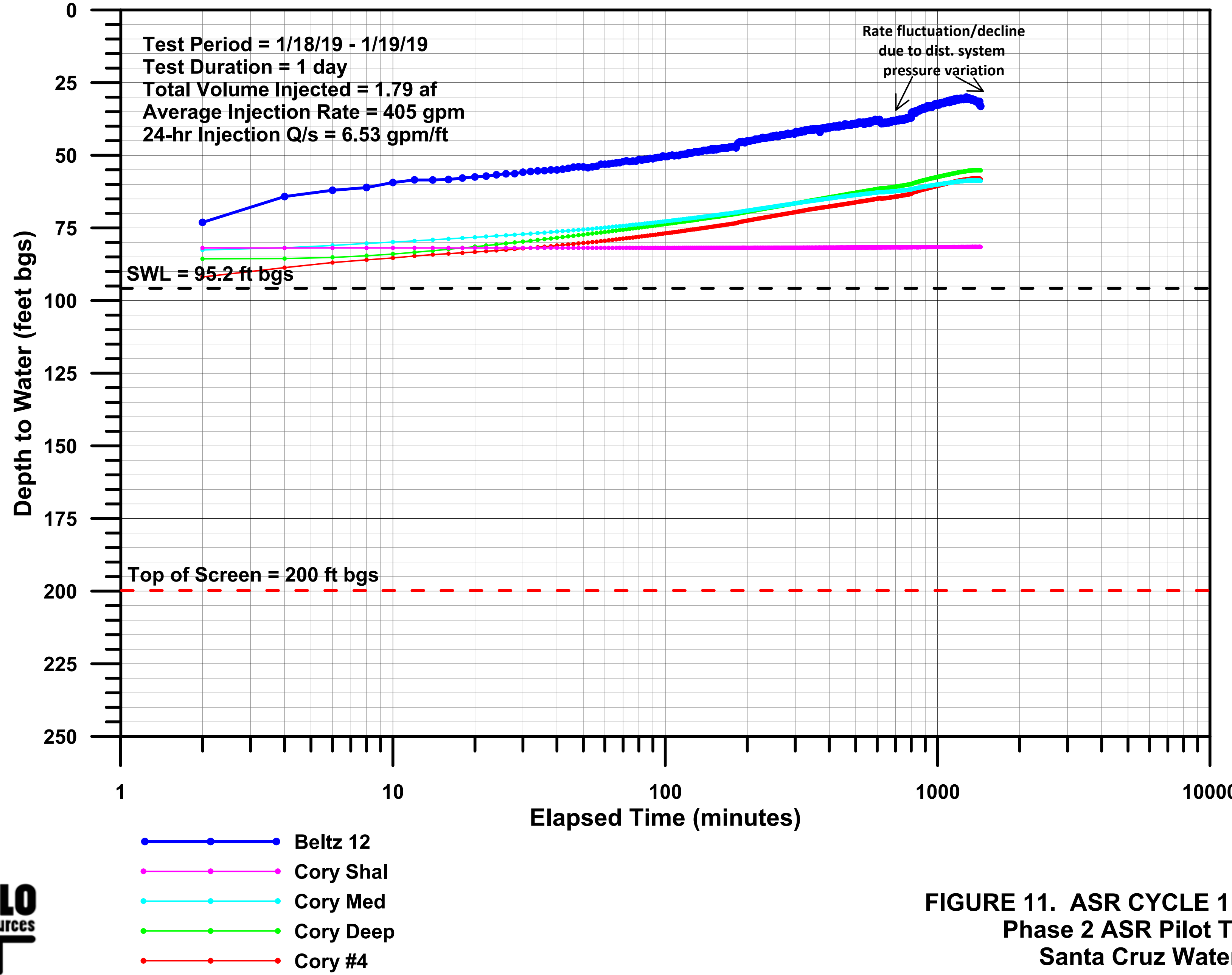

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FIGURE 11. ASR CYCLE 1 - INJECTION
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112

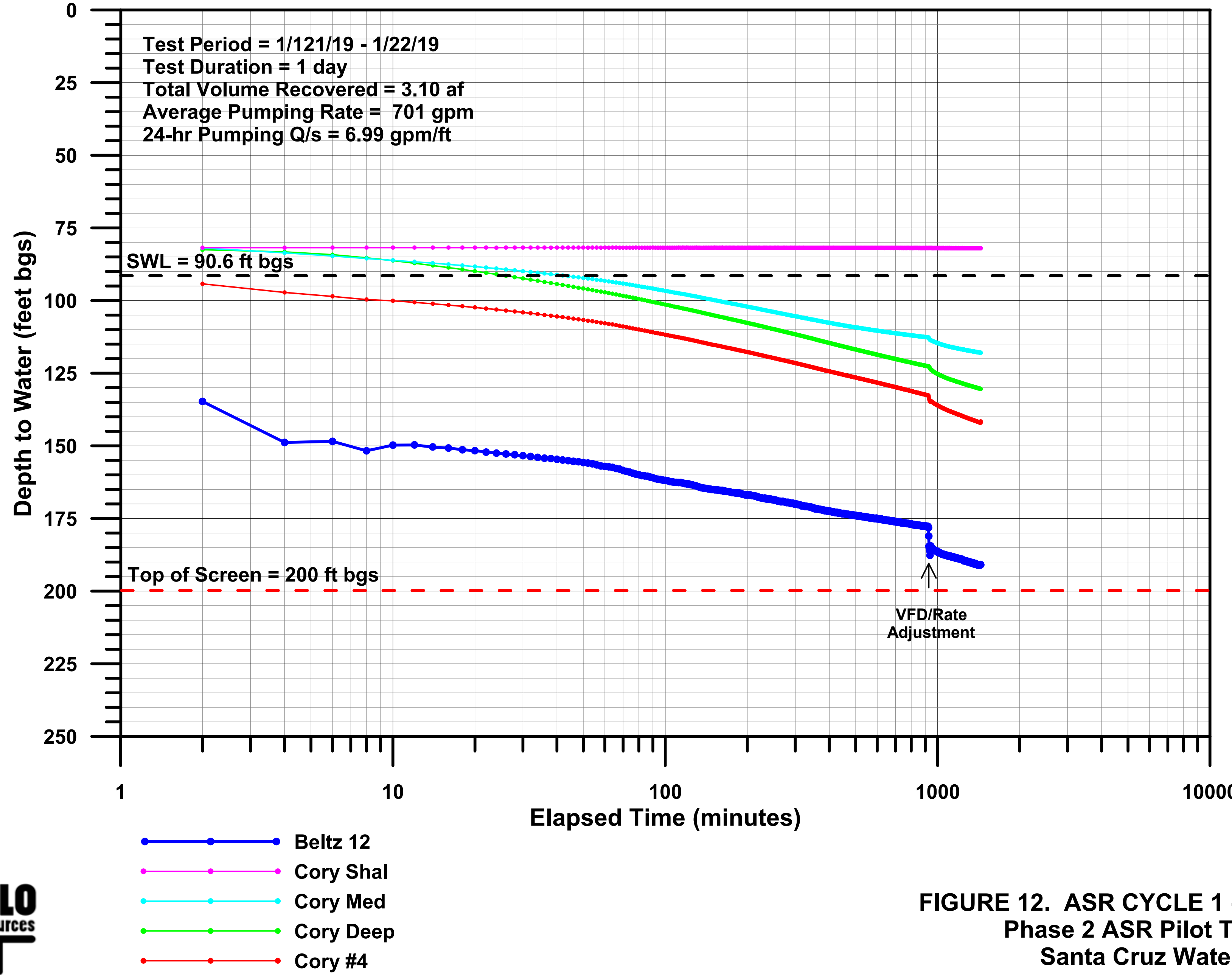
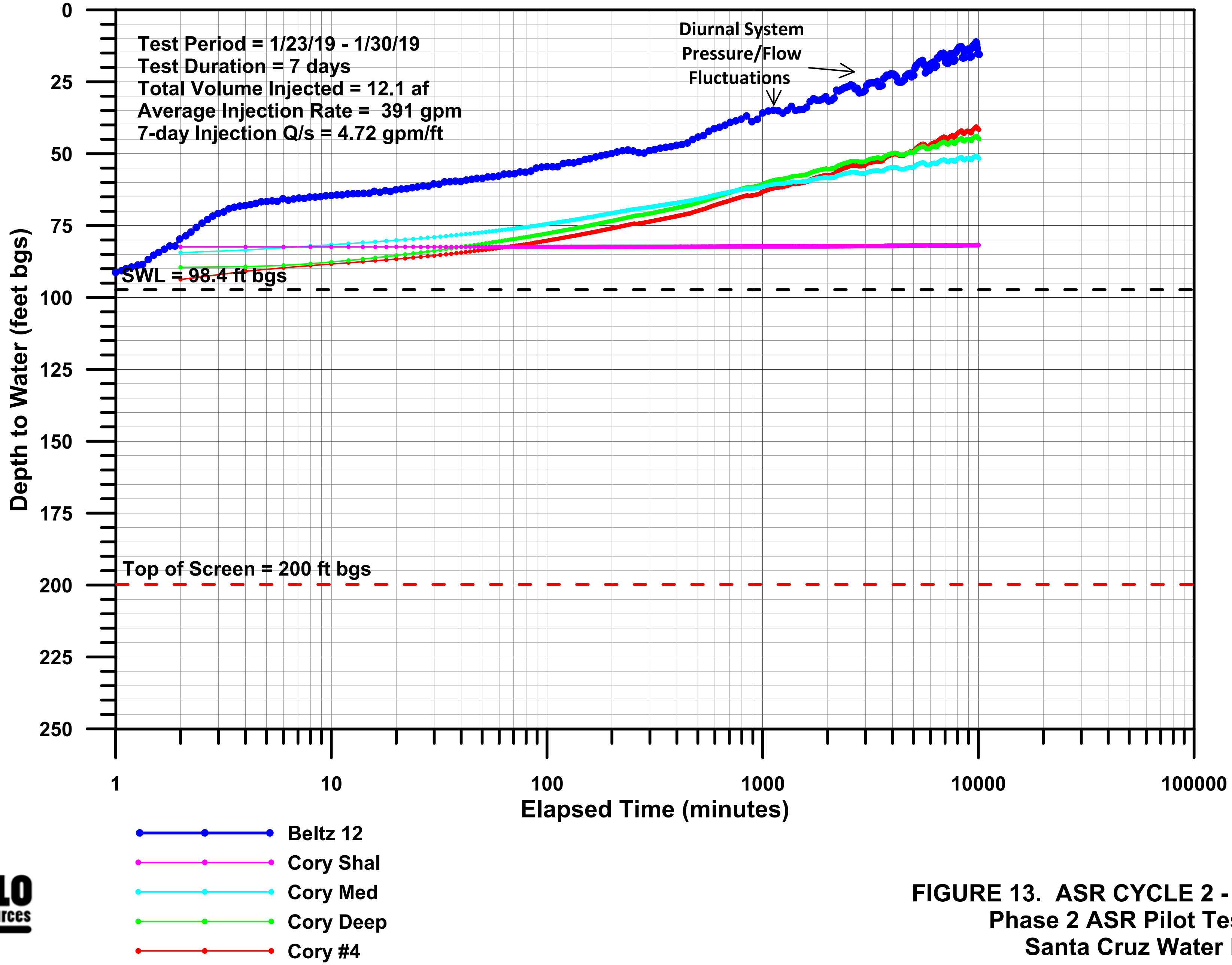


FIGURE 12. ASR CYCLE 1 - RECOVERY
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

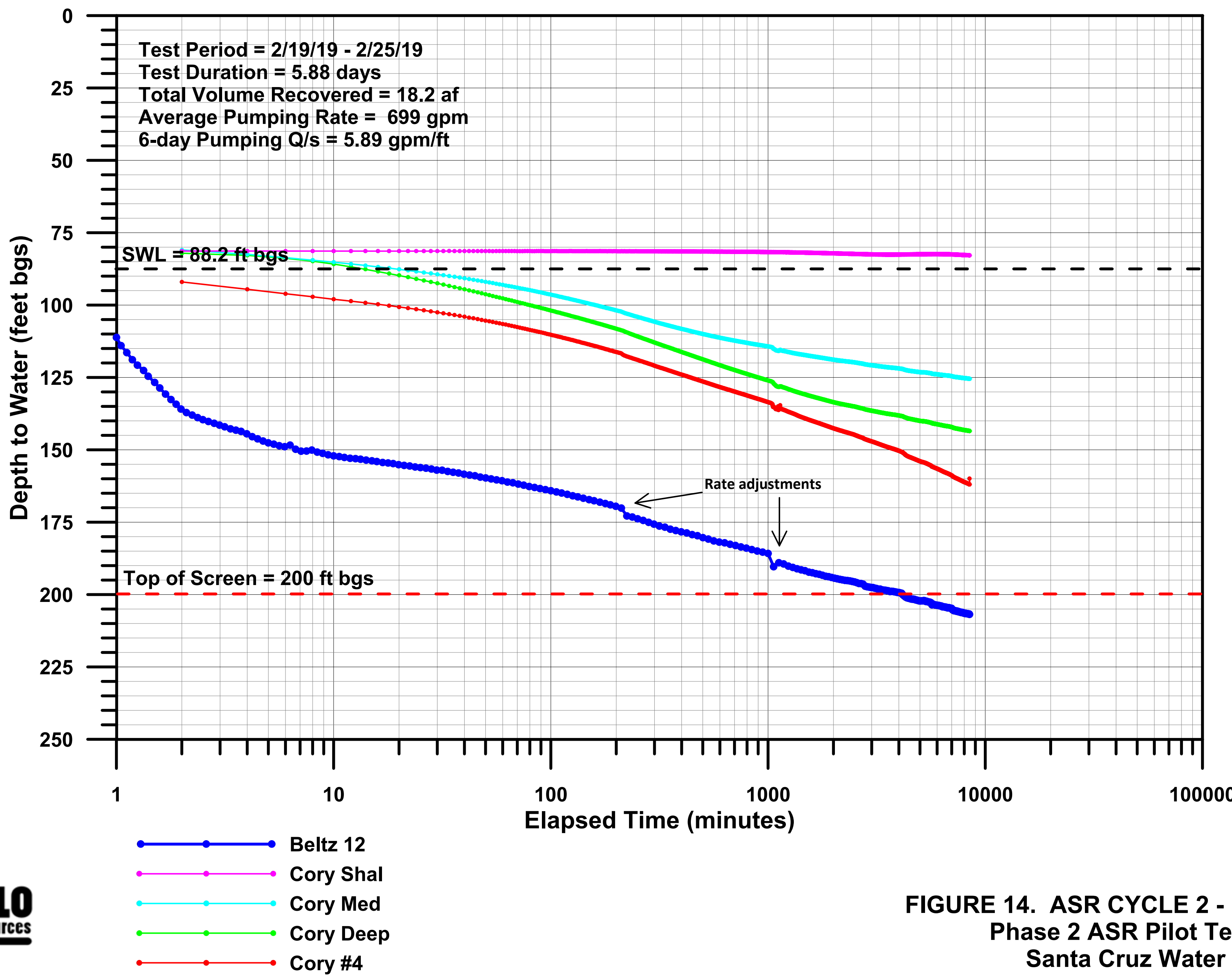
June 2020
Project No. 15-0112



PUEBLO water resources

FIGURE 13. ASR CYCLE 2 - INJECTION
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

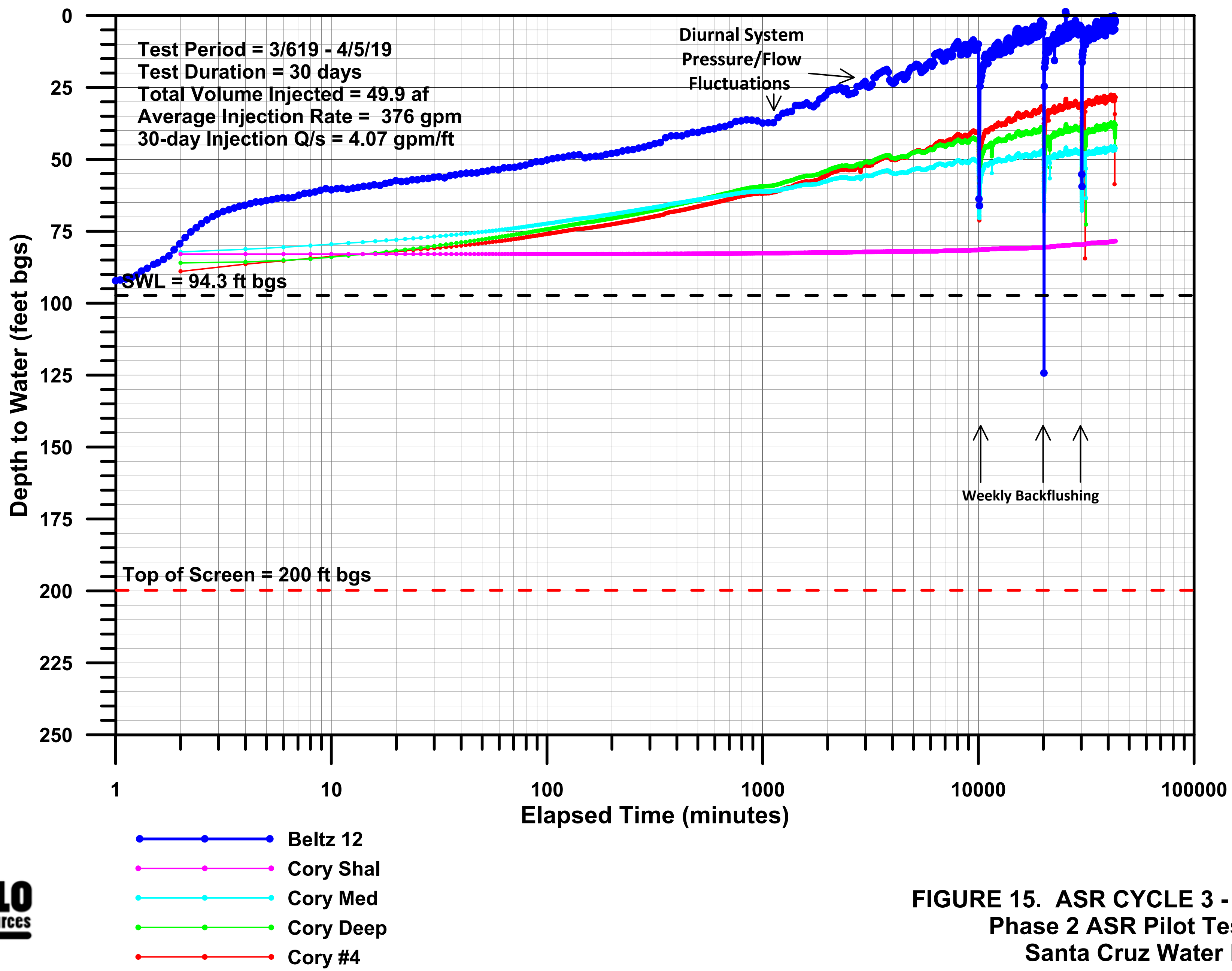
June 2020
Project No. 15-0112



PUEBLO water resources

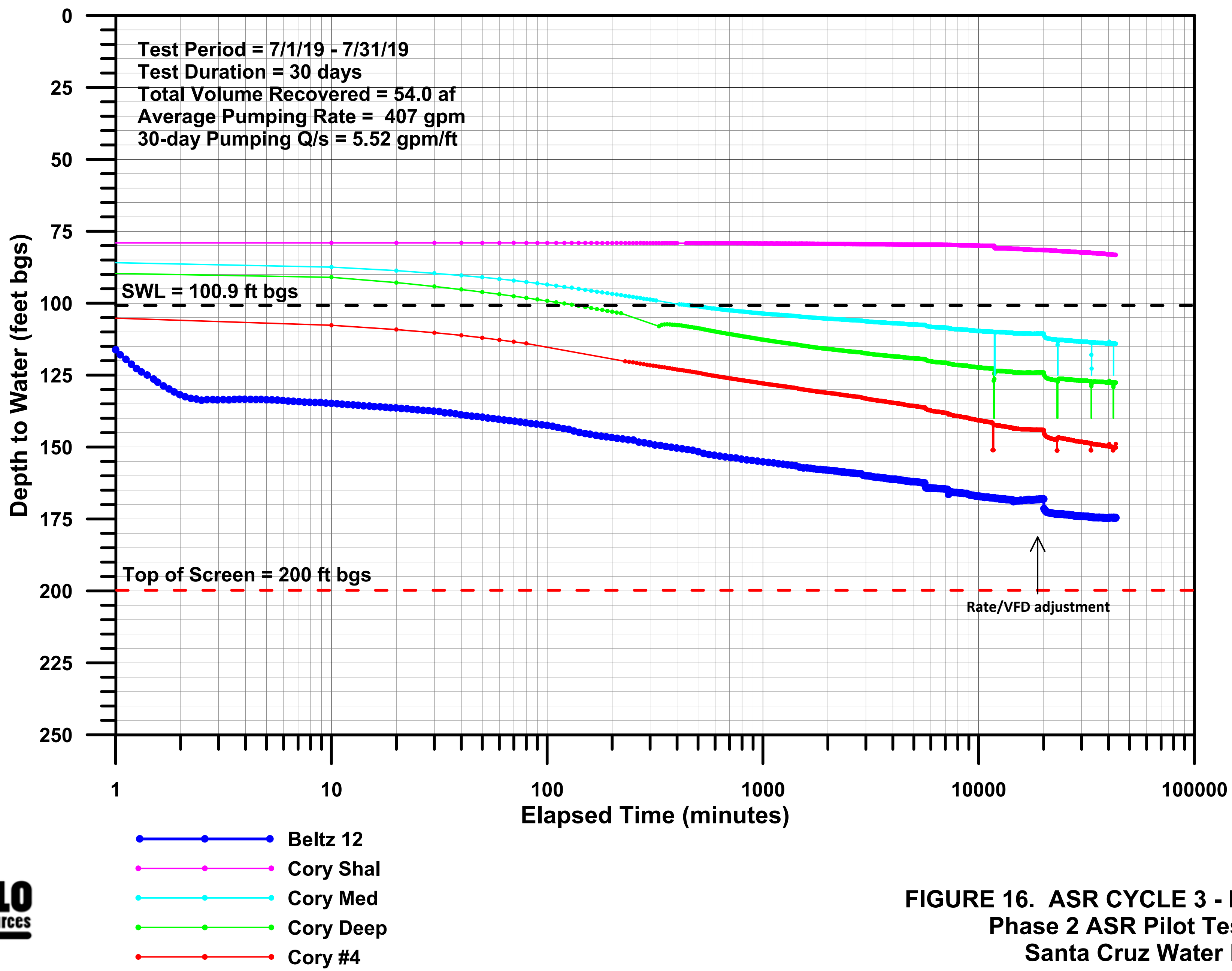
FIGURE 14. ASR CYCLE 2 - RECOVERY
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112



PUEBLO water resources

FIGURE 15. ASR CYCLE 3 - INJECTION
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



PUEBLO water resources

FIGURE 16. ASR CYCLE 3 - RECOVERY
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112

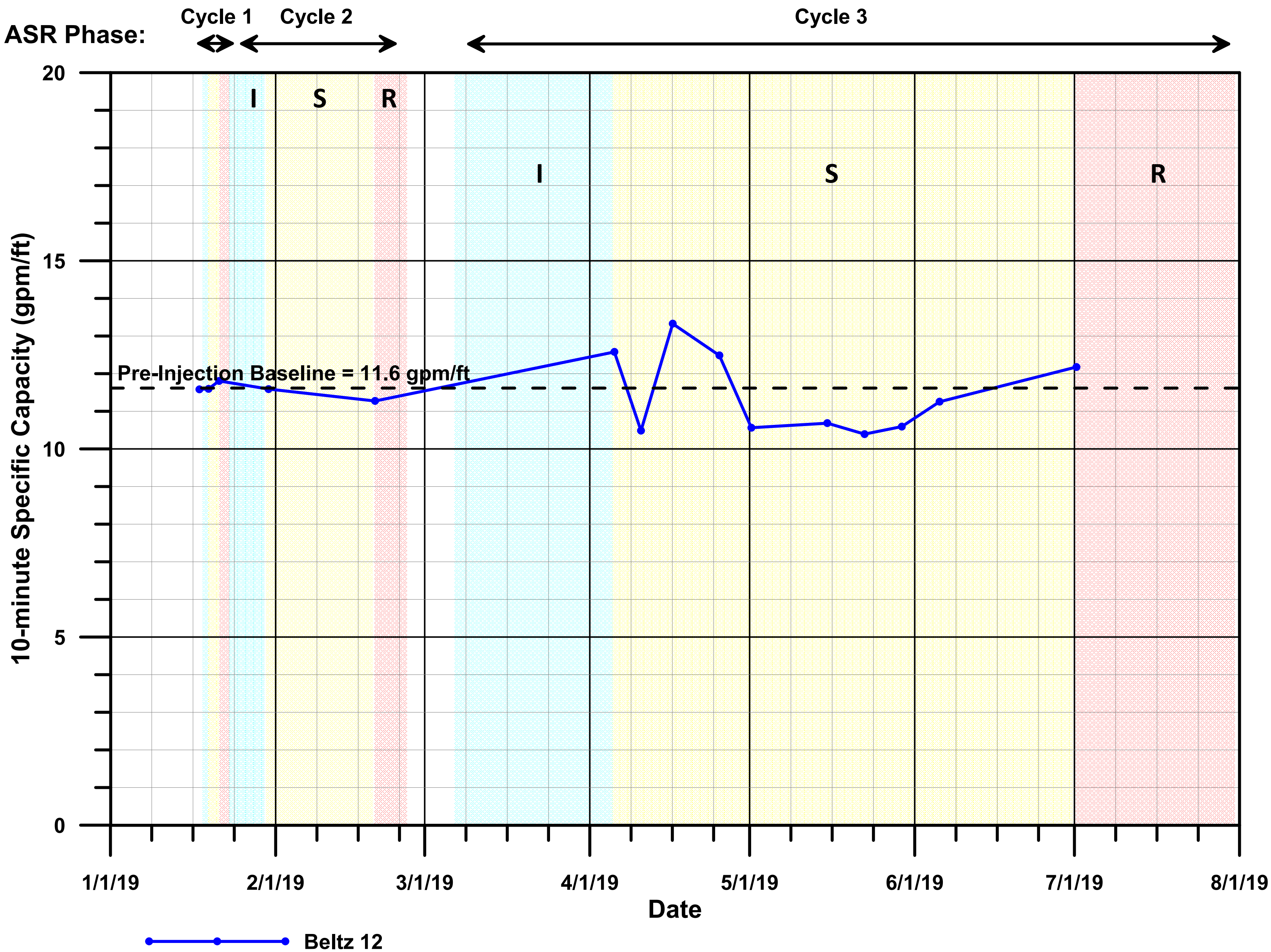
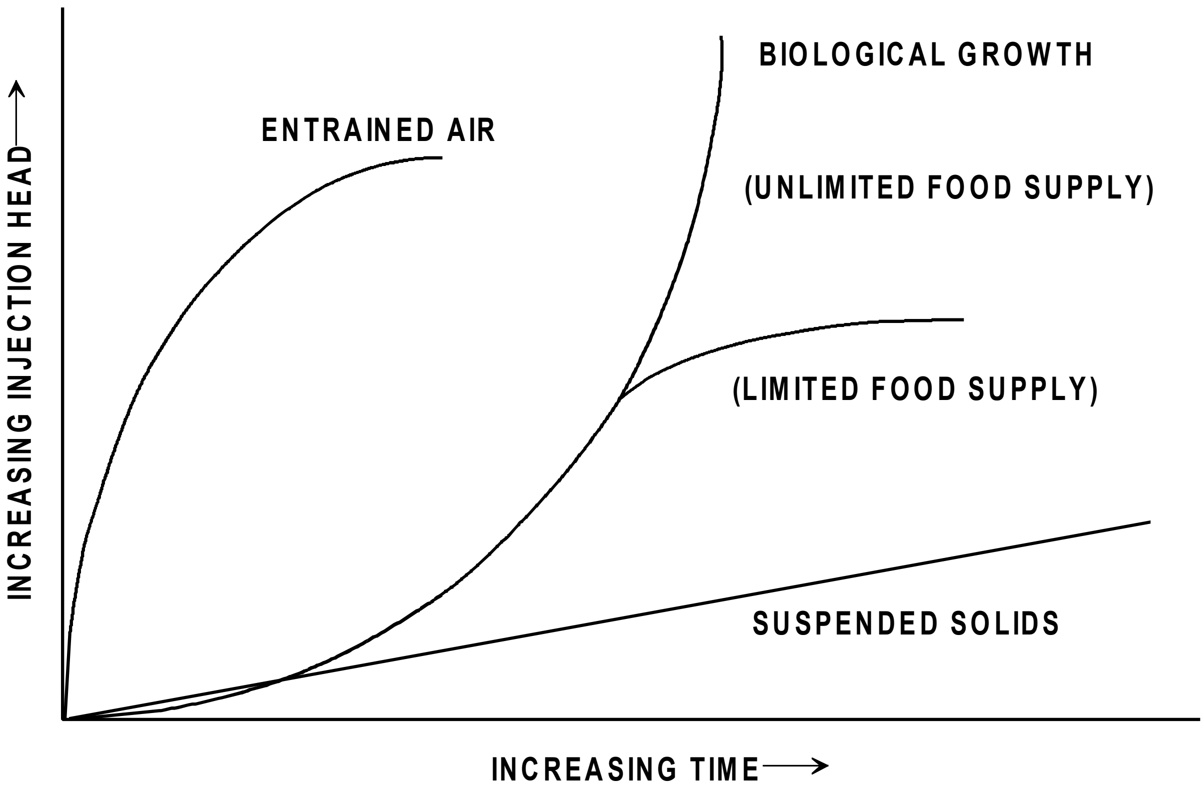


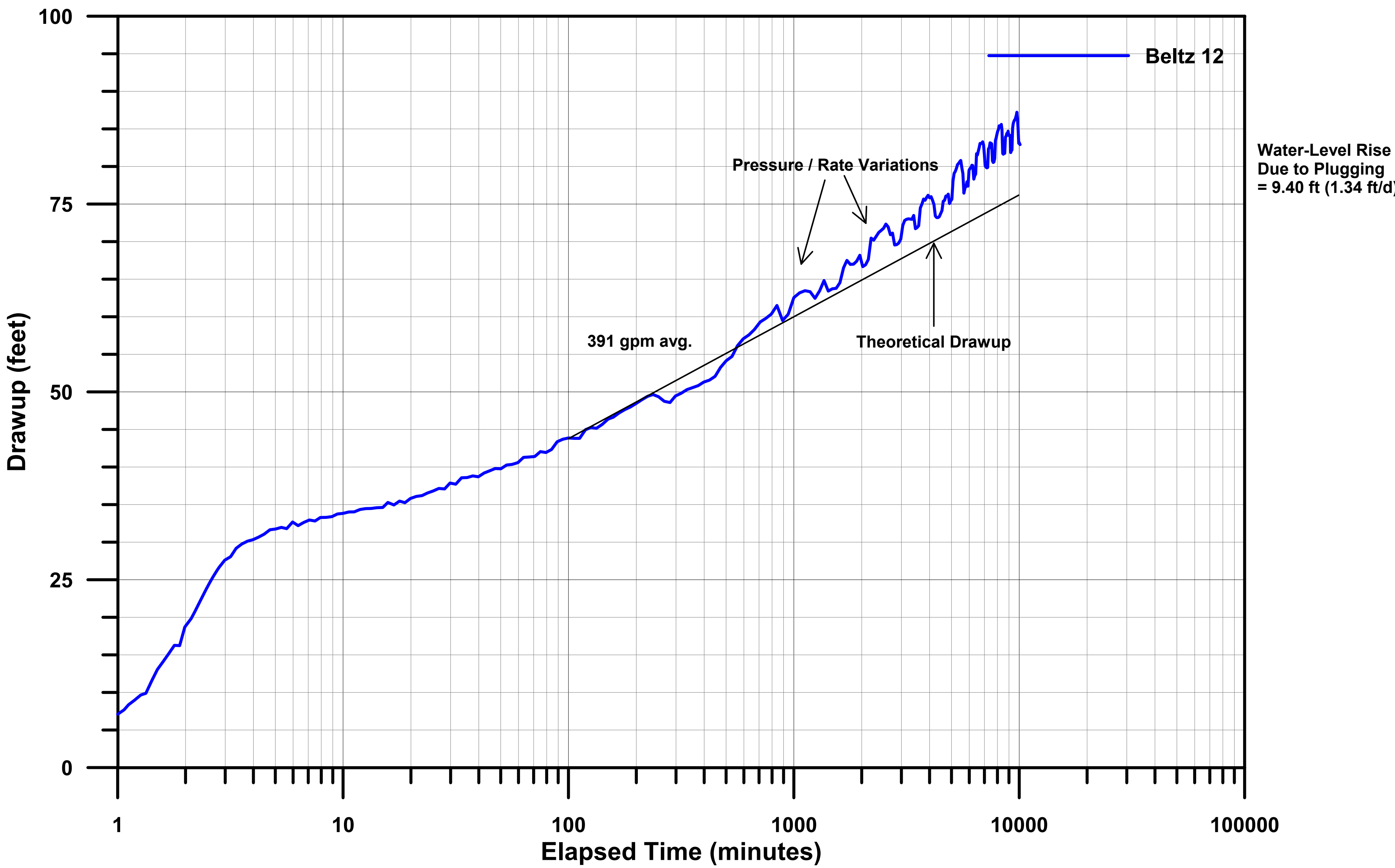
FIGURE 17. 10-MINUTE SPECIFIC CAPACITY DATA
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



SOURCE: After Huisman and Olsthoorn, 1983.

FIGURE 18. ASR WELL PLUGGING MECHANISIMS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

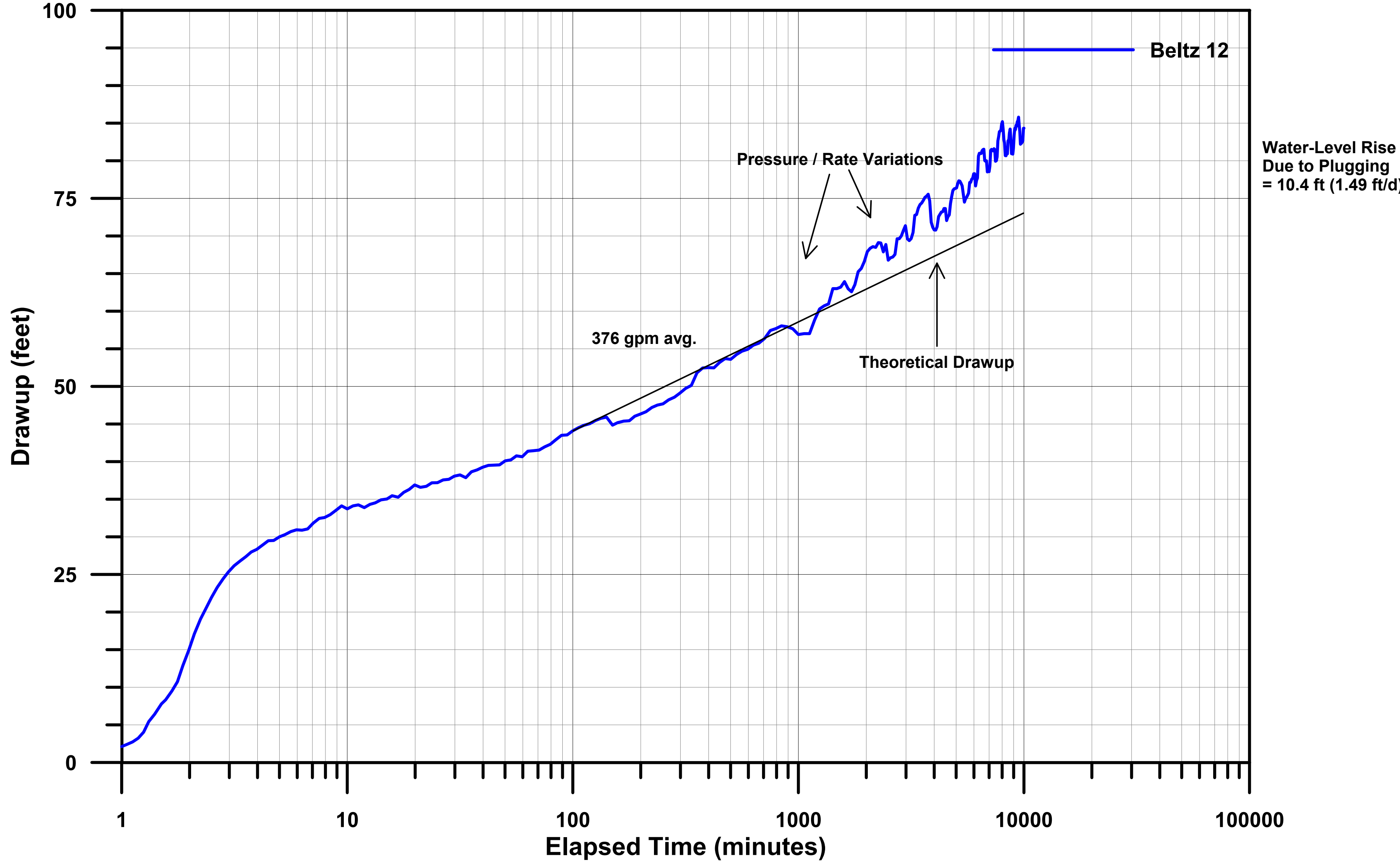
June 2020
Project No. 15-0112



PUEBLO water resources

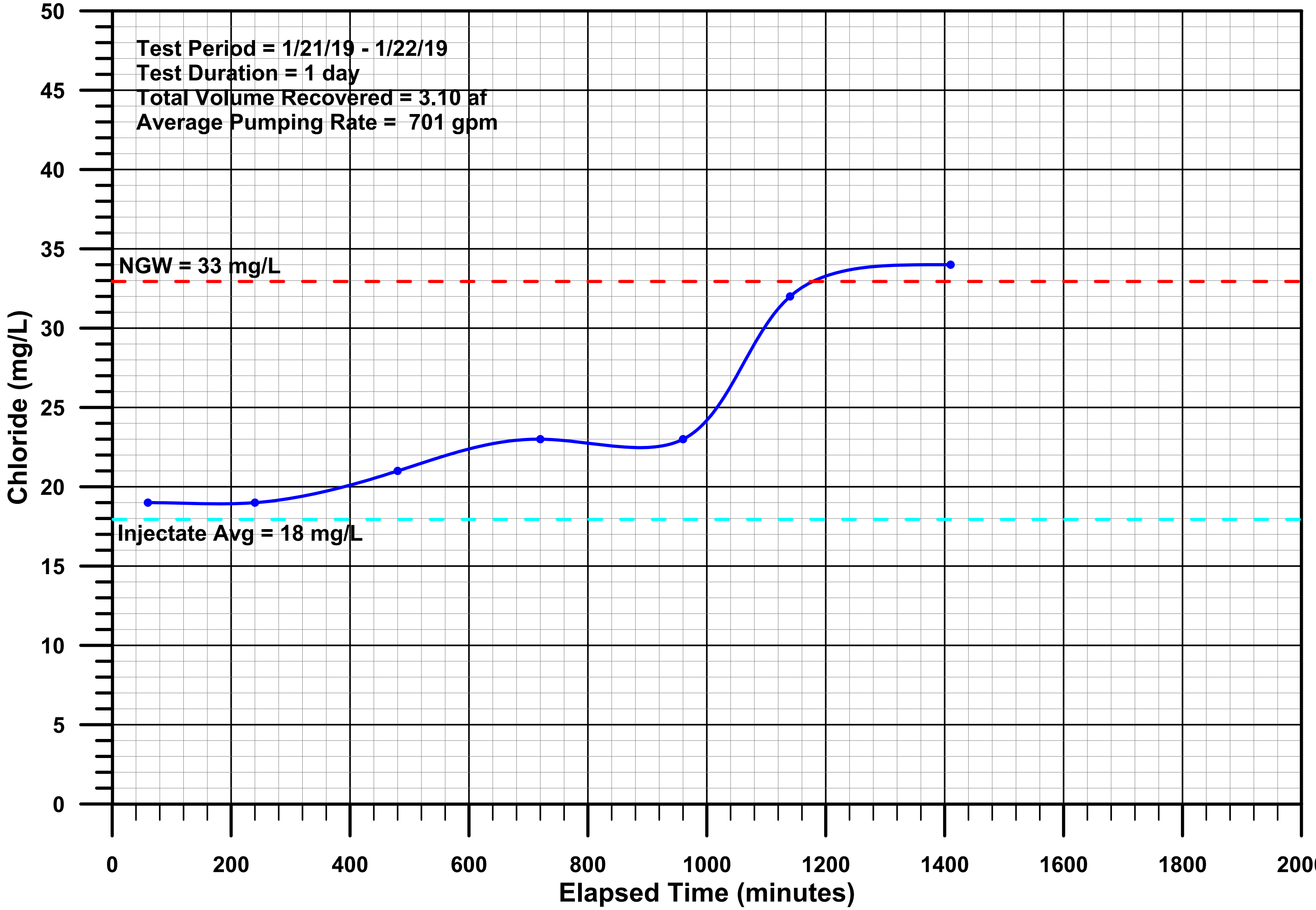
FIGURE 19. ASR CYCLE 2 - INJECTION PLUGGING RATE ANALYSIS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112



PUEBLO water resources

FIGURE 20. ASR CYCLE 3 - INJECTION PLUGGING RATE ANALYSIS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



PUEBLO water resources

FIGURE 21. ASR CYCLE 1 RECOVERY - CHLORIDE VS. TIME
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

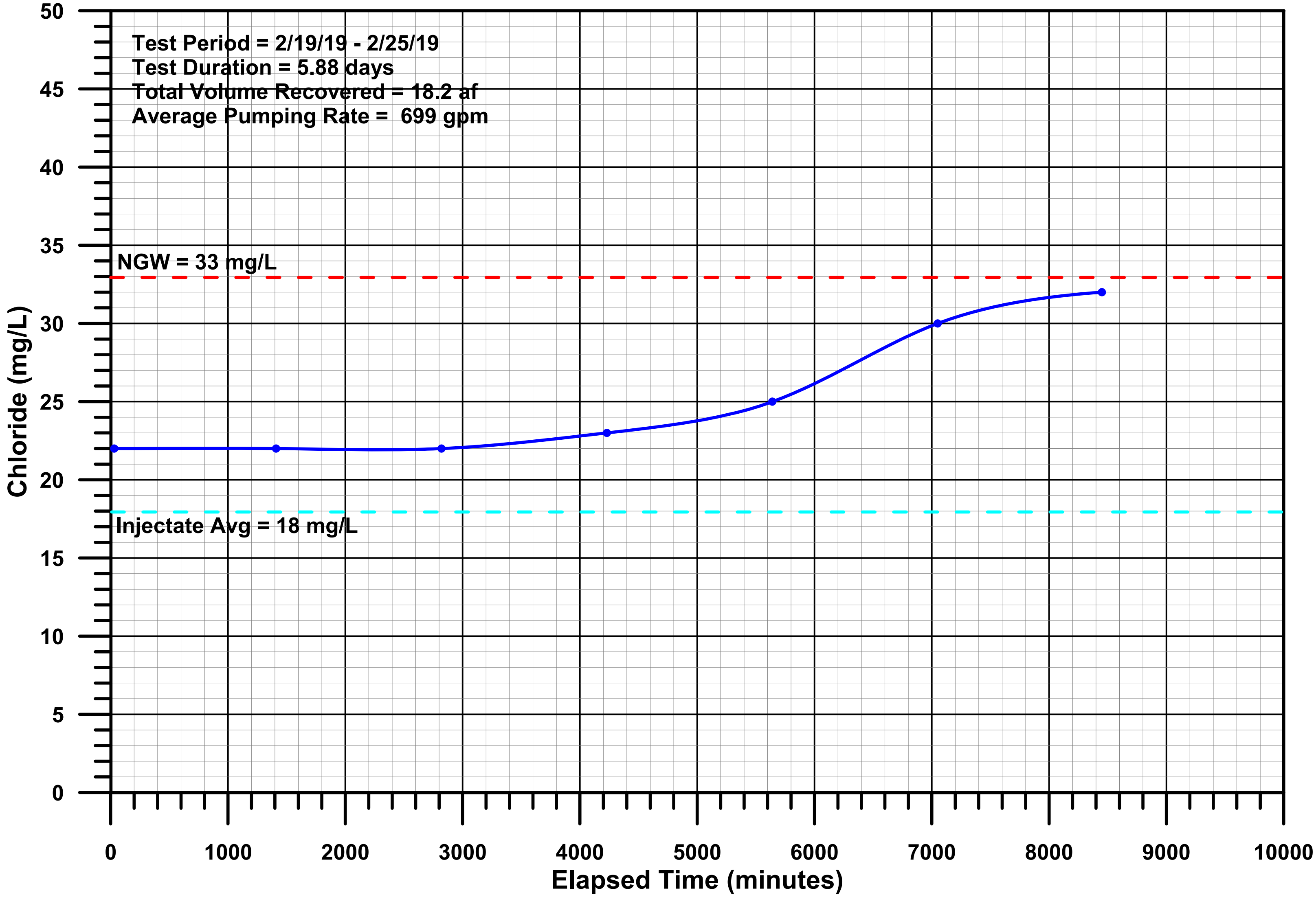


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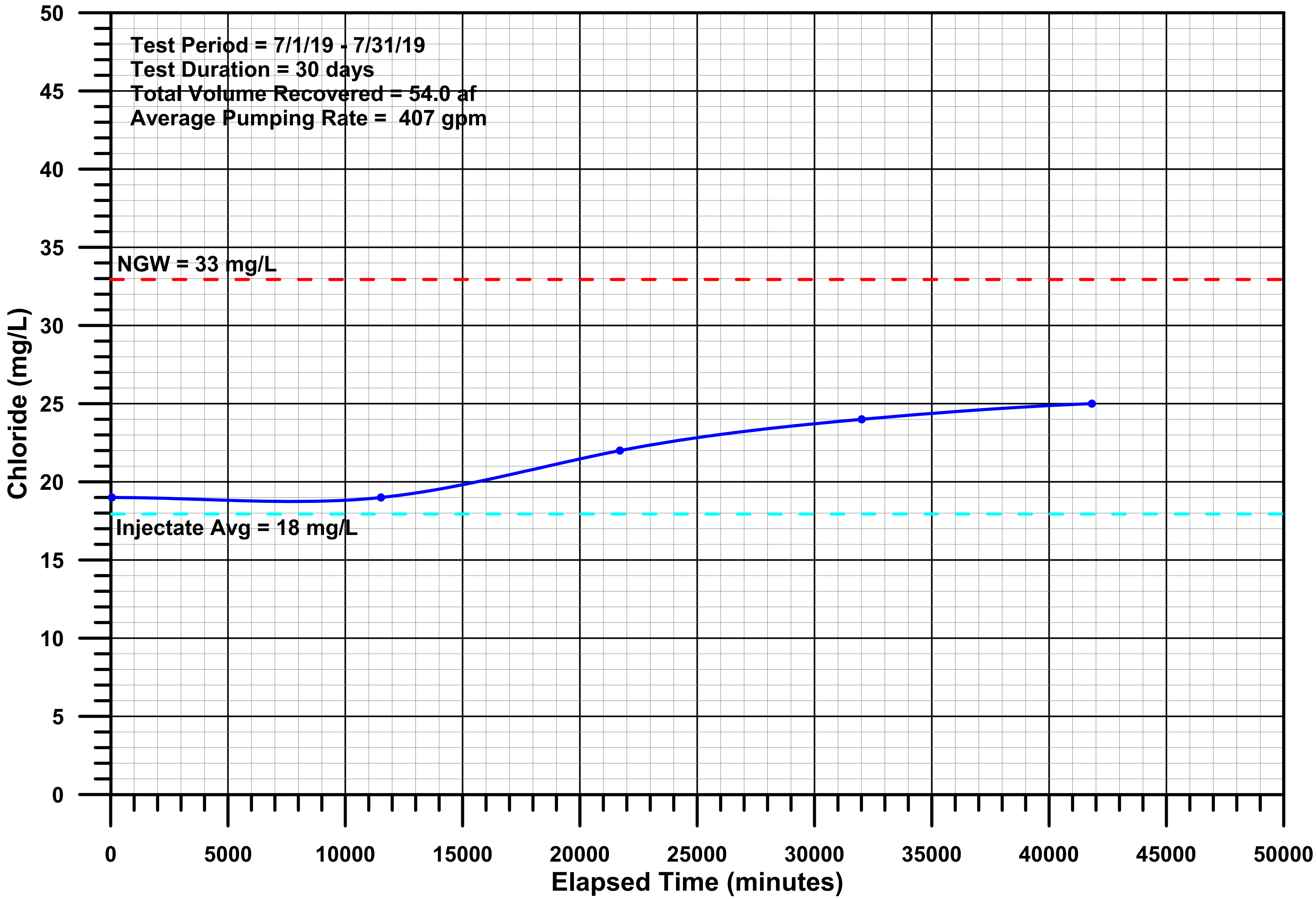
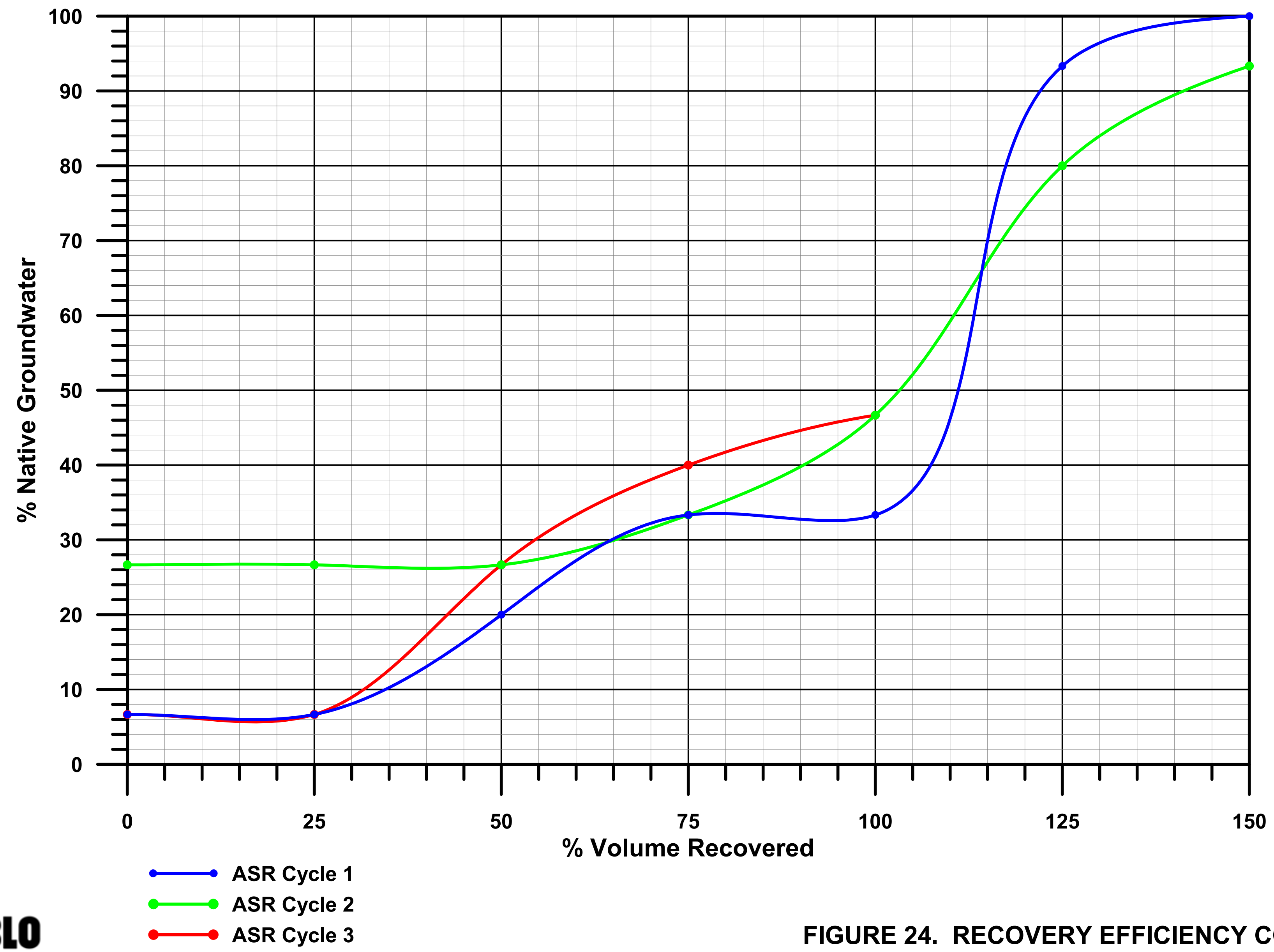
FIGURE 22. ASR CYCLE 2 RECOVERY - CHLORIDE VS. TIME
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



PUEBLO water resources

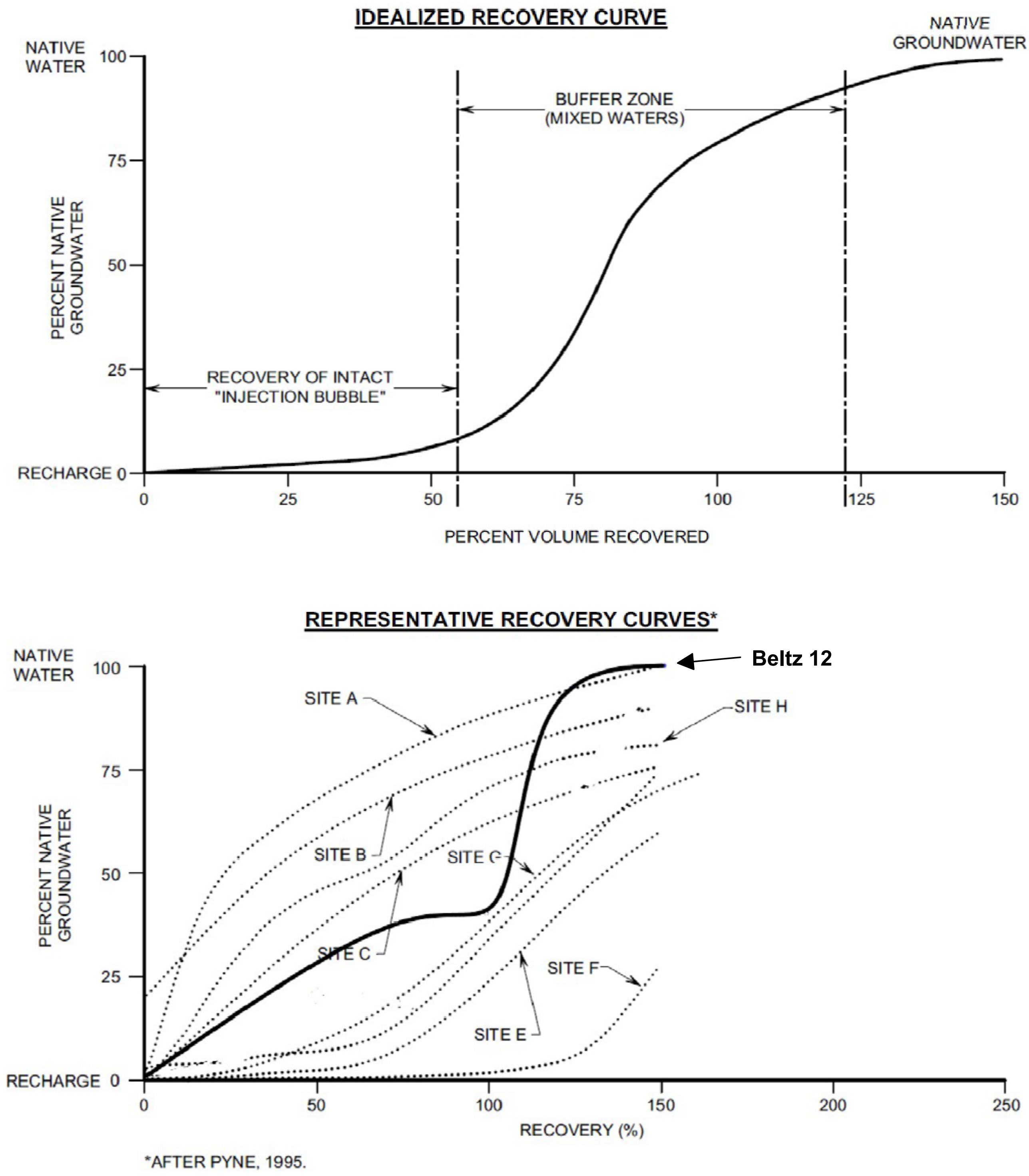
FIGURE 23. ASR CYCLE 3 RECOVERY - CHLORIDE VS. TIME
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112



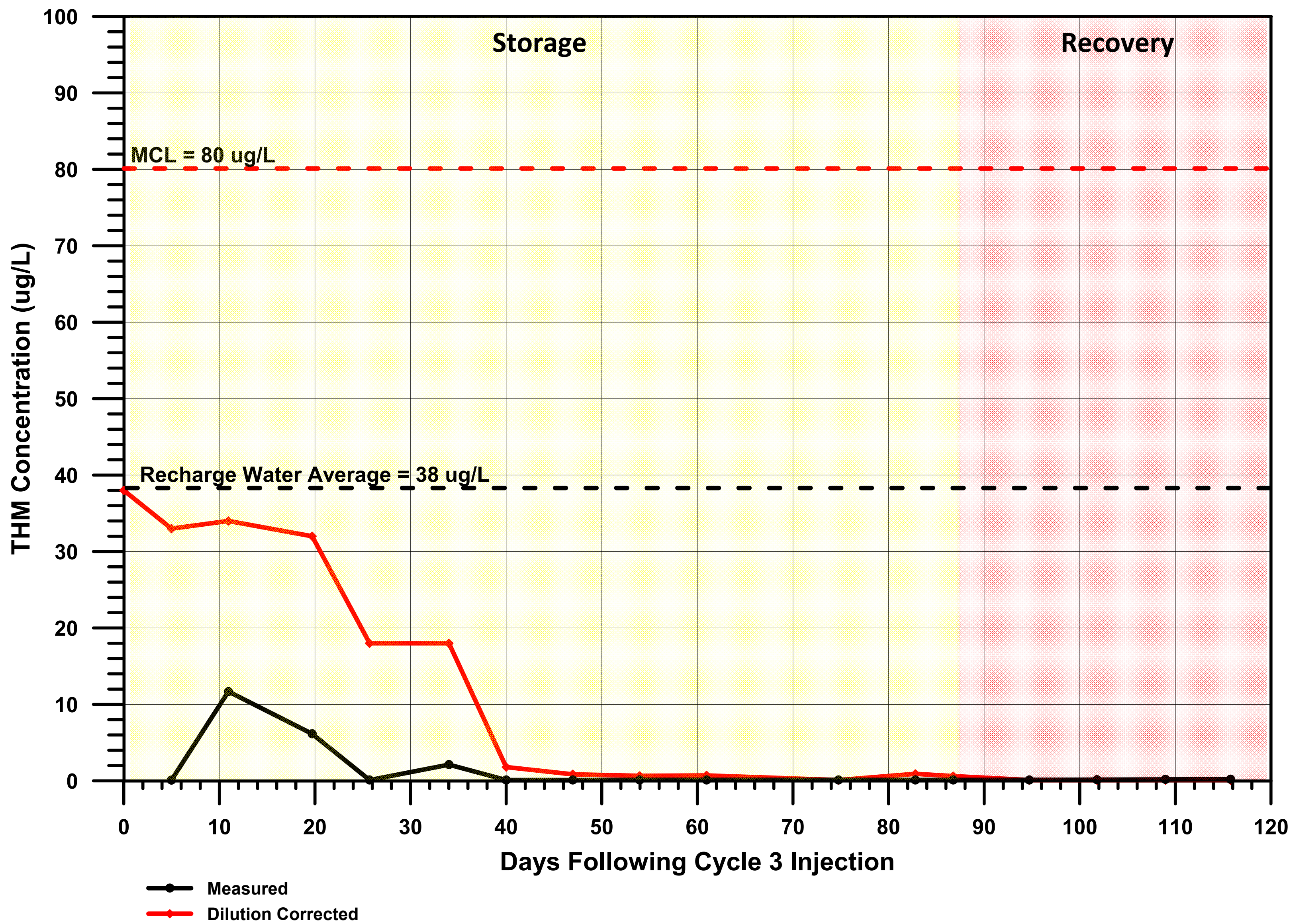
PUEBLO water resources

FIGURE 24. RECOVERY EFFICIENCY COMPARISON
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



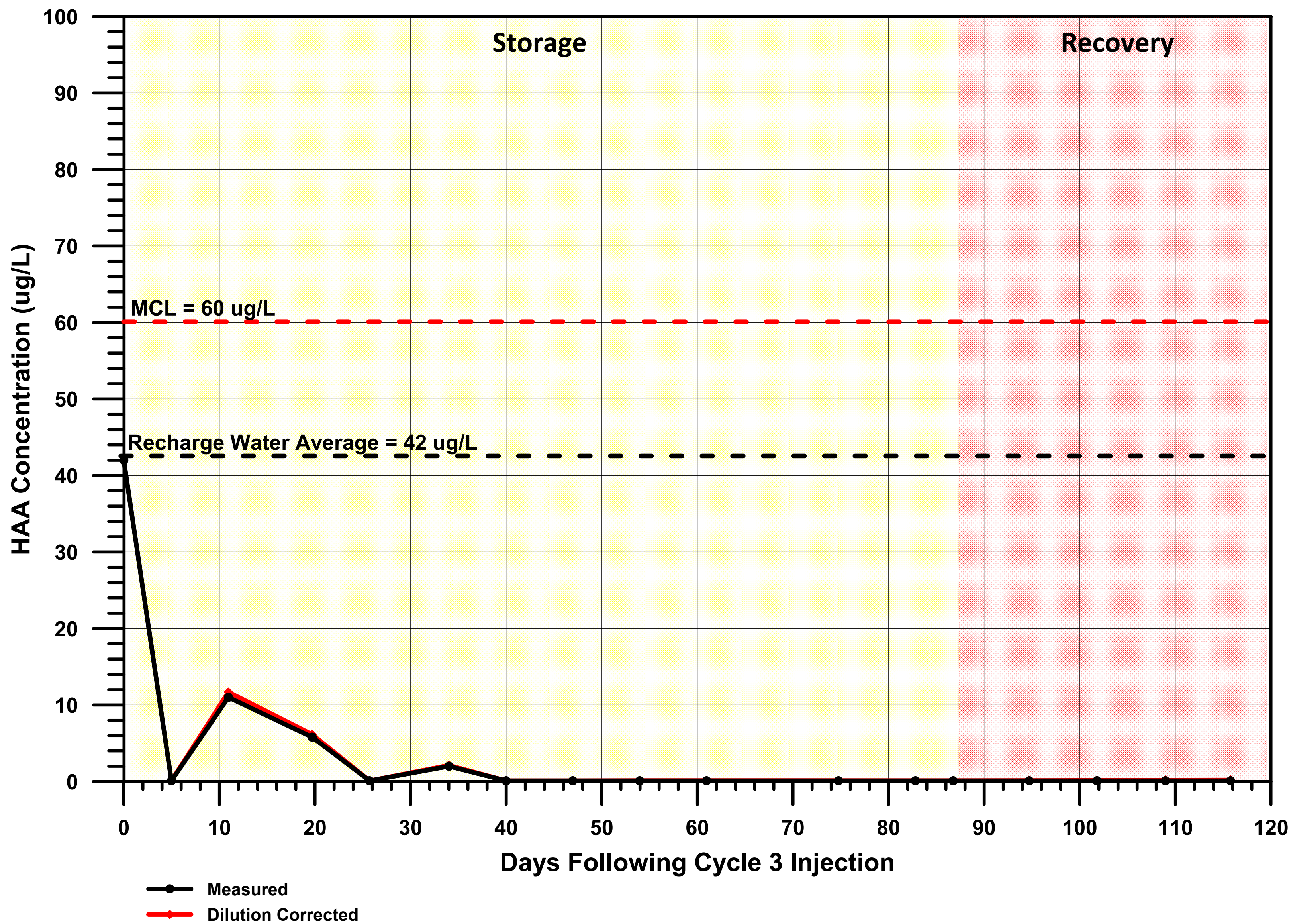
PUEBLO water resources

FIGURE 25. FIRST CYCLE RECOVERY CURVES OF VARIOUS ASR PROJECTS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



PUEBLO water resources

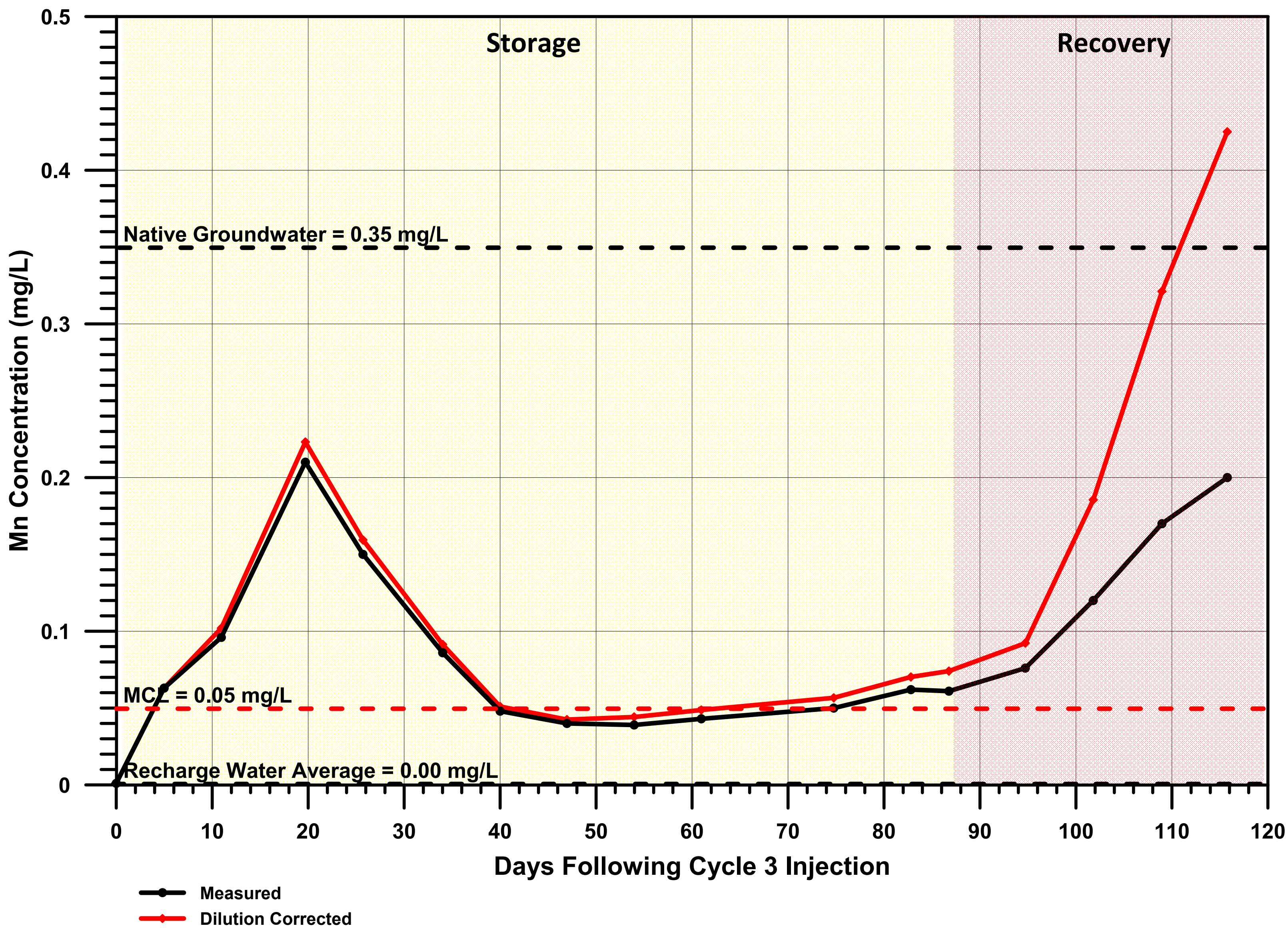
FIGURE 26. ASR CYCLE 3 THM DATA
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department



PUEBLO water resources

FIGURE 27. ASR CYCLE 3 HAA DATA
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

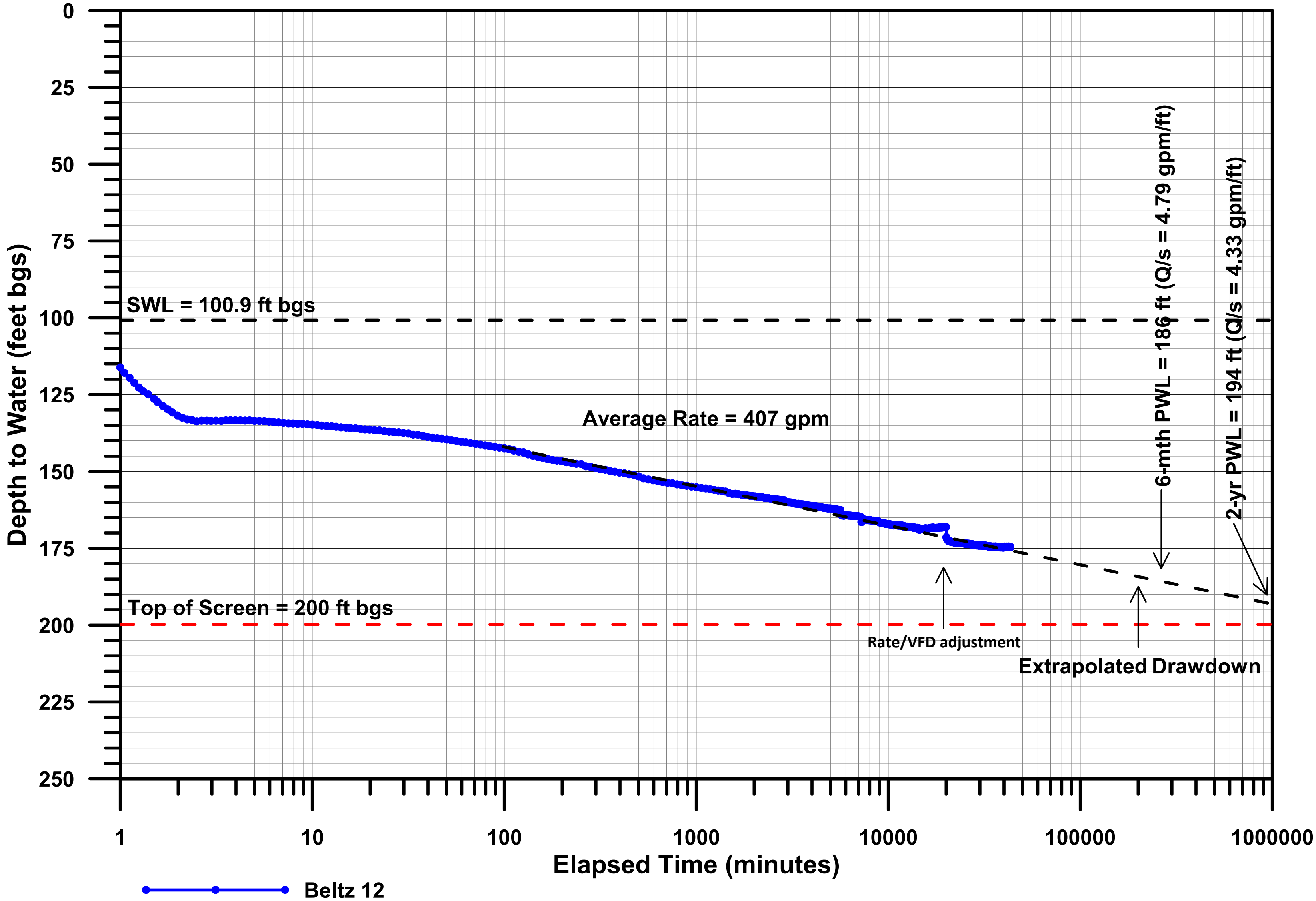
June 2020
Project No. 15-0112



PUEBLO water resources

FIGURE 28. ASR CYCLE 3 MANGANESE DATA
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

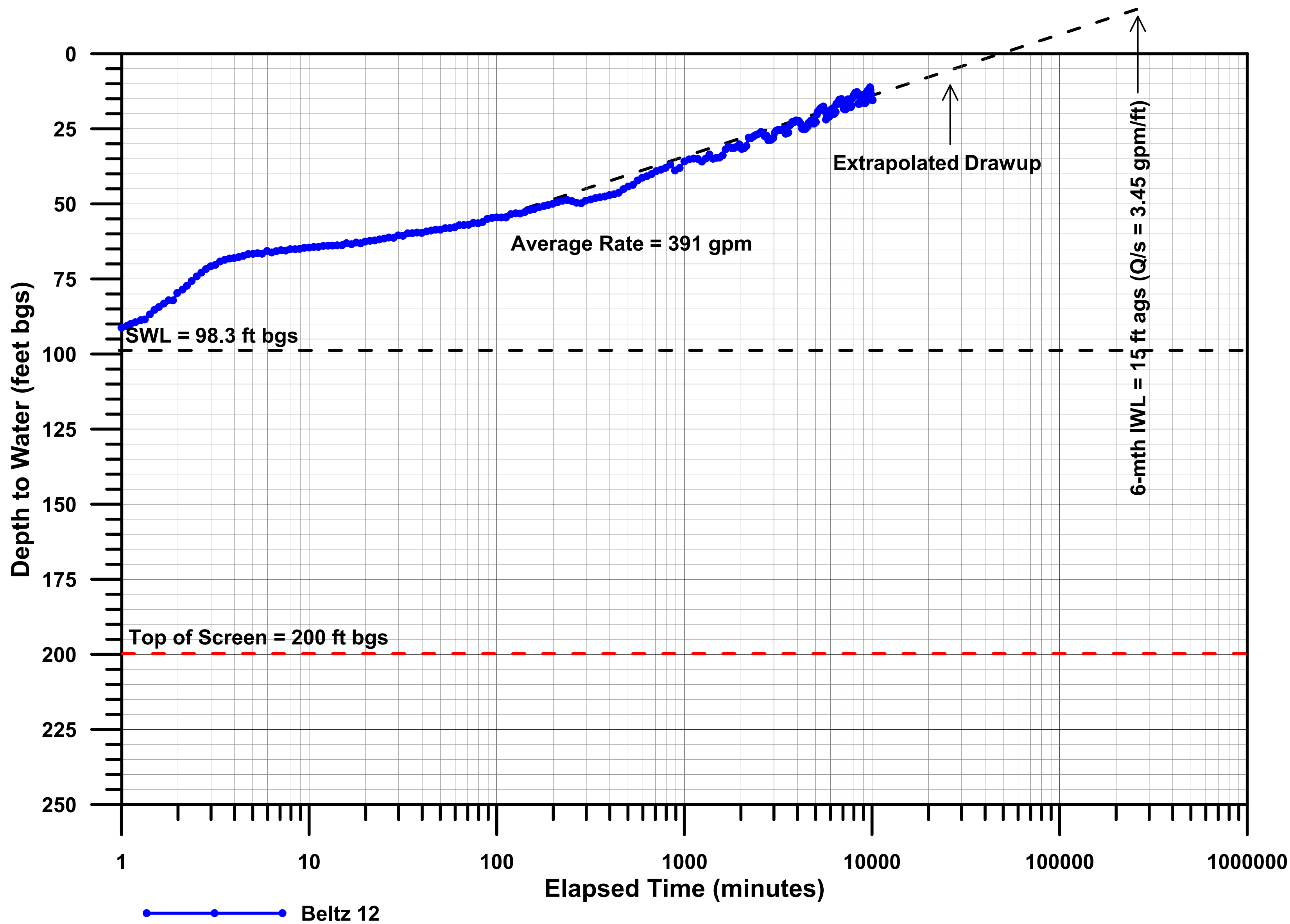
June 2020
Project No. 15-0112



PUEBLO water resources

FIGURE 29. ASR CYCLE 3 - RECOVERY PUMPING CAPACITY ANALYSIS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112



PUEBLO water resources

FIGURE 30. ASR CYCLE 2 - INJECTION CAPACITY ANALYSIS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

June 2020
Project No. 15-0112

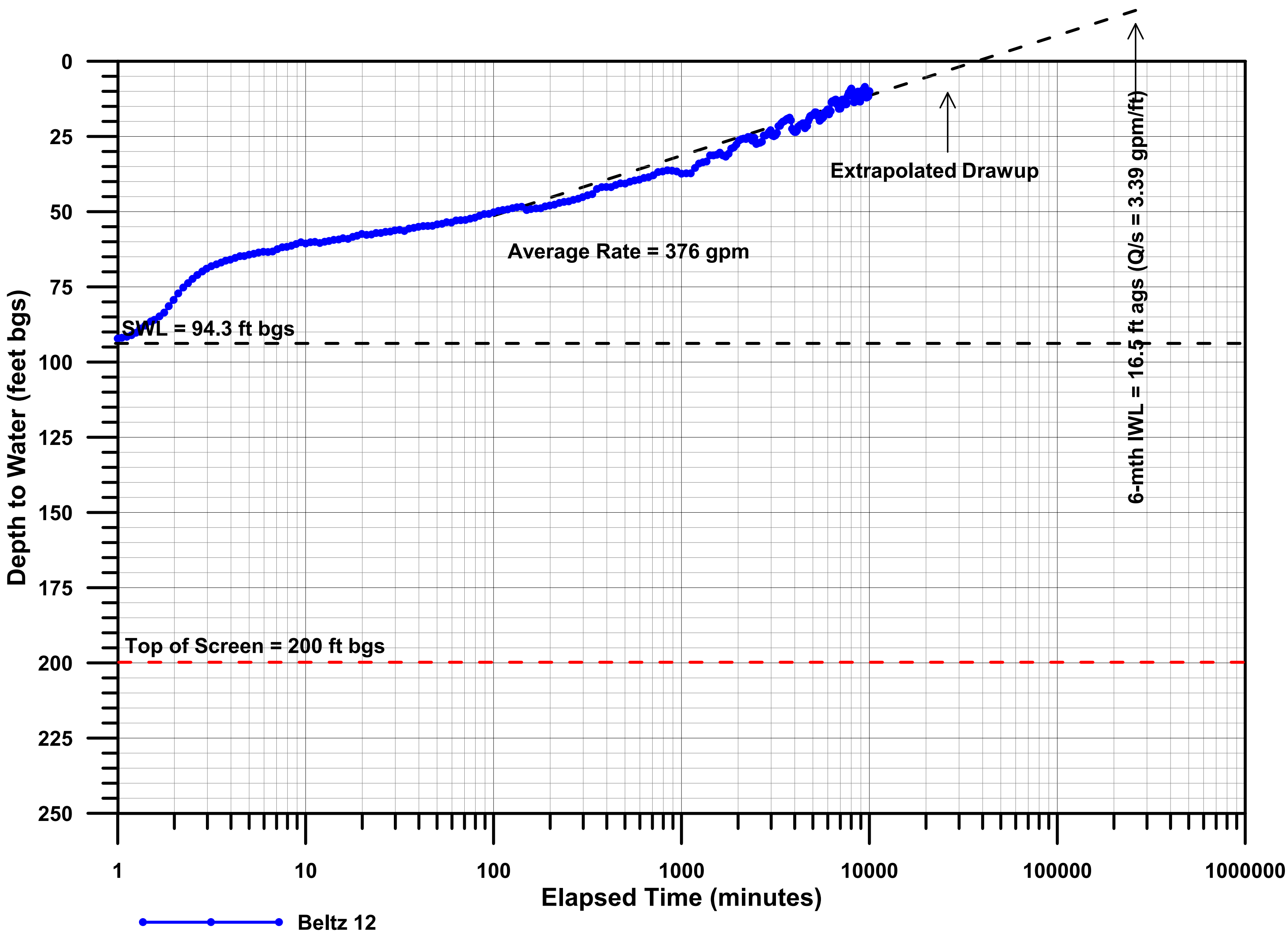


FIGURE 31. ASR CYCLE 3 - INJECTION CAPACITY ANALYSIS
Phase 2 ASR Pilot Test - Beltz 12
Santa Cruz Water Department

APPENDIX A – WORK PLAN

TECHNICAL MEMORANDUM
Pueblo Water Resources, Inc.
4478 Market St., Suite 705 Tel: 805.644.0470
Ventura, CA 93003 Fax: 805.644.0480

To:	Santa Cruz Water Department	Date:	September 25, 2018
Attention:	Isidro Rivera, P.E. Associate Civil Engineer	Project No:	15-0111
Copy to:	Heidi Luckenbach, P.E. Deputy Director/Engineering Manager Kevin Crossley, P.E. Senior Engineer		
From:	Robert C. Marks, P.G., C.Hg Principal Hydrogeologist		
Subject:	Santa Cruz ASR Project – Phase 1 Feasibility Investigation; Task 1.4 - ASR Pilot Test Work Plan for Beltz 12		

INTRODUCTION

Presented in this TM is a detailed Work Plan for implementing an Aquifer Storage and Recovery (ASR) pilot test program at the Santa Cruz Water District's (SCWD) Beltz 12 well. Beltz 12 is located in the Santa Cruz Mid-County Groundwater Basin (MCGB) and is screened in the so-called A, AA and Tu Units of the Purisima Aquifer system. The location of the subject well is shown on **Figure 1** and an As-Built Schematic of the well is shown on **Figure 2**. The overall purpose of the Work Plan is to develop and present the information required to scope, budget, permit and implement an ASR pilot test program at Beltz 12. The Work Plan consists of the following main sections:

- Permitting Requirements
- Site Preparation Details
- ASR Pilot Test Program
- Sampling and Analysis Plan
- Preliminary Project Schedule

BACKGROUND

The SCWD is investigating the feasibility of an (ASR) project to meet projected shortfalls in City water supplies during extended droughts. The project would involve the diversion of "excess"[1] winter and spring flows from the San Lorenzo River (SLR) via the Tait Street and/or Felton Diversion facilities, which would be treated to potable standards at the Graham Hill Water Treatment Plant (GHWTP), then conveyed through the existing (and/or improved) water

[1] "Excess" flows are those flows that exceed SCWD demands and in-stream flow requirements and are within City water rights.

distribution system(s) to ASR wells located in the Santa Cruz Mid-County Groundwater Basin (MCGB) and/or the Santa Margarita Groundwater Basin (SMGB) for injection, storage and later recovery when needed.

The SCWD's ASR Project is being implemented in phases, as follows:

- Phase 1 – Technical Feasibility Investigation
- Phase 2 – ASR Pilot Testing
- Phase 3 – Permanent Project Design, Permitting, and Implementation

The project is currently engaged in the Phase 1 Technical Feasibility Investigation, which consists of the following tasks:

1. Existing Well Screening
2. Site-Specific Injection Capacity Analysis
3. Geochemical Interaction Analysis
4. ASR Pilot Testing Program Development
5. Groundwater Modeling

As of this writing, the Phase 1 investigation is near completion with only Task 4 – Pilot Test Program and Task 5 - Groundwater Modeling ongoing. The findings developed from Tasks 1 through 3 have been documented previously in task-specific Technical Memoranda (TM)[2], the details of which will not be repeated here; however, key findings related to Beltz 12 are summarized below:

- Task 1.1 – Existing Well Screening identified SCWD's Beltz 12 well as the preferred existing well for conducting ASR pilot testing of the target A – AA – Tu units of the western Purisima Aquifer system of the MCGB.

- Task 1.2 – Site-Specific Injection Capacity Analysis resulted in an estimated maximum long-term injection capacity for Beltz 12 of approximately 440 gpm (as constrained by the Hydrofracturing Potential criterion).

- Task 1.3 – Geochemical Interaction Analysis indicated that there is limited potential for adverse geochemical reactions as a result of injecting treated SLR water at Beltz 12 (assuming GHWTP pH is maintained at less than 7.6);

[2] Pueblo Water Resources, Inc. (November 2016), *Task 1.1 Existing Wells Screening*, Technical Memorandum prepared for Santa Cruz Water Department (revised draft).

Pueblo Water Resources, Inc. (May 2017), *Task 1.2 Site-Specific Injection Capacity Analysis*, Technical Memorandum prepared for Santa Cruz Water Department.

Pueblo Water Resources, Inc. (August 2017), *Geochemical Interaction Analysis (Task 1.3)*, Technical Memorandum prepared for Santa Cruz Water Department (draft).

however, the potential for beneficial reduction of manganese concentrations in the recovered waters (relative to native groundwater) was identified and will be investigated further during the ASR pilot test program.

Based on the favorable results of the Phase 1 Technical Feasibility Investigation thus far, it is our understanding that the SCWD desires to advance the ASR investigation to Phase 2 - ASR Pilot Testing. The overall objective of the Phase 2 pilot testing is to field verify the findings developed from Phase 1 and empirically determine specific hydrogeologic and water quality factors that will allow a technical and economic viability assessment of ASR technology for the City. If feasible, the data gathered may also be used to complete CEQA documentation for a full scale or permanent ASR project and provide design basis information for the permanent project.

PURPOSE

The primary purpose of the Beltz 12 ASR Pilot Test is to field demonstrate the potential application of ASR in the A – AA – Tu Units of the Purisima Aquifer in the MCGB. The data will be used to assess both the economic and logistical viability of ASR and will provide the basis for the design, environmental planning, and permitting for a long-term full-scale ASR project. Primary issues to be investigated in the ASR pilot test include the following:

- Determination of well efficiency and specific capacity and injectivity
- Evaluation of injection well plugging rates (both active and residual)
- Determination of optimal rates, frequency, and duration of backflushing to maintain injection capacity
- Determination of long-term sustainable injection rates
- Determination of local aquifer response to injection at Beltz 12
- Monitor ion exchange and redox reactions
- Evaluate water-quality changes during aquifer storage and recovery pumping
- Monitor Disinfection Byproducts (DBPs) Trihalomethanes (THM) and Haloacetic Acid (HAA) ingrowth and degradation during aquifer storage
- Monitor recovery efficiencies (with particular emphasis on manganese concentrations)

FINDINGS

PERMITTING REQUIREMENTS

The State Water Resources Control Board (SWRCB) has recently recognized that it in the best interest of the state to develop a comprehensive regulatory approach for ASR projects and has adopted general waste discharge requirements for ASR projects that inject drinking water into groundwater (Order No. 2012-0010-DWQ or ASR General Order). The ASR General

Order provides a consistent statewide regulatory framework for authorizing both pilot ASR testing and permanent ASR projects, and the Beltz 12 ASR Pilot Test will be permitted under the ASR General Order. Oversight of these regulations is done through the Regional Water Quality Control Boards (RWQCBs) and obtaining coverage under the General ASR Order requires the preparation and submission of a Notice of Intent (NOI) application package to the local RWQCB. The NOI package is required to include the following key components:

a. NOI application fee
b. Complete Form 200 (RWQCB general information form for Waste Discharge Requirements or NPDES Permit)
c. Technical Report (discussed below)
d. US EPA Underground Injection Control registration (discussed below)
e. CEQA compliance documentation (discussed below)

Technical Report

The NOI Technical Report requirements include the following minimum components:

- Project location map
- Identification and description of target aquifers
- Pilot testing schedule
- Delineation of the Areas of Hydrologic Influence
- Identification of all land uses within the delineated Areas of Hydrologic Influence
- Identification of known areas of contamination within the Areas of Hydrologic Influence
- Identification of project-specific Constituents of Concern (COCs)
- Groundwater Degradation Assessment

The Technical Report would be based largely on the findings developed from the Phase 1 Investigation, including the ASR pilot test Work Plan presented herein.

EPA Underground Injection Control Program

The Beltz 12 well will need to be registered as a Class V Injection Well[3] with the US EPA Underground Injection Control (UIC) Program. This registration is a straight-forward process done via the EPA's on-line UIC Inventory Form. A registration confirmation email is provided by EPA and serves as the evidence of UIC registration required by the ASR General Order.

[3] A Class V well is used to inject non-hazardous fluids underground.

CEQA Compliance

The ASR General Order allows that a pilot test may be exempt from provisions of CEQA under CEQA Guidelines Section 15306, which exempts basic data collection that does not result in a serious or major disturbance to an environmental resource. Accordingly, the City should plan to file a Notice of Categorical Exemption (CE) from CEQA for the ASR pilot test under CEQA Guidelines Section 15306.

SITE PREPARATION DETAILS

Several temporary modifications will be necessary at the Beltz 12 site for implementation of the ASR pilot test, including the following:

- Removal of the existing 75 HP pump assembly and installation of a temporary 75 HP pump and injection drop tubes.
- Connection of temporary injection supply pipeline to the City's distribution system as the source of the injection water (injectate).
- Setup of backflush water and recovered test water pipelines
- Setup of a combination of temporary tanks and connection to existing reclaim tanks for backflush water solids settling and dichlorination prior to discharge to storm drain

A schematic of the preliminary piping plan is shown in **Figure 3**, which shows the locations of various valves, meters, sampling ports, pressure gauges, etc., in addition to the direction of flows during the recharge and pumping phases of the test program.

Based on the results of the Task 2 – Site-Specific Injection Capacity Analysis for Beltz 12, a conservative nominal long-term injection rate for the Beltz 12 ASR pilot test of **400 gpm** is recommended for planning purposes. For an injection rate of 400 gpm, a minimum backflush pumping capacity of 800 gpm will be required (i.e., twice the rate of injection) in order to limit well plugging during the test program (refer to the Task 1.2 – Site-Specific Injection Capacity Analysis TM for a discussion of backflushing requirements).

The existing 75 HP pump assembly in Beltz 12 is only rated for 400 gpm @ 500 ft Total Dynamic Head (TDH) and is designed to pump into the Greensand manganese removal filter system prior to distribution. The test program will require a pump that is rated for 800 gpm @ 240 ft of TDH for backflushing of the well during the pilot test; therefore, a temporary pump assembly will need to be installed in Beltz 12 with the following general specifications:

1. Removal of the existing 75 HP pump assembly and temporary storage on site or, at the City's option, cleaned and inspected at the pump shop.
2. Fabrication of special temporary wellhead seal plate
3. Installation of temporary submersible pump (Grundfos 800750-3A [75 HP], or approved equal) set to a depth of approximately 290 ft.

4. Installation of three (3) 2-in-dia Sch 40 PVC injection drop tubes. Injection drop tubes shall be F480 flush-threaded set to a depth approximately 100 ft. Special orifice caps for each tube will be provided by PWR for injection flow control.
5. Installation of two (2) 1-in-dia Sch 40 PVC water-level sounding tubes set to a depth of approximately 290 ft.

ASR PILOT TEST PROGRAM

ASR operations generally consist of three steps:

1. Injection of potable-quality drinking water into the aquifer;
2. Storage of the injected/recharged water within the aquifer, and;
3. Recovery of the stored water.

The structure of the ASR pilot test program includes numerous incremental steps of ASR operations to provide multiple checkpoints in the event that pilot operations deviate significantly from the predicted responses. The test program will generally involve three repeated ASR cycles of operations and monitoring, each of larger volume and duration than the preceding cycle, so that if adverse conditions are encountered at any point, the program can be adjusted, if needed.

Summary of ASR Cycles

The ASR pilot test program generally consists of a 1-day hydraulic “pre-test” to establish injection system hydraulics, followed by three (3) repeated cycles of injection-storage-recovery, with each cycle of greater duration and volume. A robust dataset of aquifer response and water quality information will be developed, while minimizing the risk of adverse effects to the well or aquifer system. A summary of the planned ASR cycles is presented in **Table 1** below:

Table 1. Summary of ASR Cycles

ASR Cycle No.	Injection					Storage	Recovery				
	Period (days)	Rate (gpm)	Total Volume (mg)	Total Volume (af)	Radius (ft)	Period (days)	Period (days)	Rate (gpm)	Volume (mg)	Volume (af)	Discharge Location
1	1	400	0.58	1.77	18	2	1	700	1.01	3.09	Storm Drain
2	7	400	4.03	12.4	46	14	6	700	6.05	18.6	Storm Drain
3	30	400	17.3	53.0	96	60	30	400	17.3	53.0	Distribution

Total Duration (days): 151
Total Injection Volume (mg): 21.9
Total Recovery Volume (mg): 24.3

As shown, the amount of water injected during each ASR Cycle will vary from approximately 0.6 mg (1.8 af) to 17 mg (53 af), with aquifer storage periods ranging from 2 to 60 days before the water is recovered. Recovery volumes for Cycles 1 and 2 are approximately 150 percent of the previously injected water and will vary from approximately 1 mg (3.1 af) to 7 mg (22 af). The recovery volume for Cycle 3 will be the same as the injected volume (17 mg / 53 af) and will essentially mimic a permanent project typical ASR cycle.

Although no adverse reactions were predicted by the Task 1.3 Geochemical Interaction Analysis[4], it is planned to discharge recovered water during ASR Cycles 1 and 2 to the storm drain system to allow for the collection and analysis of water-quality data to ensure that no adverse reactions are occurring during aquifer storage that would affect the potability of recovered water.

Assuming no adverse reactions are observed during ASR Cycles 1 and 2, the temporary test pump and injection drop tubes will be removed from the well (following thorough backflushing of the well) and the permanent pump assembly reinstalled prior to the recovery period of Cycle 3, allowing the well to be operated under normal conditions (which includes manganese removal by the Greensand filter prior to distribution). It is also noted that the recovery rate for ASR Cycle 3 is limited to 400 gpm (refer to **Table 1 above**), compared to 700 gpm (approximately 1 mgd) for Cycles 1 and 2. This is due to the capacity of the permanent pump and manganese Greensand filter system at the Beltz 12 facility, which is limited to 400 gpm.

The primary test objectives for each ASR Cycle are summarized below:

<u>ASR Cycle 1</u>

- Establish short-term injection hydraulics
- Monitor short-term ion exchange reactions

<u>ASR Cycle 2</u>

- Measure well plugging rates (active and residual)
- Evaluate backflushing efficacy
- Monitor longer-term ion exchange reactions
- Monitor redox reactions
- Evaluate water chemistry changes during storage
- Monitor recovery efficiency (the percentage of recharged water that is recovered during each cycle)
- Monitor DBPs during recovery
- Define volume of potential "buffer zone" around ASR well

[4] Assuming GHWTP water is maintained at pH of 7.6 or less to prevent calcite precipitation.

ASR Cycle 3

- Evaluate longer-term well performance and plugging rates
- Monitor injected water quality stability during storage
- Monitor DBP ingrowth/degradation during storage
- Monitor recovered water for re-chlorination and DBP reformation
- Determine economic factors of permanent ASR operations

The total duration of the ASR pilot test program is anticipated to require approximately 5 to 6 months and is tentatively scheduled to begin in December 2018 (refer to the preliminary schedule presented in a following section).

Specific procedures for well injection and backflushing during the Beltz 12 ASR Pilot Test Program are outlined below:

Injection Procedures

1. Adjust valving to flush the potable system supply to the tanks. Set de-chlorination equipment as needed if water will route to storm drain.
2. Initiate system flow to tank to flush the distribution system of scale/residue/particulates. Flushing rate should be at least 150 % of maximum ASR injection rate.
3. Perform Silt Density Index (SDI) test on flowing water stream. Record flush meter reading, time, and SDI value.
4. Repeat SDI test after 20-30 minutes. When two successive results of SDI < 3.0 are achieved, injection operations can be initiated.
5. Upon initiation of recharge operations for the test program, perform a backflush 24 hours after commencement of injection to ensure material sloughed off system piping from flow reversals in the distribution system is backflushed out of the well.
6. Regularly monitor SDI. If SDI > 4.0, immediately stop injection operations, backflush the well, and flush the distribution system to waste until SDI < 3.0 is restored.

Backflushing Procedures

1. Stop injection flow to well, being careful to avoid both water hammer to the distribution system (i.e., by closing valves to quickly) and prolonged negative pressure/cascading water conditions in the well as practical.
2. Record all meter readings and water levels.
3. Adjust valving to ‘backflush position’, routing well production to the tanks.
4. Start well at backflush rate setpoint (800 gpm) and pump for 15 minutes. Measure and record Turbidity at 1, 2, 5, 10 and 15 minutes of elapsed pumping time. Observe visual water clarity and particulate content and note observations. Turn pump off, noting the minimum ‘off-time’ (restart delay) for the specific pump motor in service.

5. Repeat Step 4 a total of 3 times, or until the discharge water is visually clear and less than 10 NTU within 1 minute of pump start-up.
6. When static water level has stabilized (15-minute minimum), start pump and set flow to normal recovery rate (700 gpm for Cycles 1 and 2, and 400 gpm for Cycle 3). Record 10-minute pumping water level and flow rate, calculate and record 10-minute specific capacity.
7. Record all meter readings and water levels.
8. Adjust valving as needed to next ASR operation (e.g., return to injection, storage, or recovery mode).
9. Following sufficient storage period to allow for solids settling and de-chlorination to meet discharge requirements, pump decanted water from tanks to storm drain and ready for next backflushing event.

SAMPLING AND ANALYSIS PLAN

During the Beltz 12 ASR Pilot Test Program, a variety of water-level and water-quality data are to be collected. Water levels in the aquifer system are to be monitored during all phases at the ASR pilot testing well (Beltz 12) as well as several existing, proximate monitoring wells owned by both SCWD and Soquel Creek Water District (SqCWD). In addition, periodic samples of the injected, stored, and recovered waters are to be collected from the Beltz 12 pilot test well and nearby Cory St. monitoring wells and analyzed for a variety of water-quality constituents. The purpose of the Sampling and Analysis Plan (SAP) described below is to identify the locations, sample collection frequency, and parameters to be monitored as part of the ASR pilot test project data collection program.

Project Wells

The Beltz 12 well facility is located in the western portion of the City's service area. Several proximate existing monitoring wells owned both by the SCWD and SqCWD will also be utilized as monitoring wells during the project. The locations of the project wells are shown on **Figure 4** and a summary of project well completion parameters is presented in **Table 2** below

Groundwater Monitoring Equipment

The equipment required to perform the groundwater monitoring as prescribed in this SAP includes:

- Pressure Transducers/Data Loggers
- Electric Water Level Sounder
- Sampling Pumps
- Field Water Quality Monitoring Devices
- Flow-Thru Cell Device(s)

- Sample Containers
- Coolers and Ice

Table 2. Project Well Construction Summary

Well	Distance from Beltz 12 (ft)	Depth (ft bgs)	Dia (in)	Screen Intervals (ft bgs)				Tp Unit(s) Completed
Beltz 12	--	650	16	200 - 290	310 - 390	410 - 470	550 - 640	A - AA - Tu
Cory St	75							
shallow		110	2	70 - 110				A (upper)
medium		240	2	200 - 240				A (lower)
deep		350	2		310 - 350			AA
#4		650	2.5				550 - 640	Tu
O'Neill Ranch *	1670	655	16	200 - 300	340 - 420	470 - 540	550 - 650	A - AA - Tu
Coffee Ln Park	2250							
shallow		150	2	110 - 150				A
deep		250	2		210 - 250			AA
Auto Plaza	2490							
shallow		120	2	120 - 160				A (upper)
medium		290	2	250 - 290				A (lower)
deep		430	2		380 - 430			AA
SC-22 **	3250							
shallow		240	2	150 - 230				A
medium		500	2		460 - 490			AA (upper)
deep		705	2			640 - 700		AA (lower)
30th Ave	4640							
shallow		240	2	200 - 240				A
medium		410	2		370 - 410			AA
deep		800	2.5			720 - 740	780 - 800	Tu

Notes:
Tp - Purisima Formation
* - SqCWD production w ell
** - SqCWD monitoring w ell

Beltz 12 will be equipped with a 75 Hp electric submersible pump. Flow for all process streams will be measured using in-line rate and totalizing flow meters. Sampling ports on the well-head piping allow for the collection of grab samples during recharge and pumping operations. In addition, a portable submersible sampling pump sized to fit inside 2-in-dia Sch 40 PVC monitoring well casings (Grundfos Redi-Flo2) will be utilized to collect periodic samples from the deepest three Cory St nested monitoring wells (medium, deep and #4).

Field water-quality monitoring is to be performed using various instruments that allow for the field analysis of a variety of constituents, including but not limited to: chlorine residual, conductivity, dissolved oxygen, pH, temperature, redox/ORP, and Silt Density Index (SDI). The field water-quality monitoring devices are to be routinely calibrated as prescribed in the operating procedures manual for each device.

The pilot test well, as well as the monitoring wells listed in **Table 2**, will be instrumented with dedicated pressure/level transducers and dataloggers[5]. Reference-point elevations will be established by existing survey records for the wells. Static water-levels will be manually measured with an electric sounder on a weekly basis (minimum) and the transducers calibrated accordingly. The transducers are to be programmed with the reference static water-level and the appropriate data-collection intervals.

Purging and Sampling

During injection periods, samples of the recharge water will be collected directly at the Beltz 12 wellhead while active injection is occurring. During storage periods, the well will be periodically purged and sampled per the below Sampling Schedule. During recovery periods, the well pump will be operating, therefore sample purging is continuous and sustained.

The sampling pumps will be used to purge a volume equivalent to a minimum of three (3) casing volumes from each well prior to sampling. Purge water from the pilot well during backflushing and sampling is to be discharged to temporary holding tanks on site (existing Reclaim tanks and/or Baker tanks?) for surge suppression and analysis prior to discharge to the on-site storm drain system. Water produced by the well during Cycles 1 and 2 recovery operations will also be discharged to the storm drain. The water-quality data collected during Cycles 1 and 2 are intended to demonstrate the potability of recovered water - assuming the results are favorable, Cycle 3 recovery operations will pump into the distribution system (i.e., to minimize “wasting” of water during the pilot test program).

During purging and prior to sampling, field water-quality parameters of temperature, pH and specific conductance are to be monitored. Stabilization of these water-quality parameters will indicate when collection of a representative sample is allowable.

Laboratory Program

A complete list of constituents and constituent “groups” to be monitored as part of the Beltz 12 ASR Pilot Test Project for injected, stored, and recovered waters is presented in **Table 3** below:

[5] Most of the project monitoring wells have existing water level transducers / dataloggers programmed on hourly data collection intervals, which will be maintained and utilized during the pilot test; Beltz 12 and the Cory St wells will be supplemental instrumentation installed by PWR and programmed with variable data collection intervals (i.e., depending on the phase of testing and particular well).

Table 3. Analytic Testing Program Constituent Summary

Parameter	Location of Analysis	Method	Unit	PQL	Field Parameters	Geo-chemical	Disinfection By-Products	Supple-mental
Group ID					**F-1**	**G-1**	**DBPs**	**S-1**
Field Parameters								
Cl Residual	on-site	Hach	mg/L	0.05	x			
Diss O2	on-site	Hach	mg/L	0.2	x			
EC	on-site	EPA 120.1	umho/cm	10	x			
ORP	on-site	USGS	mV	10	x			
pH	on-site	EPA 150.1	Std Units	0.01	x			
SDI	on-site		Std Units	0.01	x			
Temperature	on-site	SM 2550	°C	0.5	x			
Turbidity	on-site	Hach 2100Q	NTU	0.1	x			
General Mineral Analysis								
Alkalinity (Total)	Lab	SM2320B	mg/L	5		x		x
Ca	Lab	EPA 200.7	mg/L	0.03		x		x
Cl	Lab	EPA 300.0	mg/L	0.5		x	x	x
EC	Lab	EPA 120.1	umho/cm	10		x		x
F	Lab	EPA 300.0	mg/L	0.1		x		
Fe (Dissolved)	Lab	EPA 200.7	mg/L	0.05		x		x
Fe (Total)	Lab	EPA 200.8	mg/L	0.05		x		x
K	Lab	EPA 200.8	mg/L	1		x		x
MBAS	Lab	SM 5540C	mg/L	0.05		x		
Mg	Lab	EPA 200.8	mg/L	0.5		x		x
Mn (Dissolved)	Lab	EPA 200.7	mg/L	0.05		x		x
Mn (Total)	Lab	EPA 200.9	mg/L	0.05		x		x
Na	Lab	EPA 200.7	mg/L	0.05		x		x
NH3	Lab	EPA 350.1	mg/L	0.05		x		
NO2	Lab	EPA 300.0	mg/L	0.1		x		
NO3	Lab	EPA 300.0	mg/L	0.1		x		
P (Total)	Lab		mg/L	0.001		x		
pH	Lab	EPA 150.1	Std Units	0.01		x		x
SiO2	Lab	EPA 370.1	mg/L	2		x		x
SO4	Lab	EPA 300.0	mg/L	0.5		x	x	x
Sulfides (Total)	Lab	EPA 376.2	mg/L	0.1		x		
TDS	Lab	SM2540C	mg/L	5		x		x
TKN	Lab	EPA 351.2	mg/L	0.2		x		

Table 3. Analytic Testing Program Constituent Summary (con't)

Parameter	Location of Analysis	Method	Unit	PQL	Field Parameters	Geo-chemical	Disinfection By-Products	Supple-mental
Group ID					**F-1**	**G-1**	**DBPs**	**S-1**
Inorganic Trace Metals								
Ag	Lab	EPA 200.8	ug/L	10		x		
Al	Lab	EPA 200.8	ug/L	10		x		x
As	Lab	EPA 200.8	ug/L	1		x		
B	Lab	EPA 200.8	ug/L	50		x		
Ba	Lab	EPA 200.7	ug/L	1		x		
Be	Lab	EPA 200.8	ug/L	1		x		
Br	Lab	EPA 200.9	ug/L	100		x	x	x
Cd	Lab	EPA 200.8	ug/L	1		x		
Co	Lab	EPA 200.8	ug/L	1		x		
Cr	Lab	EPA 200.8	ug/L	10		x		
Cu	Lab	EPA 200.8	ug/L	5		x		
Hg	Lab	EPA 200.8	ug/L	0.025		x		
I	Lab	EPA 200.8	ug/L	100		x		
Li	Lab	EPA 200.7	ug/L	1		x		
Mo	Lab	EPA 200.8	ug/L	5		x		
Ni	Lab	EPA 200.8	ug/L	1		x		
Pb	Lab	EPA 200.8	ug/L	1		x		
Sb	Lab	EPA 200.8	ug/L	1		x		
Se	Lab	EPA 200.8	ug/L	5		x		
Sr (Total)	Lab	EPA 200.7	ug/L	1		x		
Sr 86/Sr 87 (ratio)	Lab	EPA 200.8	ug/L	0.1 (ratio acuracy)		x		
Tl	Lab	EPA 200.8	ug/L	1		x		
U	Lab	EPA 200.8	ug/L	0.5		x		
V	Lab	EPA 200.8	ug/L	1		x		
Zn	Lab	EPA 200.8	ug/L	10		x		
Bio / Organics								
Coliform	Lab		CFU	<1		x		
HAA5's	Lab	EPA 552.2	ug/L	1			x	
HPCs	Lab	SM9215B	CFU	<1		x		
Organic Carbon (Dissolved)	Lab	SM5310B	mg/L	0.1			x	
Organic Carbon (Total)	Lab	SM5310B	mg/L	0.1			x	
TTHM's	Lab	EPA 502.2	ug/L	1			x	
Miscellaneous								
CH4	Lab	RSK-175	ug/L	5		x		
Gross Alpha	Lab	EPA 900.0	pCi/L			x		
Color	Lab	SM2120B	Color Units	3		x		x
Hardness	Lab	SM2340B	mg/L	10		x		
Tu	Lab	EPA 180.1	NTU	0.1		x		x
TSS	Lab	EPA 160.2	mg/L	1		x		x

Notes:

Sampling Schedule

The planned sample constituent group frequencies for each source for the injection, storage, and recovery periods for each ASR Cycle are summarized below.

Baseline. Prior to Cycle 1 injection, samples will be collected from Beltz 12, the Cory St. monitoring wells and SqCWD's O'Neill Ranch well[6] and analyzed for F-1, G-1 and DBPs Group parameters to establish baseline conditions.

ASR Cycle 1. The sampling schedule for Cycle 1 is presented in **Table 4** below:

Table 4. Sampling Schedule – ASR Cycle 1

Analyte Group	Injection		Storage		Recovery	
	Injectate	Cory St.	Beltz 12	Cory St.	Beltz 12	Cory St.
F-1	Once	--	@end	--	@25, 50, 75, 100, 125 & 150%	--
G-1	Once	--	@end	--	@ 50 and 100%	--
DBP	Once	--	@end	--	@ 100%	--
S-1	--	--	--	--	@ 25, 75, 125, & 150%	--

As shown, the full suite of parameters (F-1, G-1, and DBPs) will be collected of the injectate once during the 1-day injection period of Cycle 1. One sample of the stored water will be collected from Beltz 12 at the end of the 2-day storage period. During recovery pumping, G-1 samples will be collected at 50 and 100 **percent recovery of the injection volume**, supplemented with the shorter S-1 group at 25, 75, 125 and 150 percent. No samples are planned to be collected from the Cory St. monitoring wells during Cycle 1 due to the limited volume of injection not anticipated to be sufficient to arrive at Cory St. during the cycle.

ASR Cycle 2. The sampling schedule for Cycle 2 is presented in **Table 5** below:

Table 5. Sampling Schedule – ASR Cycle 2

Analyte Group	Injection		Storage		Recovery	
	Injectate	Cory St.	Beltz 12	Cory St.	Beltz 12	Cory St.
F-1	Once	--	Weekly	@end	@0, 25, 50, 75, 100, 125 & 150%	@end
G-1	Once	--	Weekly	@end	@ 50 and 100%	@end
DBP	Once	--	Weekly	@end	@ 100%	@end
S-1	--	--	--	--	@0, 25, 75, 125, & 150%	--

[6] Although the volume of injection is not sufficient to be anticipated to impact the O'Neill Ranch well, which is located approximately 1,670 from Beltz 12 (refer to **Table 1** injected water radii estimates), an additional sample will also be collected from the O'Neill Ranch well after completion of ASR Cycle 3 to evaluate the extent to which, if any, injected water may have migrated to this well.

As shown, the sampling schedule for Cycle 2 is similar in scope to Cycle 1, but expanded somewhat and also includes some limited sampling of the Cory St. monitoring wells. During the 1-week injection period, again only one sample is needed. During the 2-week storage period, two samples will be collected from Beltz 12 and one sample collected from Cory St. wells at the end of the period. During recovery pumping, samples will be collected from Beltz 12 at similar percent recovery points as described above for Cycle 1, with one sample collected from the Cory St. wells at the end of the period.

ASR Cycle 3. The sampling schedule for Cycle 3 is presented in **Table 6** below:

Table 6. Sampling Schedule – ASR Cycle 3

Analyte Group	Injection		Storage		Recovery	
	Injectate	Cory St.	Beltz 12	Cory St.	Beltz 12	Cory St.
F-1	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, 100, 125 & 150%	Weekly
G-1	Once	Once	Once	Once	@ 50 and 100%	@ 50 and 100%
DBP	Weekly	Weekly	Weekly	Weekly	@0, 25, 50, 75, 100, 125 & 150%	Weekly
S-1	Weekly	Weekly	Weekly	Weekly	@ 25, 75, 125, & 150%	Weekly

As shown, the sampling schedule for Cycle 3 is the most intensive. This is due to both the extended duration and larger volumes of injection and recovery during Cycle 3. In particular, it is anticipated that the injected water will fully reach the Cory St. wells during the injection period; therefore, sampling at these wells is more relevant during Cycle 3 than the previous cycles. During the 30-day injection period, weekly samples will be collected from both Beltz 12 for the F-1, DBP and S-1 groups, with one sample of the full G-1 suite collected. A similar schedule is planned for the 60-day storage period. During the 30-day recovery period, samples will be collected from Beltz 12 at the same percent recovery levels as the previous cycles, with weekly samples collected from the Cory St. wells.

PRELIMINARY PROJECT SCHEDULE

A preliminary schedule for the Beltz 12 ASR Pilot Test Program is presented in **Table 7** below:

Table 7. Preliminary Project Schedule

Task / Activity	Time Period	Duration (months)
CEQA and Permitting	Sep 2018 - Nov 2018	3
Site Preparation	Nov 2018	1
ASR Cycles	Dec 2018 - May 2019	6
Data Analysis and Reporting	Jun 2019 - Jul 2019	2
	Total:	**12**

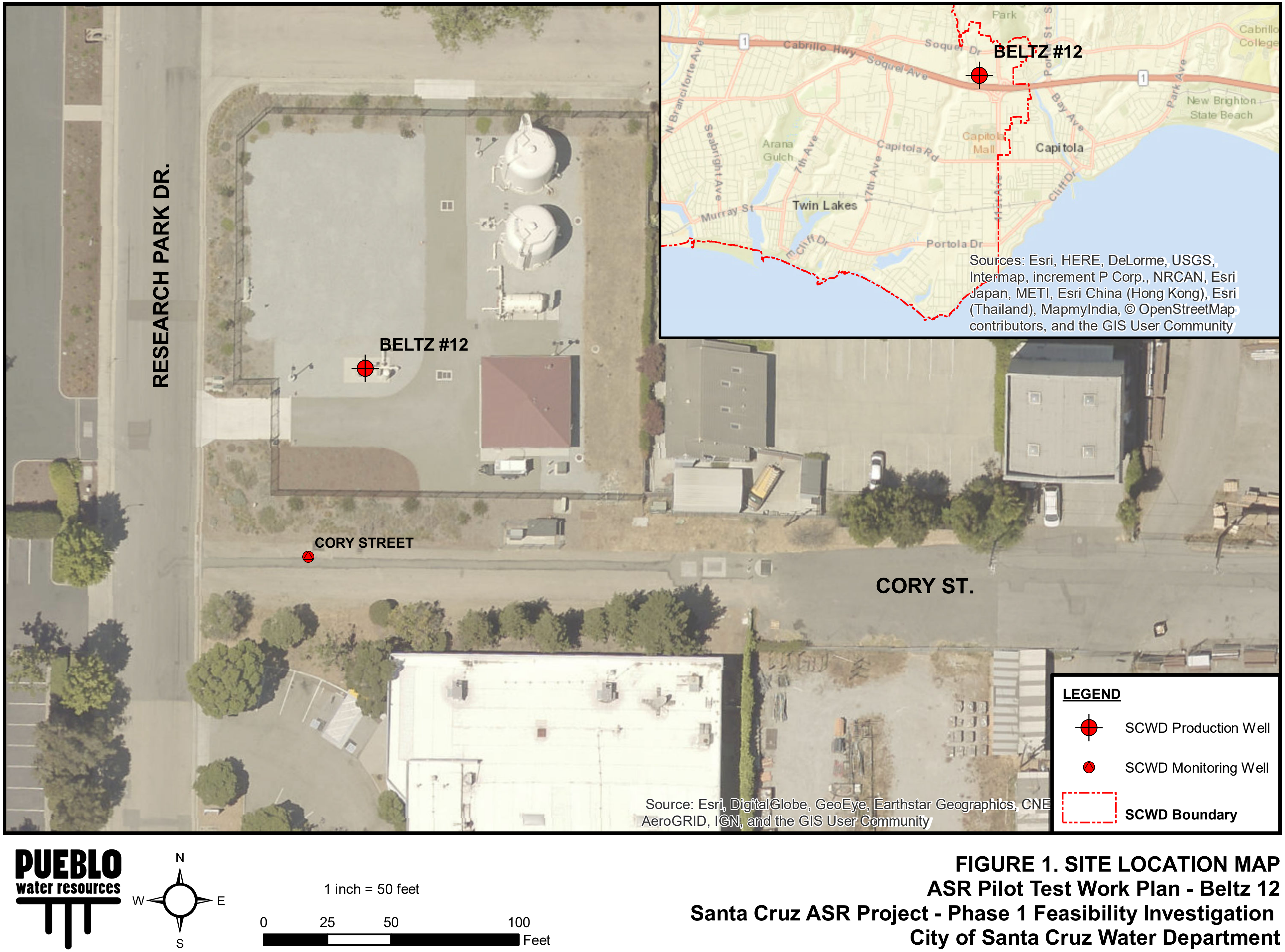
As shown, the ASR cycles are planned to be implemented during the winter/spring of the 2018/2019 water year when excess SLR flows are anticipated to be most available. There is an estimated 3 months of CEQA/permitting and site preparatory work to be completed prior to implementing the test program; therefore, this work will need to be initiated no later than September 2018. Data analysis, reporting and project completion are anticipated by July of 2019, for a total project duration of approximately 1 year.

CLOSURE

This memorandum has been prepared exclusively for the City of Santa Cruz Water Department for the specific application to the City of Santa Cruz ASR Feasibility – Phase 1 Investigation. The findings and conclusions presented herein were prepared in accordance with generally accepted hydrogeologic practices. No other warranty, express or implied, is made.

FIGURES

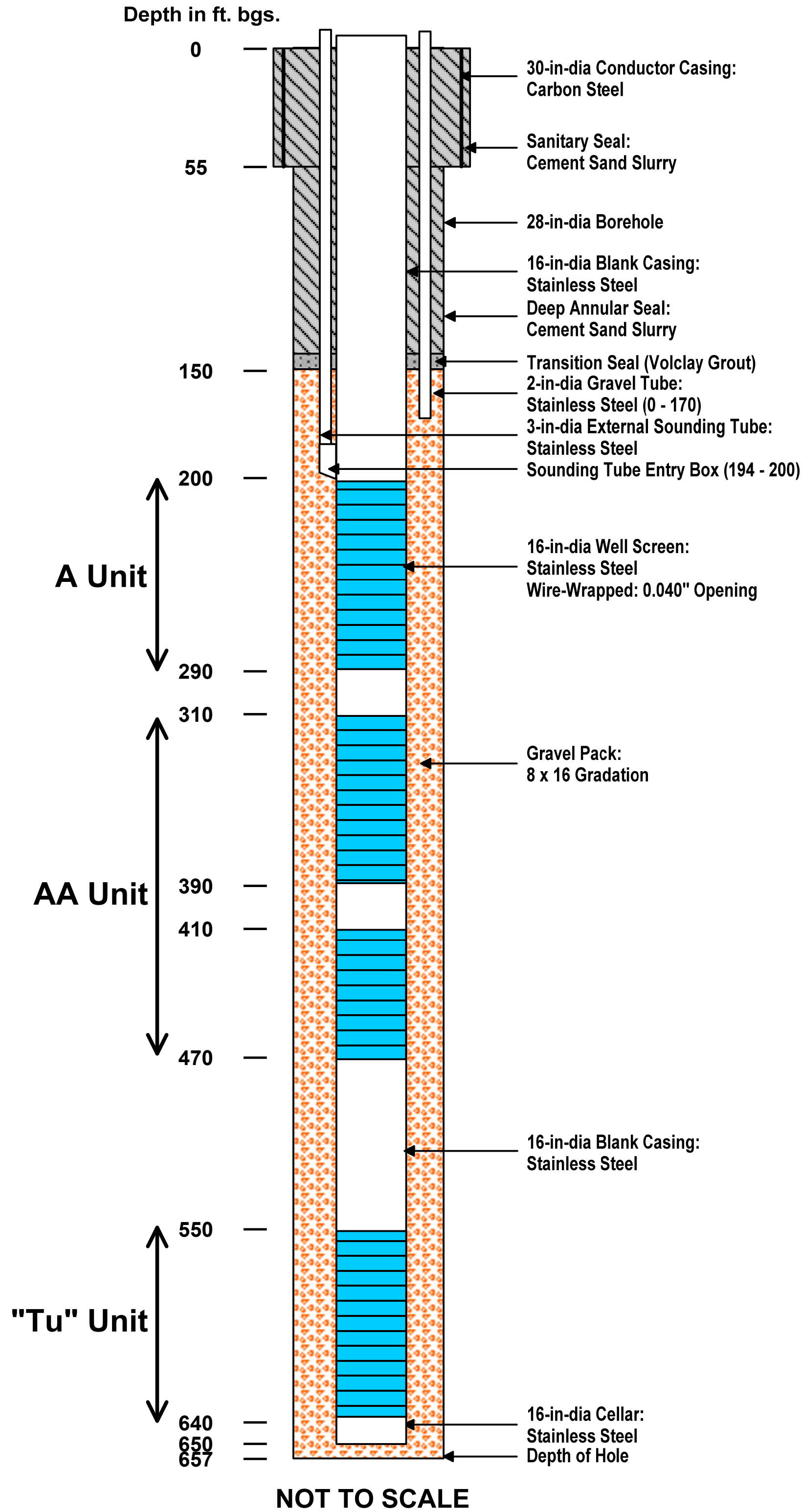
September 2018
Project No. 15-0111



PUEBLO water resources

FIGURE 1. SITE LOCATION MAP
ASR Pilot Test Work Plan - Beltz 12
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

September 2018
Project No. 15-0111



PUEBLO water resources

FIGURE 2. AS-BUILT WELL SCHEMATIC
ASR Pilot Test Work Plan - Beltz 12
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

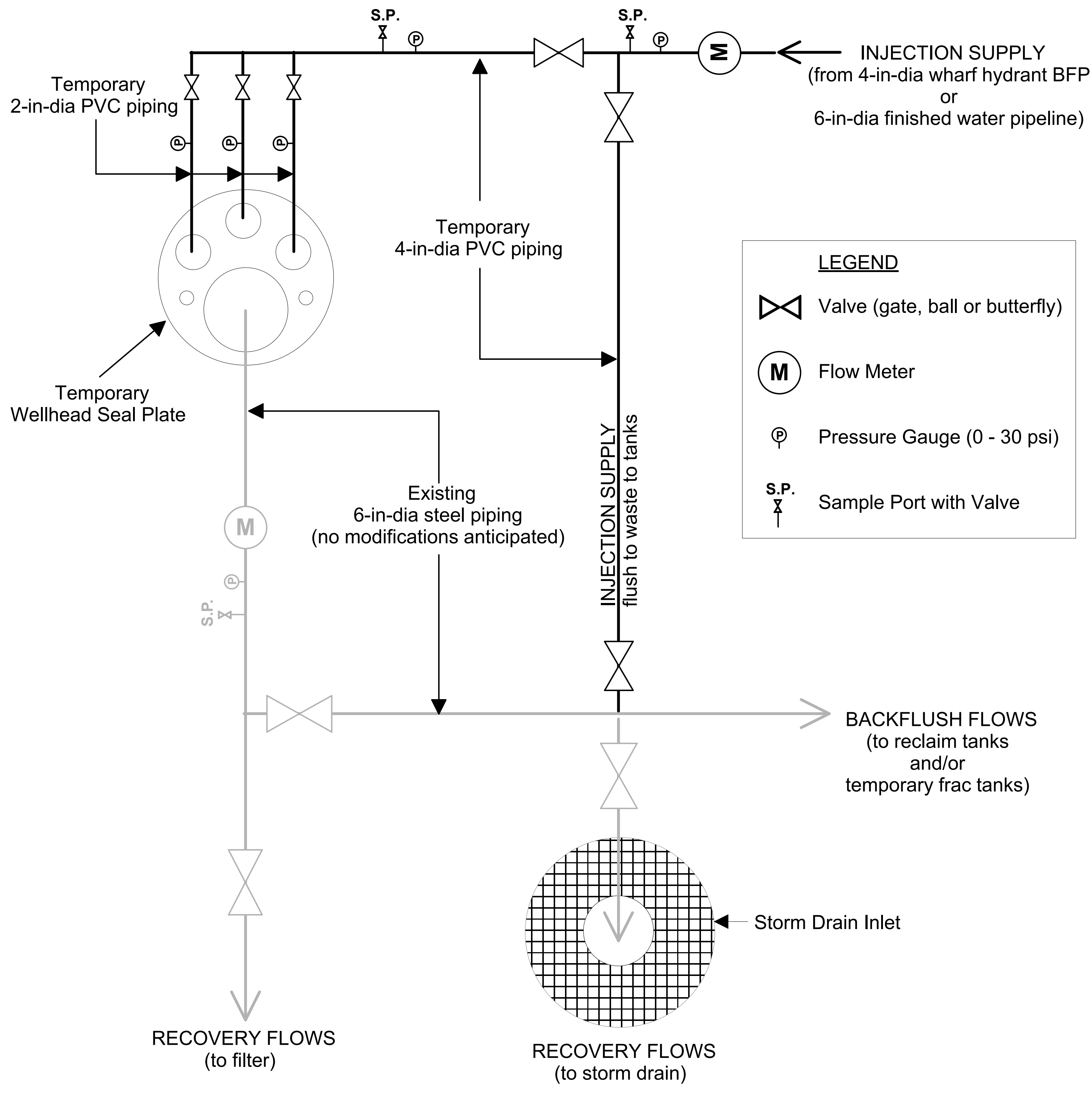
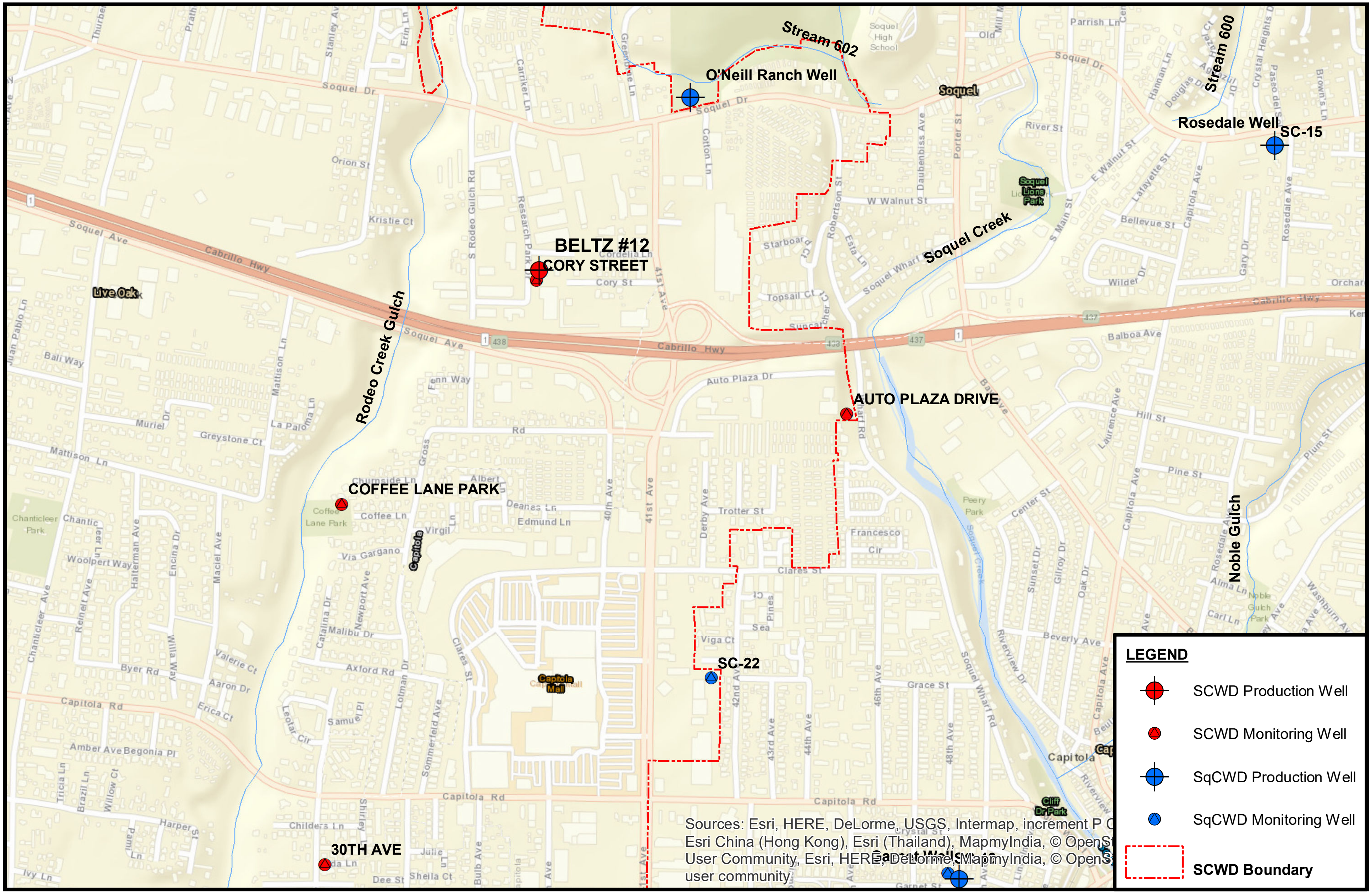


FIGURE 3. PRELIMINARY PIPING SCHEMATIC
ASR Pilot Test Work Plan - Beltz 12
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

September 2018
Project No. 15-0111



PUEBLO water resources

1 inch = 1,000 feet

0 500 1,000 2,000 Feet

FIGURE 4 WELL LOCATION MAP
ASR Pilot Test Work Plan - Beltz 12
Santa Cruz ASR Project - Phase 1 Feasibility Investigation
City of Santa Cruz Water Department

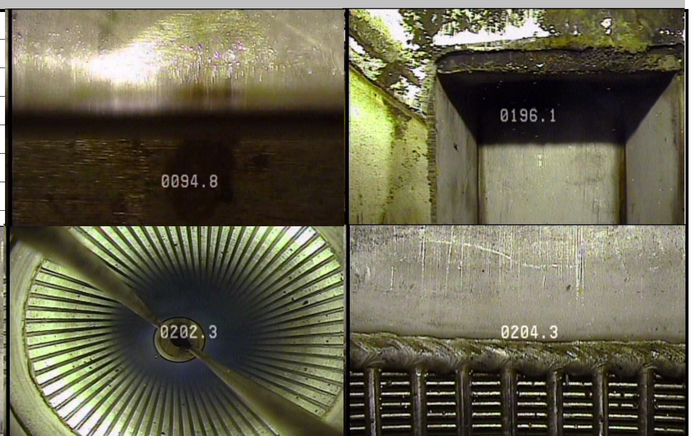
APPENDIX B – VIDEO SURVEY REPORTS

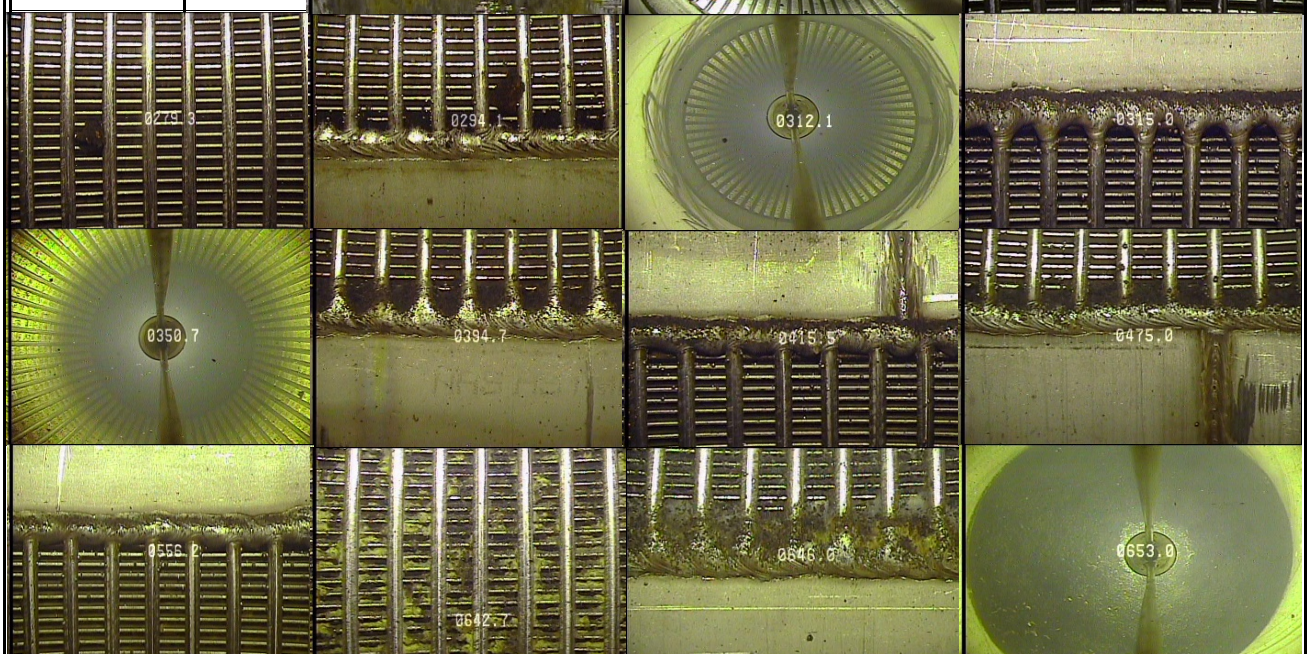
Newman Well Surveys

Video Survey Report

Company:	Maggiora Brothers Drilling	**Date:**	28-Nov-18
Well:	City of Santa Cruz- Beltz Well #12	**Run No.**	One
Field:	Soquel	**Job Ticket:**	74777
State:	California	**Total Depth:**	655.0 ft
		Water Level:	94.8 ft
Location:	2750 Research Park Dr.	**Elevation:**	121.0 ft
		lat 36.984355º	lon -121.967865º
Zero Datum:	Top of casing	**Tool Zero:**	Side view lens (Add 1.5 ft. to downward view)
Reason for Survey:	General Inspection		

Depth	Remarks
0.0 ft	15 1/2" I.D. Steel casing
94.8 ft	Water level
196.1 ft	Port begins, continues to 202 ft.
204.3 ft	Screen begins, continues to 294.1 ft.
315.0 ft	Screen begins, continues to 394.7 ft.
415.5 ft	Screen begins, continues to 475 ft.
556.2 ft	Screen begins, continues to 646 ft.
655.0 ft	Total depth





Notes: Well screen from 556.2 ft. to 646 ft. is moderatley plugged with scale.
All screen above is open. No casing damage seen.

Pacific Surveys

a full service geophysical well logging company

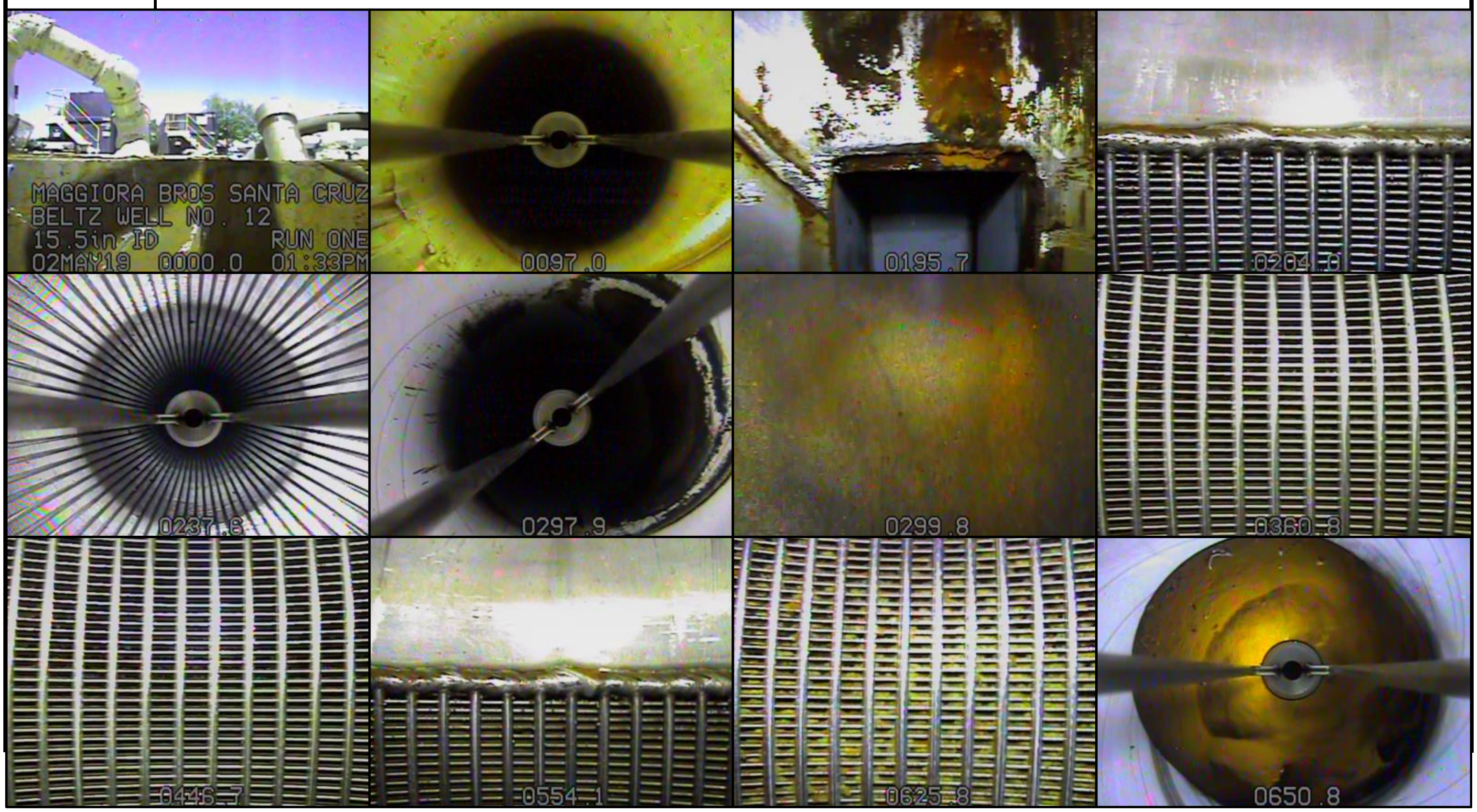
Video Survey Report

Company:	Maggiora Bros Drilling, Inc.	**Date:**	02-May-19		
Well:	City of Santa Cruz - Beltz Well No. 12	**Run No.**	One	**Truck**	PS-8
Field:	Soquel	**Job Ticket:**	25506		
State:	California	**Total Depth:**	654.1 ft		
Location:	3980 Research Park Ct.	**Water Level:**	84.3 ft	SWL	
		Oil on Water:	No	**Amount:**	N/A
GPS:	36.9845 -121.9679	**Operator:**	Schumacher		
Zero Datum:	Top of CSG **Tool Zero:** Side-Scan			**Dead Space**	1.75 ft
Reason for Survey:	General Inspection	**Guides Set @**	15 in		

Depth	Observations
0.0 ft	Begin survey at the top of the casing.
84.3 ft	SWL; water is clear with good visibility. Some staining observed on casing wall once in water.
170.0 ft	Staining appears to lessen.
195.7 ft	Top of camera port. Extends to 201.6 ft.
204.0 ft	Top of first screen interval. Wire-wrap screen appear open and in good condition.
293.3 ft	Bottom of first screen interval.
299.6 ft	Evidence of possible rubbing. Zone extends to 300.3 ft.
314.0 ft	Top of second screen interval. Wire-wrap screen appear open and in good condition.
393.4 ft	Bottom of second screen interval.
414.0 ft	Top of third screen interval. Wire-wrap screen appear open and in good condition.
473.4 ft	Bottom of third screen interval.
554.1 ft	Top of fourth screen interval. Wire-wrap appear open and in good condition.
600.0 ft	Begin to observe a minor amount of bio-material on the screen.
643.6 ft	Bottom of fourth screen interval.
652.3 ft	Soft fill encountered.
654.1 ft	Camera comes to rest.
	End survey.

Well Details

Perforation:		As-Built
Wire-Wrap		200.00 ft to 290.00 ft
		310.00 ft to 390.00 ft
		410.00 ft to 470.00 ft
		550.00 ft to 640.00 ft
Casing Size (in):		**As-Built**
O.D.	**I.D.**	
16.000	15.500	0.00 ft to 650.00 ft
Casing Material	SST	
Screen Material	SST	



800.919.7555
909.625.6262

1785 w. arrow rte., bldg. d, ste. 3,4
upland, ca 91786
www.pacificsurveys.com

fax: 909.399.3180

APPENDIX C – FIELD DATA SHEETS

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: Ph 2 ASR - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 12/14/18

Test/Data Set I.D.: Pre-Injection Q/S

Observer: RCM

Reference Pt: Top of S. Tube (0.8' atoc 1.8' ags)

Static Water Level (ft): 93.8

Pump Setting (ft): ~240

Well Depth (ft):

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
13:00	0	–	93.8	–	Totalizer - 97337615 gals
	1		129.8		
	2	~725	145.3		
	4		149.9		
	6		151.6		
	8		153.3		60.7' DDN 10-min Q/s = 11.6
13:10	10	701	154.5		Totalizer = 97344630 gals (702 gpm Avg)
	12		155.4		12 psi B.P., 49.5 HZ
	15		156.1		
13:20	20	704	157.8		Manual DTW = 157.9
13:30	30	702	159.5		pH = 7.95, EC = 640 us, T = 19.0°C
	40	702	161.2		Adj Q ↑ slightly
	50		162.7		
14:00	60		164.0		Collect WQ Samples
	70		165.1		pH = 7.54, EC = 649 us, T = 18.7°C
	80		165.9		ORP = ⊖81mv, Tu = 0.86 ntu, DO = 3.6 mg/L
14:30	90	701	166.6		
14:40	100		167.7		Q/s = 701 ÷ 73.9 = 9.49 gpm/ft
15:00	120		169.2		Stop Pump.
					Totalizer = 97421788 gals
					84,173 gal/120 min = 701 gpm Avg

Notes: Zobell's Soln = 205.4 mv @ 18.1°C
pH 7.0 = 7.03 @ 18.2°C

Sheet 1 of 1

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Injection Hydraulics Pre-Test

Sheet No. 1 of 1

Date/Time	ET (min)	Rate (gpm)	Totalizers: Inj (af)	Totalizers: BFP (ft3)	Pressure (psi): Line	Pressure (psi): Head	Pressure (psi): 0.8"	Pressure (psi): 1.1"	Pressure (psi): 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/17/19 15^{00}	-	-	26.36	104905	52	58	-	-	-	98.7	-	
15^{10}	0	-			-	-	-	-	-			open 0.8" D.Tube.
15^{20}	10	90			49	48	10	-	-	90.6		Q ↑
15^{30}	20	105			46	42	30	-	-	88.8		Close 0.8" D.Tube (DT)
15^{40}	0	-			-	-	-	-	-			open 1.1" DT.
15^{50}	10	140			48	38	-	10	-	85.4		Q ↑
16^{00}	20	165			46	44	-	30	-	82.6		Close " "
16^{10}	0	-			-	-	-	-	-	-		open 1.5" DT
16^{20}	10	205			46	42	-	-	10	78.9		Q ↑
16^{30}	20	245			44	46	-	-	30	74.0		close " "
			26.39	106243								

Backflushing (to Tanks)

	Totalizer	DTW
t_0	97451785	96.4
t_{70}	97459839	165.9
Δ	8054	60.5

16^{50} start pump
17^{00} stop pump
Tot end : 97459839

10-min Q/s = 805/60.5 = 11.6 gpm/ft

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12

Project No.: 15-0112

Well: Beltz 12

Test: ASR Cycle 1 Injection (24-hr CR)

Sheet No. 1 of 2

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/18/19 9:15	0	-	26.46	109349	46	48	-	-	-	97.1	-	Start Inj.
	1											
	2											
	4											
	6	405			36	32	11	12	11	63.9		
	8	398								62.9		Q ↑ slightly
9:25	10	400			36	34	16	15	17			
	12	415										Q ↓ slightly
	16									60.1		
9:35	20	404	26.48	110387	36	35	11	14	16	59.1		1038 ft³/20 mins = 388 gpm avg
9:45	30	403								57.6		
	40	402					14	14	17	56.6		
	50											
10:15	60	402	26.53	112501	36	36	16	16	16	55.1		Q ↑ slightly. 2114 ft³/40 mins
	80											= 395 gpm Avg
10:45	90	402	26.57	114145	36	36	16	16	16	53.1		
10:55	100	402	26.58	114633	36	36				52.6	44.5	Q ↑ slightly 4246 ft³/80 mins
11:15	120	401			36	36	16	16	16	51.1		= 397 gpm Avg
												100-min Q/s = 397/44.5
												= 8.92 gpm/ft
												11:15 Q ↑ slightly
11:50		402			36	36	18	19	18	49.7*		*Manual DTW
13:40		413	26.79	123555	42	38	23	24	22	44.9*		*n/a - System pres. up. No adj.

PUEBLO water resources

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12

Project No.: 15-0112

Well: Beltz 12

Test: ASR Cycle 1 Injection (24 hr CR)

Sheet No. 2 of 2

Date/Time	ET (min)	Rate (gpm)	Totalizers: Inj (af)	Totalizers: BFP (ft3)	Pressure (psi): Line	Pressure (psi): Head	Pressure (psi): 0.8"	Pressure (psi): 1.1"	Pressure (psi): 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/18/19 18:20		410	26.99	132266	44	40	23	24	22	41.9		
20:15		391	27.28	144832	40	35	21	21	20	40.6		No Adj.
1/19/19 8:25		400	28.20	184527	44	40	25	25	24	33.3		
9:15	1440	380	28.27	187125	40	34	21	21	20	35.1	62.0	System pressure drop! Shut down Injection
												9:18 off.
9:20		Ø	28.27	187229	-	-	-	-	-			Avg Rates Inj = 409 gpm BFP = 404 gpm
												24-hr Q/s = 404 gpm / 62.0 ft = 6.52 gpm/ft

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 1/21/19 - 1/22/18

Test/Data Set I.D.: ASR Cycle 1 Recovery

Observer: RCM

Reference Pt: Top of S. Tube (

Static Water Level (ft): 92.3

Pump Setting (ft):

Well Depth (ft):

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
9[30]	0	-	92.3	-	Totalizer = 97484910 gals
	1				
	2	~770			
	4				
	6	735			~5 psi back pressure, 49.5 Hz
	8				
9[40]	10	728	151.5		Totalizer = 97491900 gals Adj Q ↓
	12				
	16	705	152.8		~47.5 Hz, 5 psi
9[50]	20				
10[00]	30				Cl_2 = 0.01 mg/L (ND)
	40				
10[20]	50	701	157.9		47.5 Hz No Adj.
10[30]	60	703			
	70				
	80				
11[00]	90				
	100				
11[30]	120				
11[50]	150	702	167.2		46.4 Hz
12[30]	180				
* 13[30]	240				

Notes: 10[00] Zobell's soln = 236.5 mV @ 16.2°C
pH 7.0 std = 7.03

Sheet 1 of 2

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2

Project No:

Well: Beltz 12

Date: 1/21/19

Test/Data Set I.D.: ASR Cycle 1 Recovery

Observer: RCM

Reference Pt: Top of S. Tube (2.6' ags)

Static Water Level (ft): 92.3

Pump Setting (ft):

Well Depth (ft):

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
	14^{30}	300	702	171.9		Totalizer = 97695700 (703 gpm Avg)
	15^{30}	360				48.2 Hz
	16^{30}	420				
*	17^{30}	480	702	175.9		
	18^{30}	540				
	19^{30}	600				
	20^{30}	660				
*	21^{30}	720	702	178.5		Totalizer = 97990800 (702 gpm Avg ET 10-720)
	22^{30}	780				
	23^{30}	840				
1/22	0^{30}	900				
*	1^{30}	960				~1^{00} flow @ 665 gpm. Q ↑ 705 gpm
	2^{30}	1020				
	3^{30}	1080				
	4^{30}	1140				
*	5^{30}	1200				
	6^{30}	1260				
	7^{30}	1320				
	8^{30}	1380				
*	9^{30}	1440	705	192.7		Stop Pump
						Totalizer End = 98484780 gals
						701 gpm Avg.

Notes:

24-hr Q/S = 701 gpm / 100.4 ft = 6.98 gpm/ft

Sheet 2 of 2

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 2 Injection

Sheet No. 1 of 4

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/23/19 10:50	0	-	28.36	191466	56	54	-	-	-	100.2	-	Start Inj.
	1									93.1		
	2	400								81.5		
	4	420			42	30	11	12	11	72.6		Adj Q ↓
	6									67.5		
	8	410			42	32	10	11	11	66.9		
	10									66.3		
	12									65.8		
	16									64.9		
	20	400	28.39	195513	44	32	11	11	12	64.4		Adj Q ↑
11:20	30	400			46	34	12	13	13	62.5	37.7	
11:30	40	401	28.41		44	32	12	14	14	61.0	39.2	
	50									60.4		
11:50	60	402					13	14	14	59.2	41.0	pH = 7.38
12:00	70									58.8		SDI: t_0 = 40 secs
12:10	80	398								58.2		Q ↑ t_5 = 48
12:20	90	400			44	32	15	15	16	56.4	43.8	t_{10} = 59 = 2.86
12:30	100	403	28.49	196739	44	32	16	16	15	56.3	43.9	t_{16} = 70
12:50	120									55.2		
13:50	180									52.5		
14:50	240	402	28.66	204217	48	34	18	18	18	50.2	50.0	397 gpm Avg. No Adj.
15:50	300									50.7		SDI: t_0 = 39 secs
16:50	360	392	28.80	210345	42	30	15	15	15	49.3		Sys t_5 = 48
17:50	420									48.6		Pres Drop t_{10} = 60 = 3.50
18:50	480									46.9		No Adj t_{15} = 82
19:50	540	393	29.01	219507	44	34	18	18	17	44.9		Q ↑ slightly
20:50	600	401					21	21	20	43.1		

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 2 Injection

Sheet No. 2 of 4

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Head	0.8"	1.1"	1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/24/19 8:50	1320	393	29.98	260871	44	34	23	23	22	36.4		Adj Q ↑
9:50	1380	401			44	32	26	26	22	35.1		SDI: t_0 = 40 secs
10:50	1440	384	30.12	267130	40	28	23	23	19	36.2		sys t_5 = 49
11:30	1500									36.5		Predep t_{10} = – = 2.75
12:30										36.4		t_5 = 68
13:30										35.6		
14:30										33.7		
15:30										32.7		
16:30										33.2		
16:50		400	30.56	285877	44	34	27	27	23	32.6		Manual DTW. (398/392 gpm Avg)
17:30												
18:30												
19:30												
20:30												
21:30												
22:30												
23:30												
1/25 0:30												
1:30												
2:30												
3:30												
4:30												
5:30												
6:30												9:30 SDI: t_0 = 39 secs t_5 = 47 secs
7:30												t_{10} = 59 t_{15} = 67
8:30												= 2.79
9:30	2800	378	31.78	338719	42	30	24	24	20	30.3		sys pres down (intertie open?)

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 2 Injection

Sheet No. 3 of 4

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Head	0.8"	1.1"	1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/25 10:30	2860											
11:30												
12:30												
13:30		346			46	36	29	29	25	27.6	72.6	Adj Q ↑ slightly
14:30												
16:30		403			46	40	26	27	28	26.9	73.3	
16:30												(382 gpm Avg BFB)
1/26 11:35	4365	374	33.68	420389*	40	34	22	22	23	26.5	73.7	*@ 11:35 Sys Pres down. No Adj. (intake open?) SDI: t_0 = 41 secs; t_5 = 60; t_{10} = 74; t_{15} = 86; = 3.49. pH = 7.29, 13.9°C
1/27 10:05	5715	373	35.31	490639	40	34	24	24	25	23.6	76.6	Sys pres. down (intake open?)
												11:50 SDI: t_0 = 40 secs; t_5 = 46; t_{10} = 54; t_{15} = 64; = 2.50. pH = 7.35. 389 Avg
10:20	5730	380			40	34	26	26	26	22.5		Adj Q ↑ slightly
1/28 8:30	7060	380	36.95	561156	40	36	28	27	26	19.7	80.5	Sys pres down. SDI: t_0 = 42 secs; t_5 = 46; t_{10} = 51; t_{15} = 58; = 1.84. pH = 7.45. 382 gpm Avg since 1/27; " " " Test ET

1345

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 2 Injection

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
1/28/19 14:00	7390	400	37.34	578073	46	42	32	32	30	16.8	83.4	
1/29 8:50	8520	377	38.72	637356	40	36	28	28	26	17.8	82.4	Sys pres down (intertie open?) SDI: t_0 = 40 secs, t_5 : 47, t_{10} = 55, t_{15} = 65 = 2.56; pH = 7.41; 392 gpm Avg 7390 - 8520 mins; 391 gpm Avg 0 - 8520 mins; No Adj.
17:00	9010	396	39.31	662776	46	40	33	33	32	15.3	84.9	No Adj
1/30 10:20	10050	377	40.56	716862	40	36	28	28	26	16.3	83.9	Sys pres. down (intertie open?) SDI: t_0 = 41 secs, t_5 = 48, t_{10} = 58, t_{15} = 67 = 2.58; pH = 7.41
10:50	10080	377	40.60	718353	42	36	28	28	26	16.9		Shut Down (start closing valves)
10:55		∅	40.60	718500			–	–	–			off. 391 gpm Avg

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/14 - 25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.67'

Pump Setting (ft): ~290

Well Depth (ft): 650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
16:30	0	-	89.7		Totalizer = 98,573,880 gals
	1		141.4		
	2	760	145.0		48 HZ
	4		148.1		
	6		152.2		
	8	725	152.8		
	10		154.0		
	12	725	155.3		49.5 HZ
	16		156.3		
	20		157.4		
	30	720	159.1		
	40		160.5		
	50		161.9		
17:30	60	715	162.5		49.5 Hz, 7 psi B.Pres.
	70		163.6		
	80		164.8		
18:00	90		165.5		
18:10	100		165.9		
18:30	120		167.2		↗ 706 gpm Adj
19:30	180		170.8		20:10 Totalizer = 98,729,300 DTW = 171.7'
20:30	240		174.9		695 gpm / 49.6 Hz, Adj Q ↑
21:30	300		177.5		20:20 708 gpm 50.6 Hz

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19-25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.7

Pump Setting (ft): ~290

Well Depth (ft): 650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
22:30	360		179.2		
23:30	420		180.5		
2/20 0:30	480		181.5		
1:30	540		182.6		
2:30	600		183.7		
3:30	660		184.5		
4:30	720		184.9		
5:30	780		185.7		
6:30	840		186.2		
7:30	900		186.7		
8:30	960		187.2		724,120 gal/1035 min = 700 Avg
9:10	1000	687	187.6		9:45 Totalizer = 99298000 gals
10:10	1060		192.2		9:40 Manual DTW = 187.8' btst
11:10	1120	705	190.8		9:50 Adj Q ↑ 54.1 Hz / 20 psi B.Pres.
12:10	1180		191.2		
13:10	1240		191.9		
14:10	1300		192.4		
15:10	1360		192.8		
16:10	1420	706	193.2		
17:10	1480		193.6		
18:10	1540		194.1		
19:10	1600		194.3		

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR Ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19 - 25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.7

Pump Setting (ft): ~290

Well Depth (ft): 650

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
	20:10	1660		194.6		
	21:10	1720		194.8		
	22:10	1780		195.1		
	23:10	1840		195.5		
2/21	0:10	1900		195.6		
	1:10	1960		195.9		
	2:10	2020		196.2		
	3:10	2080		196.4		
	4:10	2140		196.6		
	5:10	2200		196.7		
	6:10	2260		196.9		
	7:10	2320		197.0		Note:
	8:10	2380		197.1		(Rate fluctuating between ~680 - 710 gpm)
	9:10	2440	700			Totalizer = 100282800 gals
	10:10	2500				(54.1 Hz) = 984,800 / 1405 mins
	11:10	2560				(22 psi B.P.) = 701 gpm Avg.
	12:10	2620				
	13:10	2680				
	14:10	2740	695			Totalizer = 100491500 gals
	15:10	2800				= 208,700 / 300 mins
	16:10	2860				= 695 gpm Avg. Adj Q↑
	17:10	2920				

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 – Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19–25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.7

Pump Setting (ft): 290

Well Depth (ft): 650

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
	18:10	2980		199.3		
	19:10	3040		199.4		
	20:10	3100		199.6		
	21:10	3160		199.7		
	22:10	3220		199.9		
	23:10	3280		199.9		
2/22	0:10	3340		200.2		
	1:10	3400		200.2		
	2:10	3460		200.3		
	3:10	3520		200.4		
	4:10	3580		200.5		
	5:10	3640		200.7		
	6:10	3700		200.7		
	7:10	3760		200.7		
	8:10	3820		200.8		
	9:10	3880		200.9		
	10:10	3940		201.0		
	11:10	4000		201.1		
	12:10	4060		201.2		13:25 Totalizer = 101462200 gals
	13:10	4120	695	201.3		= 970,700 / 1395 mins
	14:10	4180		201.9		= 696 gpm. Avg Adj Q ↑
	15:10	4240		202.3		

Notes:

16:30

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR Ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19-25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of s.Tube

Static Water Level (ft): 89.7

Pump Setting (ft): 290

Well Depth (ft): 650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
16^{10}	4300		202.7		
17^{10}	4360		202.9		
18^{10}			203.1		
19^{10}			203.2		
20^{10}			203.3		
21^{10}			203.4		
22^{10}			203.4		
23^{10}			203.5		
2/23 0^{10}			203.6		
1^{10}			203.7		
2^{10}			203.8		
3^{10}			204.0		
4^{10}			204.0		
5^{10}			204.0		
6^{10}			204.0		
7^{10}			203.9		
8^{10}			203.9		
9^{10}			204.2		
10^{10}			204.1		
11^{10}			204.3		
12^{10}			204.4		
13^{10}			204.5		

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19-25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.7

Pump Setting (ft): 290

Well Depth (ft): 650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
14[10]	5620	699	204.6		Totalizer = 102500700 gals
15[10]			205.3		= 1038500 gals/1485 mins
16[10]			205.1		= 699 gpm Avg. (Adj Q ↑)
17[10]			205.2		
18[10]			205.4		
19[10]			205.4		
20[10]			205.5		
21[10]			205.5		
22[10]			205.5		
23[10]			205.7		
0[10]			205.7		
1[10]			205.7		
2[10]			206.0		
3[10]			206.0		
4[10]			206.0		
5[10]			206.2		
6[10]			206.1		
7[10]			206.3		
8[10]			206.4		
9[10]			206.3		
10[10]			206.3		
11[10]			206.5		

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19 - 25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.7

Pump Setting (ft): 290

Well Depth (ft): 650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
12[10]			206.6		
13[10]			206.6		
14[10]	7060	700	207.1		Totalizer = 103,507,700 gals
15[10]			207.2		= 1,007,000 gals / 1440 mins
16[10]					= 699 gpm Avg (Adj Q ↑)
17[10]			207.4		(54.1 Hz, 16 psi B. Press.)
18[10]					
19[10]					
20[10]			207.5		
21[10]					
22[10]					
23[10]					
2/25 0[10]			207.9		
1[10]					
2[10]					
3[10]					
4[10]					
5[10]					
6[10]					
8[10]			208.3		
9[10]			208.4		
10[10]			208.4		

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR Ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 2/19 - 25/19

Test/Data Set I.D.: Cycle 2 Recovery

Observer: RCM

Reference Pt: Top of S. Tube

Static Water Level (ft): 89.7

Pump Setting (ft): 290

Well Depth (ft): 650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
11:10			208.5		
12:10			208.5		
13:10	8440	700	208.5		
13:30	8460		208.6		STOP
					Totalizer End = 104,488,653 gals
					= 5,914,773 gals/8460 mins
					= 699 gpm Avg.
					Total DDN = 208.6 - 89.70
					= 118.9'
					6-Day
					Q/s = 699 gpm / 118.9 ft
					= 5.88 gpm/ft

Notes:

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

PUEBLO water resources

Sheet No. 1 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers		Pressure (psi)					DTW (ft btst)	Drawup (ft)	Comments/Other
			Inj (af)	BFP (ft3)	Line	Head	0.8"	1.1"	1.5"			
3/6/18 15^{30}	0	-	40.72	723,673	56	56	-	-	-	96.1	-	Restart Log x10 cycle
	1											
	2	410			48	38	8	8	8			
	4											
	6	405					10	10	10	65.7		
	8	409					14	14	14	62.1		
	10		40.73	724,163								
	12	406			46	34	14	14	14	61.4		
	15											
	20	405			46	34	14	14	14	59.4		SDI: t_0 = 41 secs
16^{00}	30	402								57.9		t_5 = 57
	40											t_{10} = 74 = 3.69
	50	400			46	34	15	15	15	56.3		t_{15} = 92
16^{30}	60											
	70	398					16	16	16	54.0		Adj; Q ↑ slightly
	80	404					18	18	16	53.2		
17^{00}	90											
17^{10}	100	403	40.84	728,945	46	34	18	18	16	52.2		
17^{30}	120									51.0		Q Avg = 394 gpm
18^{00}	150									51.25		
18^{30}	180									50.7		
19^{30}	240									48.6		
20^{30}	300	383			40	30	18	18	16	46.9		20^{50}
21^{30}	360									44.3		
22^{30}	420									43.6		
23^{30}	480									42.4		
3/7 0^{30}	540									41.2		

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

PUEBLO water resources

Sheet No. 2 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
3/7 1:30	600											
2:30	660											
3:30	720											
4:30	780											
5:30	840											
6:30	900											
8:10	1000									39.2		
9:10												
9:30	1080	370	42.01	779,272	42	30	18	18	16	38.9		Intertie open? No Adj; Q Avg = 385 Adj; Slightly
10:45		376			40	30	20	20	18			SDI: t_0 = 42 secs, t_5 = 66, t_{10} = —, t_{15} = 97 = 3.74
14:30		388			44	34	22	24	22			
15:40		401	42.45	798,101	44	38	26	26	24			Adj; Q ↑

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

PUEBLO water resources

Sheet No. 3 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Head	0.8"	1.1"	1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
03/07/19 14:15		388	42.35	793,637	43	32	23	24	22	34.33		SG
03/08/19 09:15		385	43.75	854,138	40	34	24	26	21	28.60		SG
03/09/19 09:00		375	45.50	929,510	40	34	25	26	24	24.25		SG Intertie confirmed on
03/10/19 09:10		386	47.16	1,000,890	44	38	30	30	28	19.68		SG
[illegible]		371	47.22	[illegible]	40	34	26	26	24	[illegible]		SG
[illegible]		380	47.24	1,004,405	40	24	29	26	26	20.48		SG Adjustment
03/11/19 09:00		396	48.90	1,075,725	44	38	34	32	30	15.41		SG
09:25		395	48.93	1,077,043	44	38	34	32	30	15.46		SG
09:35		397	48.94	1,077,568	44	38	36	34	30	15.29		SG Adjustment
10:00		398	48.97	1,078,882	44	40						SG Butterfly valve Adjustment
10:05		[illegible]		1,079,138	40	36	32	30	27	16.78		SG Intertie
03/12/19 09:05		381	50.67	1,152,273	40	35	32	31	28	14.43		SG + IR Intertie Confirmed on
03/13/19 09:10		381	52.42	1,227,709	41	36	33	31	28	13.12		SG 0.8" + 1.1" leaking at valve; intertie confirmed on

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

Date/Time	ET (min)	Rate (gpm)	Totalizers: Inj (af)	Totalizers: BFP (ft3)	Pressure (psi): Line	Pressure (psi): Head	Pressure (psi): 0.8"	Pressure (psi): 1.1"	Pressure (psi): 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
3/13 14:00	9,990	395	52.77	1,242,526	44	40	38	36	32	11.4		
14:30	10,020											
14:35		0	52.81	1,244,245	54	54	–	–	–			Shut down Injection off @ 1435
												Backflush (see field obs)
16:10		0	52.81	1,244,245	58	58	–	–	–	67.9	–	Resume Injection
16:30		402			48	42	26	26	28	27.7		
17:00		377	52.86	1,246,749	40	36	24	24	24	27.1		Intertie open? No Adj
20:10		371	53.08	1,256,108	40	34	26	24	26	22.2		Adj Q↑
20:15		375			40	34	28	26	26			
3/14 8:30		373	53.96	1,293,845	40	36	28	26	26	17.8		(Intertie open) SDI: t_0 = 42 secs
9:00		386		1,295,348	44	40	32	30	30			(" closed) t_5 = –
9:30		400			44	42	34	34	32	14.6		9:30 Adj Q↑ t_{10} = 56 = 2.55
												t_{15} = 68
17:15		378			42	40	28	28	28	15.9		Intertie open?

PUEBLO water resources

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12

Project No.: 15-0112

Well: Beltz 12

Test: Cycle 3 Injection

Sheet No. 5 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers: Inj (af)	Totalizers: BFP (ft3)	Pressure (psi): Line	Pressure (psi): Head	Pressure (psi): 0.8"	Pressure (psi): 1.1"	Pressure (psi): 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
03/15/19 09:05		386	55.75	1,370,913	44	42	30	30	31	13.25		SG
10:20		370	55.84	1,374,691	40	38	28	28	28	14.81		SG Intertie on
10:40		375		1,375,683	40	38	28	30	28	14.53		SG Adjustment
03/16/19 09:20		369	57.49	1,445,919	40	38	28	30	28	12.98		SG Intertie confirmed on
10:10		370	57.54	1,448,359	40	38	28	30	28	13.18		SG
10:40		375	57.58	1,449,842	39	36	32	31	28	12.44		SG Adjustment
03/17/19 09:10		394	59.23	1,520,952	44	41	38	36	32	8.61		SG
03/18/19 09:15		378	60.96	1,595,651	42	38	34	32	30	9.08		SG+IR Intertie confirmed on
03/19/19 09:10		377	62.68	1,669,857	41	38	34	32	30	8.41		SG Intertie confirmed on
3/20/19 10:30		378	64.51	1,748,958	40	37	34	33	30	7.25		IR Intertie confirmed on

PUEBLO water resources

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

Sheet No. 6 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Head	0.8"	1.1"	1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
3/20/19 14:15		402	64.79	1,760,758	48	44	42	40	36	4.0		close valves/stop Inj.
14:2?		0	64.79	1,760,894	58	56	–	–	–			off
												Backflush (see field obs)
16:00		–	64.79	1,760,894	56	54	–	–	–	62.1	–	Resume injection
16:10		371			48	46	22	22	22	26.8		Adj; Q ↑
16:30		373			48	44	24	24	24			Adj; Q ↑ SDI: t_0 = 41 secs
16:45		380			46	44	26	26	26	20.9		t_5 = 48
18:35		353	64.97	1,768,361	42	40	24	22	24	18.6		Adj; Q ↑ t_{10} = 58 – 2.39
19:00		360		1,769,549	42	40	24	24	24	17.7		t_{15} = 64
3/21 8:10		356	65.91	1,809,256	40	38	26	26	25	13.9		Adj; Q ↑
8:25		360			40	38	26	26	26			
13:00		373	66.24	1,823,296	44	42	30	30	28			Adj; Q ↑ SDI: t_0 = 40 secs
13:15		382			44	42	32	32	30	10.3		t_5 = –
												t_{10} = 47 = 1.33
												t_{15} = 50

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

PUEBLO water resources

Sheet No. 7 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
03/22/19 09:10		364	67.64	1,883,738	40	37	28	28	27	10.84		SG Intertie confirmed on, cap off manual [illegible]
09:25		368	67.66	1,884,464	41	38	30	30	28	10.58		[illegible]
09:55		362	67.69	1,88[illegible],897	43	40	28	29	[illegible]	10.98		SG adjust Q ↓
10:40		379	67.74	1,888,081	48	44	32	[illegible]	30	9.21		SG Intertie confirmed OFF
03/23/19 09:15		366	69.32	1,956,057	44	41	30	30	28	9.31		SG Intertie confirmed OFF
10:40		363	69.42	1,960,147	43	40	30	30	28	9.38		SG
11:00		369	69.44	1,961,124	43	40	30	32	28	8.76		SG adjust Q ↑
03/24/19 09:05		418	71.00	2,028,580	42	39	50	22	28	1.06		SG
09:45		369		2,030,617	44	42	20	14	20	6.87		SG adjust Q ↓
03/25/19 09:05		379	72.65	2,099,443	48	45	22	16	22	5.49		SG Intertie confirmed OFF
03/26/19 09:05		379	74.32	2,171,607	42	39	18	13	18	6.92		SG Intertie confirmed on
03/27/19 09:30		358	7[illegible].01	2,244,313	[illegible]	38	18	[illegible]	[illegible]	[illegible]		[illegible] confirmed ON

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test:

PUEBLO water resources

Sheet No. 8 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
3/27 1300		375	76.24	2,254,408	48	44	20	16	20	6.2		
1330												shut down injection
1335		0			56	54	–	–	–			off
												Backflush (see field obs)
1515		0	76.28	2,256,033	56	54	–	–	–	60.5		Resume injection
1530		380			50	40	10	10	10	23.2		close butterfly valve slightly
1630		379			50	40	14	14	14	17.1		SDI: t_0 = 39 secs
1920		355			42	34	12	12	12	14.9		Adj Q ↑; t_5 = 45
1930		360	76.56	2,268,499	42	34	14	12	14	14.2		t_{10} = 49 = 1.85; t_{15} = 54
3/28 735		369	77.42	2,305,176	46	38	16	16	16	9.4		No Adj
845		355			42	34	14	14	14			Adj Q ↑
855		360			42	34	16	14	16			
1215		379			50	40	18	16	18	8.1		No Adj

INJECTION TESTING DATA

PUEBLO water resources

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

Sheet No. 9 of 10

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Pressure (psi) Head	Pressure (psi) 0.8"	Pressure (psi) 1.1"	Pressure (psi) 1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
03/29/19 09:10		353	79.18	2,381,003	42	34	14	14	15	9.71		SG Intertie confirmed on
09:42		354	79.21	2,382,498	42	34	14	14	15	9.66		SG
10:00		[illegible]	79.23	2,383,360	42	34	14	15	16	9.10		SG Adjust QT
03/30/19 09:00		371	80.80	2,451,004	45	37	16	18	18	6.98		SG Intertie confirmed OFF
03/31/19 09:15		368	82.48	2,523,349	46	38	16	18	18	5.97		SG Intertie confirmed OFF
04/01/19 09:10		373	84.10	2,593,471	46							Intertie opened @ [illegible]
09:15		353	84.11	2,593,707	42	34	14	16	16	6.97		SG [illegible]
04/[illegible]/19 [illegible]		366	85.74	2,664,415	46	38	16	[illegible]	[illegible]	5.48		SG
04/03/19 09:[illegible]		381	87.39	2,735,366	49	41	18	20	20	5.3[illegible]		SG Intertie [illegible]

INJECTION TESTING DATA

Project: Santa Cruz ASR Ph 2 - Beltz 12
Project No.: 15-0112
Well: Beltz 12
Test: Cycle 3 Injection

Sheet No. 10 of 16

Date/Time	ET (min)	Rate (gpm)	Totalizers Inj (af)	Totalizers BFP (ft3)	Pressure (psi) Line	Head	0.8"	1.1"	1.5"	DTW (ft btst)	Drawup (ft)	Comments/Other
4/4/19 14:05		368	89.38	2,821,462	46	38	16	18	18	4.9		SDI: t_0 = 39 secs, t_5 = 47, t_{10} = 52, t_{15} = 64; = 2.60
4/5 8:15		354	90.64	2,875,729	42	36	14	16	16	5.5		
14:45		375	91.08	2,894,637	50	40	18	20	20	2.8'		SDI: t_0 = 38 secs, t_5 = 41, t_{10} = 50, t_{15} = 59; = 2.37
15:30		377										
15:35		0	91.13	2,897,009			-	-	-			Shut down off. Close BFP valves
												15:45 Backflush (see field obs)

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph 2 - Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 5/15/19

Test/Data Set I.D.: Post-Injection Q/S

Observer: RCM

Reference Pt: Top of S.Tube C

Static Water Level (ft): 94.7'

Pump Setting (ft): ~290

Well Depth (ft): ~650'

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
14:30	0	–	94.7	–	Totalizer = 104,944,827 gals
	1				60 Hz / 16 psi B.Press.
	2	~720	150.7		Adj Q ↓
	4				
	6	715	156.0		
	8	710	158.9		
	10	707	160.4		
	12	708	161.3		60 Hz / 18 psi
	15		162.0		
	20		163.3		
15:00	30		165.2		
	40		166.7		
	50		168.2		
15:30	60	701	169.1		Adj Q ↑ Slighty
	70	705	170.7		
	80		171.5		
16:00	90		172.3		
16:10	100		173.1		Stop. Totalizer = 105,015,054 gals
					100-min Q/S = 702 gpm / 78.4 ft
					= 8.95 gpm/ft

Notes:

Sheet 1 of 1

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR ph2- Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 7/1/19 - 7/31/19

Test/Data Set I.D.: Cycle 3 Recovery

Observer: RCM

Reference Pt: Top of S.Tube (2.1' ags)

Static Water Level (ft): 102.7

Pump Setting (ft): ~290

Well Depth (ft): ~650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
9^00	0	–	102.7		Totalizer = 105,333,165 gals
	1				
	2				
	3	410			~39.9 Hz
	4				
	5				
	6	409			
	7		136.1		Adj Q/Hz ↓
	8	403			39.3 Hz / ~6 psi B.Pres.
	9				
	10	404	136.7		Totalizer = 105,337,300 gal (414 gpm)
	12				
	15				
	20	401	138.2		
	30	398	139.4		Adj Q↑ slightly
	40	404	140.9		39.7 Hz
	50				
9^00	60				
10^10	70	401	142.9		
	80				
10^30	90				
10^40	100				

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC

Project: ASR Ph 2- Beltz 12

Project No: 15-0112

Well: Beltz 12

Date: 7/1/19 – 7/3/19

Test/Data Set I.D.: Cycle 3 Recovery

Observer: RCM

Reference Pt: Top of S.Tube (2.1' ags)

Static Water Level (ft): 102.7

Pump Setting (ft): ~290

Well Depth (ft): ~650

Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
11:00	120	400			Totalizer = 105,381,400 gals (
11:30	150	405	145.0*		11:10 Adj. Q ↑ → 40.1 Hz
12:00	180				* WL from City XD on PLC from this pt
13:00	240	400	147.1		fwd.
14:00	300				13:10 Adj Q ↑ → 40.3 Hz
15:00	360	401	149.5		
16:00	420				
17:00	480	399	151.0		17:15 Adj Q ↑ → 40.5 Hz / 6 psi B.P.
18:00	540	405			17:40 " → 40.7 Hz
19:00	600				
20					
21:00		405	153.5		21:15 40.7 Hz
22:00					
23:00					
7/2 0:00					
1:00					
2:00					
3:00					
4:00					
5:00					
6:00					
7:00					

Notes:

PUMPING TEST DATA

PUEBLO water resources

Client: City of SC
Project: ASR Ph 2 - Beltz 12
Project No: 16-0112

Well: Beltz 12
Date: 7/1/19 – 7/31/19
Test/Data Set I.D.: Cycle 3 Recovery
Observer: RCM

Reference Pt: Top of S.Tube (2.1' ags)
Static Water Level (ft): 102.7
Pump Setting (ft): ~290
Well Depth (ft): ~650

	Clock Time	Elapsed Time	Rate (gpm)	Water Level (feet)	Sand (ml)	Other Observations (visual, odor, spec. capacity, totalizer, field wq, etc.)
	8⁰⁰	1380	401	156.2		40.7 Hz
	9⁰⁰	1440	400	156.2		Totalizer = 105,813,660 gals (403 Avg)
						9⁰⁵ Adj Q ↑ slightly (40.9 Hz / 406 gpm)
						T = 16.38, EC = 523 uS, pH = 7.11
						ORP = 41.1 mV, DO = 0.01 mg/L,
						Tu = 2.43 NTU.
7/9	9⁰⁰	11520	405	167.4		Totalizer = 109,973,830 gals
						(41.5 Hz / 6 psi B.P.)
7/23	14⁰⁰	31980	412	173.9		Totalizer = 118,291,300 gals
						(42.5 Hz / 6 psi)
7/30	9¹⁵	41770	415	174.4		Totalizer = 122,342,520 gals
						(42.5 Hz / 6 psi)
7/31	9⁰⁰	43,200	409	174.4		STOP. Totalizer = 122,929,406 gals
						(407 gpm Avg)

Notes:

APPENDIX D – WATER-QUALITY LABORATORY REPORTS
available for download here:
https://pueblo-water.sharefile.com/d-saf9f15870ea4821b